European Commission

Study on Semantic Assets for Smart Appliances Interoperability

D-S1: FIRST INTERIM REPORT

A study prepared for the European Commission
DG Communications Networks, Content & Technology
by:

TNO innovation for life

Digital Agenda for Europe

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0.7	12 May 2014	For review by the Advisory Board
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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 unified data model should in principle be possible. One single, unified 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 common ontology and document the ontology into the ETSI M2M architecture

TNO was invited to perform this study. This document, *D-S1 Interim Study Report*, presents the results of task 1. It takes stock of existing semantic assets and use case assets, describes their semantic coverage, and presents an initial semantic mapping.

The Invitation to Tender already listed 27 assets. We have identified 16 more that need to be included in our study given the scope as set out by the European Commission. Of these in total 43 assets we were able to short-list 20 which provide a good basis for further common ontology development. The short list is composed solely based on how well the asset is covering the scope of the project and if the asset provides concrete semantic specifications, preferably in the form of XML or OWL files. These assets have been described in terms of their:

a) Model Acronym and Full Name
b) Most relevant URL and other precise references
c) Overall description
d) Description of the semantic coverage
e) Overall description of the consensus driven process leading to the model

The other assets included have been described more briefly. Table 1 lists the assets by name and reference. The first 20 form the short list. An asset does not have (own) semantic assets if the references is N/A. The URL is then a generic URL rather than referring to the semantic asset.

The considered assets form a heterogeneous set when considering their semantic coverage. However, we could identify three main trends with a focus on 1) devices, sensors and their specification in terms of services, functions and states, 2) energy consumption information and profiles to optimize energy efficiency, and 3) buildings related semantic models. We think that assets covering different trends can be connected starting from the most recurrent terms shown in our visual representation of key terms, namely Device, Sensor, Service, State and Event. The assets on our short list are in the core of these trends and furthermore provide complete information in terms of data models and product specifications that we can use to build the common ontology. As such we make sure that we base the common ontology on the actual models that were defined in the projects or organizations, and not on our own interpretation of the semantics implicitly represented by these assets.

Table 1. All 43 semantic assets studied in this document

Model Acronym	Reference	URL
DECT ULE HAN FUN	HF-Overview, HF-Protocol, HF-Service, HF-Interface, HF-Profile, V1.00, 2014-23-1	http://www.ulealliance.org/registration.aspx?f=11
ECHONET	ECHONET Specifications Appendix "Detailed Requirements for ECHONET Device Objects" Release C, 31 May 2013	http://www.echonet.gr.jp/english/spec/pdf_spec_app_c_e/SpecAppendixC_e.pdf
eDIANA	D2.2-A "Ontology for Device Awareness", 30 November 2009	http://s15723044.onlinehome-server.info/artemise/documents/D22A_Ontology_for_Device_Awareness_m10_IMSML.pdf
EnOcean EP	EnOcean Equipment Profiles (EEP), Version 2.6, 17 December 2013	http://www.enocean-alliance.org/eep/
FAN FPAI	HEGRID AD1305 Interface description: Interface report, Version 1.0 (final), 7th January, 2014	http://www.flexiblepower.org/downloads/
FIEMSER	D5 FIEMSER Data Model, February 2011	http://www.fiemser.eu/wp-content/uploads/2011/12/D5_FIEMSER-data-model_m9_CSTmb_REVIEW.pdf
FIPA	FIPA Device Ontology Specification, SC00091E, 3 December 2002	http://www.fipa.org/specs/fipa00091/SI00091E.pdf or http://www.fipa.org/specs/fipa00091/SI00091E.html
HYDRA	Deliverable D6.6 Updated MDA Design Document, version 1.0, 20 August 2009	http://www.hydramiddleware.eu/hydra_documents/D6.6_Updated_MDA_Design_Document.pdf
KNX	KNX System Specifications Interworking Datapoint Types, Version 1.07.00, 26 April 2012	http://www.knx.org/media/docs/downloads/03%20-%20KNX%20Standard/KNX%20Standard%20Public%20Documents/03_07_02%20Datapoint

		%20Types%20v1.07.00%20AS.zip
MIRABEL	D7.5 "MIRABEL-ONE: Initial draft of the MIRABEL Standard, version1.0", 22 December 2011	http://wwwdb.inf.tu-dresden.de/miracle/publications/D7.5.pdf
OMA Lightweight M2M	OMA Lightweight Machine-to-Machine Technical Specification Candidate version 1.0, 10 December 2013	http://technical.openmobilealliance.org/Technical/release_program/docs/LightweightM2M/V1_0-20131210-C/OMA-TS-LightweightM2M-V1_0-20131210-C.pdf
OMS	Open Metering System Specification Vol.2 – Primary Communication Issue 4.0.2, and OMS-Data Point List –RELEASE A, Annex B to Volume 2: Primary Communication Issue 4.0.2, 27 January 2014	http://oms-group.org/fileadmin/pdf/OMS-Spec_Vol2_Primary_v402.pdf , http://oms-group.org/fileadmin/pdf/OMS-Spec_Vol2_AnnexB_A031.pdf
OSGi DAL	RFC-196 OSGi Alliance Device Abstraction Layer, Draft, February 2014	https://github.com/osgi/design/blob/master/rfcs/rfc0196/rfc-0196-DeviceAbstractionLayer.pdf
SEEMPubs	Deliverable D5.1 "Data Format Definition, version 1.0", 30 September 2012	http://seempubs.polito.it/images/stories/documents/WP5/D.5.1.pdf
SEIPF	Dario Bonino, Fulvio Corno, Faisal Razzak "Enabling Machine Understandable Exchange of Energy Consumption Information in Smart Environments", Energy and Buildings 43 (2011) 1392–1402	http://dx.doi.org/10.1016/j.enbuild.2011.01.013
SEP2	Zigbee Alliance / HomePlug Alliance Smart Energy Profile 2 Application Protocol Standard, ZigBee Public Document 13-0200-00, April 2013	http://www.zigbee.org/Standards/ZigBeeSmartEnergy/ZigBeeSmartEnergy20Standard.aspx
SmartCoDE	Deliverable D1.1.2 "Model of local energy resource cluster", 31 December 2012	https://www.fp7-smartcode.eu/system/files/page/d-1.1.2.pdf
UPnP	UPnP Device Architecture 1.1, SolarProtectionBlind:1, HVAC:1, Lighting Controls:1	http://upnp.org/specs/arch/UPnP-arch-DeviceArchitecture-v1.1.pdf , http://upnp.org/specs/ha/solarprotectionblind1/ , http://upnp.org/specs/ha/hvac/ , http://upnp.org/specs/ha/lighting/
W3C SSN	Semantic Sensor Network Ontology,	http://www.w3.org/2005/Incubator/ssn/ssnx/ssn
Z-Wave	Z-Wave Technical Basics Chapter 4 "Application Layer", 1 June 2011	http://www.domotiga.nl/attachments/download/1075/Z-Wave%20Technical%20Basics-small.pdf
Adapt4EE	D3.2 Adapt4EE Middleware Specification, Ontology and Semantic Components, May 2013	http://www.adapt4ee.eu/adapt4ee/files/document/deliverables/Adapt4EE-Deliverable-D3.2.pdf
Agora	N/A	http://www.reseau-domiciliaire.fr/home/
AIM*	N/A	http://www.ict-aim.eu/
BACnet	BACnet - A Data Communication Protocol for Building Automation and Control Networks - Overall description, ANSI/ASHRAE Standard 135-2012, Chapter 12 "Modeling Control Devices as a Collection of Objects"	http://www.techstreet.com/ashrae/products/1852610

Broadband Forum	Broadband Forum SD-282 "Control Signaling Device Abstraction Layer"	http://www.broadband-forum.org/technical/technicalwip.php
CECED	• PI Standard 15.0, 21 March 2014, • EDI-WHITE Final Messages, , 5 April 2006.	http://www.picertified.com/download/xml_download/Lang_PI15_0_EN_all.xml, http://www.ceced.eudata.be/ICECED/easnet.dll/ExecReq/Search?eas:parent_id=201013
CEN/CLS ETSI Smart Grid CG M490	N/A	ftp://ftp.cen.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/First%20Set%20of%20Standards.pdf , ftp://ftp.cencenelec.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/Reference_Architecture_final.pdf
CoAP	N/A	https://datatracker.ietf.org/doc/draft-ietf-core-coap/
DLMS/ COSEM	Companion Specification for Energy Metering: COSEM interface classes and OBIS identification system, DLMS User Association, 27 August 2013.	http://dlms.com/PASSWORD/Books/Blue_Book_11th_edition.pdf, http://dlms.com/documents/members/OBIS_list_v2.3_GK051026.zip
DEHEMS	Nazaraf Shah, Kuo-Ming Chao, Tomasz Zlamaniec, Adriana Matei, "Ontology for Home Energy Management Domain", Digital Information and Communication Technology and Its Applications, Communications in Computer and Information Science, Volume 167, 2011, pp 337-347.	http://dx.doi.org/10.1007/978-3-642-22027-2_28
ebbits	• D3.2 "Vertical and horizontal business vocabularies" • D4.3 "Coverage and scope of a semantic knowledge model" • D4.5 "Analysis and design of semantic interoperability mechanisms", • D7.2 "Event and data structures, taxonomies and ontologies"	http://www.ebbits-project.eu/downloads.php?cat_id=1&download_id=27, http://www.ebbits-project.eu/downloads.php?cat_id=1&download_id=28, http://www.ebbits-project.eu/downloads.php?cat_id=1&download_id=47, http://www.ebbits-project.eu/downloads.php?cat_id=1&download_id=31 .
Energy @Home	Energy@Home Data Model, version 0.9, revision 0.5, 3 February 2014	http://www.energy-home.it/Documents/2014-02-dm/E@h_data_model_v0.9.pdf
ENERsip	N/A	https://sites.google.com/a/enersip-project.eu/enersip-project/results/deliverables/wp3
Eu.bac	N/A	http://www.eubac.org
HGI	HGI-GWD042 Smart Home Appliance (Device) Model Template	http://www.telecomitalia.com/content/dam/telecomitalia/it/archivio/documenti/Innovazione/HotTopic/Casa%20connessa/Overall%20slide%20pack%20BBWF%202013_final.pdf
IFC	IFC4 (Industry Foundation Classes 4) Specifications (March 2013)	http://www.buildingsmart-tech.org/ifc/IFC4/final/html/index.htm , http://www.buildingsmart-

		tech.org/downloads/ifc/ifc4/ifc4-html-documentation-68mb
Lighting Europe	IES TM-23-11 “Lighting Control Protocols”, Illuminating Engineering Society of North America (IES 2011)	http://www.ies.org/PDF/Store/TM-23-11_FINAL.pdf
LonWorks	LonMark Device Classes and Functional Profiles	http://www.lonmark.org/technical_resources/resource_files/spid_master_list#DeviceClasses
oBIX	OASIS, obix-v1.1-csprd02, Committee Specification Draft 02 /Public Review Draft 02, 19 December 2013	http://docs.oasis-open.org/obix/obix/v1.1/csprd02/obix-v1.1-csprd02.pdf
SensorML	OGC SensorML: Model and XML Encoding Standard, v2.0.0, 4 February 2014	https://portal.opengeospatial.org/files/?artifact_id=55939
SESAME	Slobodanka Tomic, Anna Fensel, Tassilo Pellegrini, “SESAME Demonstrator: Ontologies, Services and Policies for Energy Efficiency”, in Proceedings of the 6th International Conference on Semantic Systems I-SEMANTICS 2010, 1-3 September 1-3, Graz, Austria	http://dx.doi.org/10.1145/1839707.1839738
TIBUCON	TIBUCON D2.3 High Level Data Models and Message Structures	http://www.tibucon.eu/docs/D2%203%20High%20Level%20Data%20Models%20and%20Message%20Structures%20V1.0.pdf
VoCamp	N/A	http://cps.cs.uni-kl.de/vocamp

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
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	Konnex
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	Open Service Gateway initiative

OWL	Web Ontology Language
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
SCL	The 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
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 common ontology, a unified data model.

Various workshops and FP7 projects already have explored this field and concluded that defining a useful and applicable unified 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, unified 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.

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:

Stakeholders associations

- 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

Standardisation Bodies and Organisations

- 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, doors, stores), micro renewable home solutions (solar panels, solar heaters, wind, etc.), multimedia and home computer equipment and all Building Energy

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

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 common ontology and document the ontology into the ETSI M2M architecture

The study will thus contribute with recommendations for a unified 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 unified ontology to be contributed to ETSI for consideration as a future standard.
- Documentation of the proposed the ontology into the ETSI M2M architecture.

This document, *D-S1 Interim Study Report*, presents the results of task 1 "take stock of existing semantic assets and use case assets". Later in 2014, the project will publish *D-S2 Second Interim study report,* which will cover a translation to OWL and a mapping between the various models found in the semantic and use case assets. *D-S3 Third Interim study report,* will cover the definition of the smart appliances unified ontology and a description of this ontology within the ETSI M2M architecture. *D-S4 Final Study report,* will include all the results described in the previous reports, as well as an executive summary. The ontologies produced by the project will be published as .owl files online.

It should be emphasized that this report, D-S1, is an *Interim* study report. D-S4, to be published next year, is the final result of the study and it is only D-S4 that will be officially passed to ETS Smart M2M for further development into, as is currently foreseen, a Technical Specification. In D-S4 the results of DS-1 will be updated with the newest insights. This will include an assessment of how well the long-listed assets fit into the common ontology constructed from the short-listed assets.

1.3. Structure of the document

In the following chapter we describe the scope of the study and in particular of this document. We give a brief overview of ETSI's work in this field and the relation of this study to ETSI's Smart M2M Technical Committee. We then provide a long list and short list of the semantic assets we have identified to be relevant for the interoperability of smart appliances. The long list is a list of organisations and projects working in this field, which developed and published relevant use cases. Only a fragment of these bodies have produced semantic assets to go with these use cases though. They are given by the short list.

Chapter 3 is the core of this document. Here we present, in alphabetical order, the relevant semantic assets. An asset here refers to a source which presents a project, a set of documents, an ISO standard, a working group, a committee, a paper, a homepage (of a wiki, or of any other website) that is somehow related to energy management and/or home appliances. An asset is semantic if the source points towards a collection of highly reusable metadata (e.g. xml schemata, generic data models) and reference data (e.g. code lists, taxonomies, dictionaries, vocabularies) which are used for smart appliances. An asset may refer to one well-defined single ontology, but in most cases is a pointer to a set of multiple documents, several related standards and distinct articles on a web site or wiki, from which a single ontology should be derived.

The description of the assets follows the following template: one section per semantic asset, with per asset given:

- Model Acronym and Full Name
- Most relevant URLs, and other precise references
- Overall description
- Description of the semantic coverage
- Overall description of the consensus driven process leading to the model, including a description of the relevant teams of developers, consultants, and subscribers or supporters

The overall description of the consensus driven process is largely based on an analysis of which companies invested most in the development of the asset, and which companies were most influential in promoting it. It does not discuss the degree of adoption that the resource has already found by various partners in industry, government and academia, as we deem this irrelevant for the study. Semantic assets from unpopular standards can be of high quality nevertheless. If our ontology is going to be used to create backwards compatibility with devices in the market, then a good understanding of the legacy would be useful. But the ontology may also be used to create new protocols and standards and choose to re-use semantics from existing standards with little adoption.

There are many different ways possible to subsequently classify the various assets. For instance, some assets describe product properties for cataloguing and information modelling purposes, whereas others describe dynamic parameters to be exchanged by intercommunication protocols between devices. Within the realm of protocols one can e.g. distinguish between protocols that define device classes containing a set of attributes and capabilities describing the behaviour of devices, vs. protocols that only define commands that address a certain capability and trigger some behaviour. Or between Internet and non-Internet protocols. One can also classify on the basis of which domain the asset was primarily developed for (energy, building, lighting, …) or if it supported by an R&D community (e.g. when it is developed by European Framework project) or by an industrial consortium, and if it has been formally standardized or not. Although such classifications may provide valuable insights we have chosen not to provide those in this document, as they are not needed for constructing a common ontology.

Chapter 4 elaborates on the approach that has been taken to analyse the considered assets and presents a visual representation of the key terms covered by these assets. For each of the assets, we have selected between 10 and 15 key terms and we have created a corresponding visual representation. This representation is an initial step towards the definition of a common semantics for the smart appliances domain. As such, it should be considered as a preliminary and partial result that will be taken as input in the following task of our study, namely creating ontologies that reflect the semantic coverage of the assets based on an accurate semantic analysis.

Chapter 5 shows our conclusions, including an indication of which existing models are in the core of the smart appliances domain.

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.)

[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)

- Manufacturers of multimedia and home computer equipment

Furthermore stakeholders from directly linked industries are consulted:

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

Stakeholders were consulted either via analysing their websites, direct emailing, joint meetings, or the stakeholders LinkedIn Group we initiated[5]. In most cases the available semantic assets were easy to find on the stakeholders' websites and were verified by TNO co-workers active in the respective bodies or projects. In some cases the assets were verified via email contact or personal contact with representatives of the projects or bodies. In other cases we were pro-actively provided with the relevant information. Overall we can safely state that we obtained enough data to support our conclusions.

2.2 ETSI Smart M2M

One of the SDOs (Standard Development Organization) playing a key role in this ecosystem is ETSI Smart M2M. ETSI[6] is one of the world's leading standards development organizations for Information and Communication Technologies (ICT). Founded initially to serve European needs, ETSI is now a highly-respected producer of technical standards for worldwide use. ETSI membership is composed of manufacturers and network operators plus national administrations, ministries, regulators, universities, research groups, consultancies and user organizations from more than 60 countries on 5 continents.

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 [4]. 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 [5], 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 1. 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.

[5] www.linkedin.com/groups/Workshop-Stakeholders-on-Smart-Appliances-7450648
[6] www.etsi.org

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).

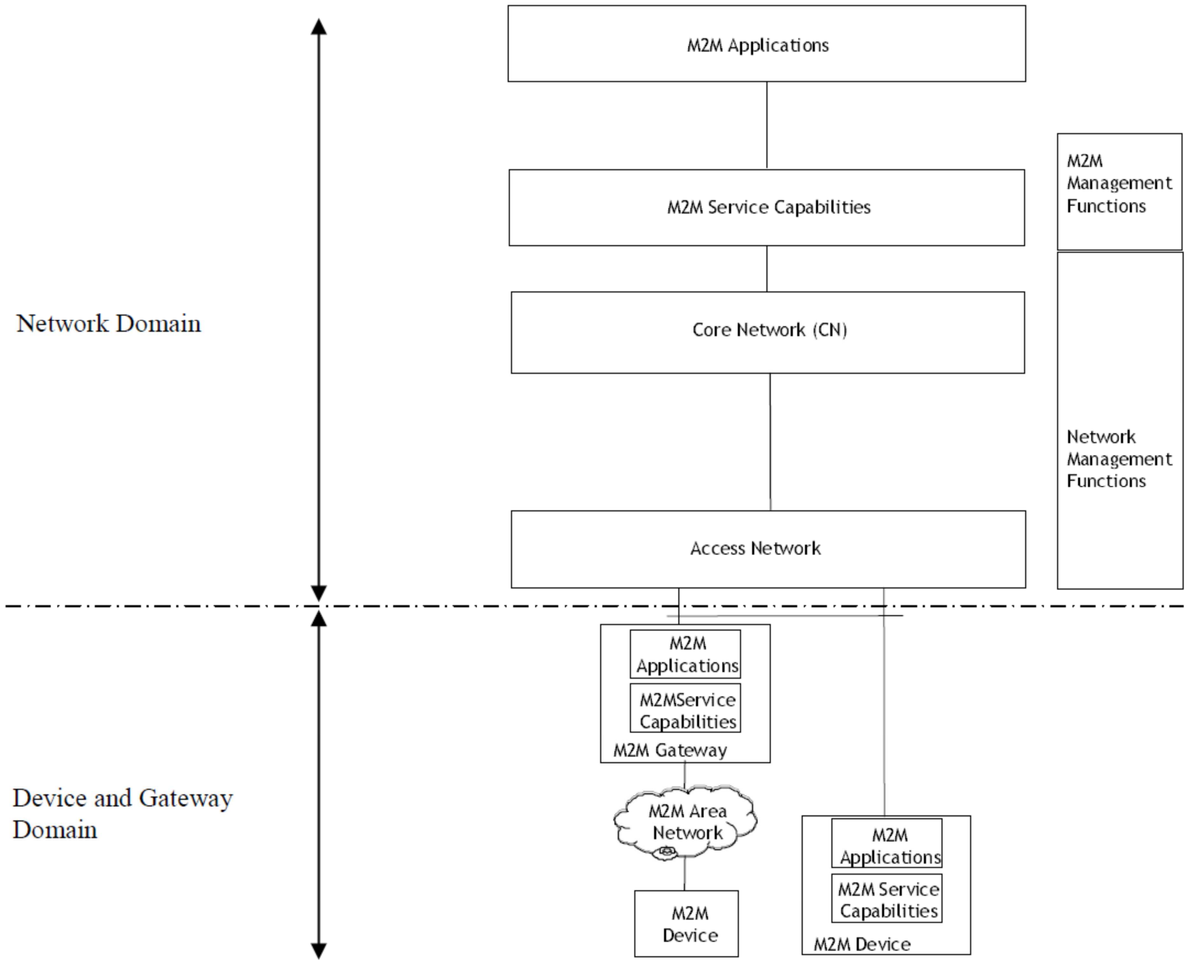

Figure 1. ETSI M2M High Level Architecture [5]

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 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

The M2M Applications run the service logic and use M2M Service Capabilities accessible via an open interface. It is this interface that forms the target object of the ontology targeted by the study on “Available Semantics Assets for the Interoperability of Smart Appliances. Mapping into a Common Ontology as a M2M Application Layer Semantics”.

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. At the moment, the Service Capability Layer is handling only data containers without any knowledge of the data contained. As described in [6], 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 [6] 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. An Ontology is here defined as a formal specification of a conceptualization, which defines Concepts as objects with their properties and relationships versus other Concepts. A Concept is a fundamental category of existence, also called "entity type", "category", "subsystem", or "class". Examples include “Device”, “Service”, “Washing Machine”, “Thermostat”, etc.

The ontology 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 [7], 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 [8] ETSI Smart M2M elaborated some preliminary examples on how this interoperability could be achieved given an ontology

The goal of our study is to provide this ontology within the scope as described in Section 2.1, taking a bottom-up approach, learning from the semantics already developed in other bodies and projects. These bodies and projects are typically the ones that develop legacy M2M Area Networks. However, in the long term, M2M Applications are not only expected to just facilitate direct communication between local devices, but also to enable novel services, such as interaction with Building Information Models [9] and automatic updating of product catalogues. It is these type of M2M Application that is believed to be instrumental in achieving the sustainability goals of the EC.

2.3 OneM2M

ETSI Smart M2M has finished their work on the M2M functional architecture with [5]. In 2012, the OneM2M Partnership Project[7] was formed with the goal to develop the technical specifications which address the need for a common M2M Service Layer like described in [5], that can be readily embedded within various hardware and software, and relied upon to connect the myriad of devices in the field with M2M application servers worldwide. OneM2M is a worldwide industrial organization and is not tied to the telecommunications sector or the ETSI scope, regulations, and infrastructure. OneM2M's scope includes:

- Use cases and requirements for a common set of Service Layer capabilities;
- Service Layer aspects with high level and detailed service architecture, in light of an access independent view of end-to-end services;
- Protocols/APIs/standard objects based on this architecture (open interfaces & protocols);
- Security and privacy aspects (authentication, encryption, integrity verification);
- Reachability and discovery of applications;
- Interoperability, including test and conformance specifications;
- Collection of data for charging records (to be used for billing and statistical purposes);
- Identification and naming of devices and applications;
- Information models and data management (including store and subscribe/notify functionality);
- Management aspects (including remote management of entities); and
- Common use cases, terminal/module aspects, including Service Layer interfaces/APIs between:
    - Application and Service Layers;
    - Service Layer and communication functions

OneM2M's Working Group 5 "Management, Abstraction and Semantics" will focus on the technical aspects related to management of M2M entities and/or functions. This WG will also focus on providing support by the M2M system for application specific abstraction and semantics with regard

[7] www.onem2m.org

to execution of M2M services. Working Group5 is working on a draft TR-007 “Abstraction & Semantics Capability Enablement” which is expected to absorb the results of ETSI Smart M2M in this field in due time.

2.4 Semantic Assets described in this document

2.4.1 Long List

The Invitation to Tender [3] lists the following assets to be studied (proper references can be found in chapter 3):

- From E2BA and the eeSemantics community:
    - eeSemantics Wiki and eeSemantics library of ontologies
    - FIEMSER Data Model for Monitoring & control network
    - eDiana (ARTEMIS) ontology for device discovery and interoperability
    - ENERsip M2M Communications Infrastructure Modelling Ontology
    - SmartCoDe EUP classification with respect to energy management
    - TIBUCON
    - SEEMPubS Ontology
    - SEIPF ontology
    - DEHEMS Digital Environment Home Energy Management System project
    - AIM*
    - Ebbits
    - SESAME Demonstrator
    - LinkSmart ontologies
    - Adapt4EE
    - MIRABEL Flex
    - eeSemantics EupP VoCamP
- Hydra
- From CECED, the EDI-SERVICE, EDI-WHITE, IRIS, and PI standards
- From European Lamp Companies Federation (now called Lighting Europe), the CEN/TC 169 - CIE Newsletter - searchable online database International Lighting Vocabulary
- buidlingSmart’s Industry Foundation Classes (IFC)
- FIPA
- Semantic Sensor Network Ontology (SSN)
- CEN/CLC/ETSI Smart Grid CG M490
- BACnet
- KNX
- LonWorks
- Related to BACnet, KNX, and LonWorks: the assets produced by Eu.Bac and various CENELEC TCs
- oBIX
- SensorML

Our study identified various other assets that need to be included also, given the scope of the study as presented in section 2.1:

- ECHONET
- HGI
- UPnP
- Agora
- OMA Lightweight M2M
- SEP2 (Zigbee, HomePlug, Wi-F)i
- EnOcean
- OMS
- Broadband Forum
- OSGi DAL
- Energy@Home
- FAN
- DECT ULE
- Z-Wave
- DLMS/COSEM
- CoAP

2.4.2 Short List

In order to perform the stocktaking task, we have followed a systematic approach that allowed us to deal with the quantity of assets to be considered and their complexity.

The first step was to filter the most representative resources that could characterize a specific asset. This activity resulted in the selection of a few documents for each asset, usually the specification of a standard, a project deliverable, sometimes a presentation, and in a few cases a scientific paper. We also collected XML schema specifications when available. On average, we have selected two or three documents per assets. The length ranged from 20 pages to more than 1000 pages in case of the BACnet specification, however we encountered an average length of 100 pages per document. Note that whenever a project deliverable or a paper described an ontology, our analysis was based only on the documentation and excerpts of the ontology provided by these documents, but not on an actual OWL file, since in all cases no URL was provided nor we could find it searching on the Web. This was the case for eDiana, FIPA, Hydra, SEIPF, Adapt4EE, DEHEMS, ebbits and SESAME.

The second step was to analyze the selected documents for each assets. The content and level of details of the selected documents was different but mainly spanning 1) architectural overviews useful to have a general idea of the considered asset, 2) explicit data models or ontologies from which we could (more or less) straightforward attempt to define a semantic coverage, 3) protocols descriptions with implicit semantics, 4) low-level data-container specifications from which it was cumbersome to capture a semantic coverage.

The third step was to define a semantic coverage based on key terms found in the selected documents, and give an initial indication whether the asset was aligned with the scope of our study, and/or whether the semantics was sufficiently explicit to be translated into an ontology, regardless to the fact that an ontology was actually provided. For example, some documents did not directly provide an ontology, but provided an explicit, clear and well-structured specification in natural language with the support of tables.

The fourth step was to make a short list to narrow down the 43 assets based on the following criteria:

1. Given the scope of this study “Available Semantics Assets for the Interoperability of Smart Appliances. Mapping into a Common Ontology as a M2M Application”, does the considered asset target M2M Devices that run M2M Application(s) using M2M Service Capabilities, as described in Section 2.2?

2. Does the considered asset address (one of) the smart appliance categories as laid out in section 2.1?
3. Does the asset provide a clear and well-structured specification that can be used to explicitly capture the semantics in an ontology?
4. Could the asset be translated into an ontology with maximum 20-25 classes and some corresponding relations, or would this simplification harm the actual purpose and meaning of the asset?
5. If the entire asset seems to be too extensive and complex to be reduced to 20-25 classes, could we focus on one single part/module that is especially relevant according to the criteria 1 and 2 mentioned above?
6. Does the asset directly provide an ontology and OWL representation?
7. Does the asset provide XML schemas that could be used to automatically support the translation to an OWL ontology?

Therefore the reader should be aware that this short list is NOT an endorsement by TNO or the European Commission, NOR does it signify anything about the relevance of the underlying technology for the industry or the market, nor any other commercially valuable qualification. On the contrary, most long-listed bodies and projects have provided useful assets, if not in the form of ready-to-use XML or OWL files, such as use cases, low-level data-container specifications, and interoperability specifications.

As such, the following assets were identified as providing a good basis for further ontology development in this study. They are described in detail in chapter 3, one asset per section, in alphabetical order. The other assets are summarily described together in the final section of chapter 3. The short list consists of:

- ECHONET
- FIEMSER
- UPnP
- SmartCoDE
- OMA Lightweight M2M
- SEP2
- EnOcean
- OMS
- Hydra
- KNX
- W3C SSN
- OSGi DAL
- eDIANA
- FAN
- DECT ULE
- Z-Wave
- SEEMPubs
- SEIPF
- FIPA
- Mirabel

3. Assets

3.1 DECT ULE

Model Acronym and Full Name

DECT (Digital Enhanced Cordless Telecommunications) ULE (Ultra-Low Energy) HAN FUN (Home Area Network FUNctionality)

Most relevant URLs, and other precise references

DECT ULE HAN FUN is described in 5 complementary documents:

- HF-Overview V1.00 (2014-23-1)
- HF-Protocol V1.00 (2014-23-1)
- HF-Service V1.00 (2014-23-1)
- HF-Interface V1.00 (2014-23-1)
- HF-Profile V1.00 (2014-23-1)

They can be downloaded for free after registration at http://www.ulealliance.org/registration.aspx?f=11

Overall description

DECT is a wireless protocol used for in-home cordless phones. The air interface has been standardized by ETSI as EN 300 175 [10]. ULE is its Ultra-Low Energy variety of DECT, which is designed for use of DECT with home automation, security, and climate control devices and applications. The ULE specification was created as an initial cooperation between DECT Forum[8] and ETSI.

The physical layer of ULE makes use of the existing ETSI DECT specification EN 300 175-2. The technical specification work for the upper part of the ULE transport layer has been carried out in ETSI TC DECT, with the following updates:

- Medium Access Control Layer (EN 300 175-3)
- Data Link Control (EN 300 175-4)
- Network Layer (EN 300 175-5)
- Security (EN 300 175-7)
- Interworking Unit and Application Layer Protocol Negotiation (TS 102 939-1) [11]

ULE has its own application layer protocol called HAN FUN (Home Area Network FUNctionality) or simply HF. It has been released by the ULE Alliance[9] in November 2013. HAN FUN ensures interoperability for the specified applications and devices. In addition it supports proprietary extensions where required.

Description of the semantic coverage

The HF-Protocol document describes the network topology, the network entities (concentrator and device), the HF message formats and types. DECT is based on a star network topology, where a single Concentrator is the network's master device and supports up to thousands of HF Devices connected

[8] www.dect.org
[9] www.ulealliance.org

to it. A Unit is a conceptual entity inside a HF device that instantiates the functionality of a specific type. Unit types, for example smoke detector, simple switch and more are described in the HF-Profile document. An Interface is a conceptual entity inside a unit that defines a collection of commands and attributes, allowing for units to understand one another. Interfaces can be mandatory or optional to implement by a unit, and they have a role – client or server – associated with them. Interfaces are described in the HF-Interface document. The Service document lists the services of the HF standard. The semantic coverage is shown in Figure 2.

List of services:

– Device Management, Service responsible for device registration and discovery.
– Bind Management, Service that allows for the creation of logical communication links between devices.
– Group Management, Service that allows for the creation of logical groups for message broadcasts.
– Identify, Service that provides a simple method of identifying devices without the hassle of looking and matching serial numbers.
– Device Information, Service that defines information that any HF device can/must provide.

List of interfaces:

– Alert, Use when device wants to indicate an alert
– On-Off, Use to turn some device feature On or Off (you may also toggle it)
– Level Control, Use to set some device feature to a defined level
– Simple Power Metering, Use when device requires doing or providing measurements over electric quantities.
– Reserved, Use for proprietary features (e.g. technical , manufacture, etc)
– Attribute Reporting , Service that allows a unit to receive automatic notifications about other units or device's attributes whenever an event triggers.
– Tamper Alert, Service that allows a device to indicate it is being tampered with.
– Time, Service that allows a device to maintain time referenced to UTC.
– Power, Service that allows a device to provide information about the power supplies it has and their characteristics.
– Keep Alive, Service that allows a device to signal it is alive.

List of Unit types:

– Home control unit types: Simple On-Off Switchable, Simple On-Off Switch, Simple Level Controllable, Simple Level Control, Simple Level Controllable Switchable, Simple Level Control switch, AC Outlet, AC Outlet with Simple Power Metering, Simple Light, Dimmable Light, Dimmer Switch, Simple Door Lock, Simple Door Bell, Simple Power Meter (definitions of each type are available in Table 3 of the document).
– Security unit types: Simple Detector, Door Open Close Detector, Window Open Close Detector, Motion Detector, Smoke Detector, Gas Detector, Flood Detector, Glass Break Detector, Vibration Detector, Siren ((definitions of each type are available in Table 3 of the document).
– Homecare Unit Types: Simple Pendant
– Application Unit Types: User Interface, Generic Application Logic
– Proprietary Unit Types: Proprietary

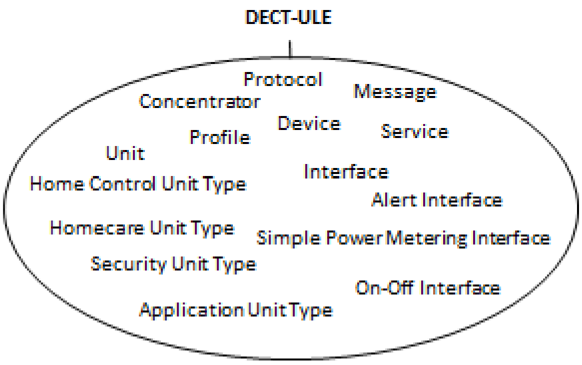

Figure 2. Visual representation of the semantic coverage of DECT-ULE

Overall description of the consensus driven process leading to the model

ULE Alliance has 5 Promotor Members, 9 Contributor Members, and 38 Adopter Members. Only the Promotor Members and Contributor Members pay a fee and can contribute. Promotor Members are the semiconductor manufacturers Dialog Semiconductor and DSP Group, and the device manufacturers Gigaset and Vtech. They drive the agenda of the alliance. Also DECT Forum is a Promotor Member. Contributors are Arcadyan, AVM, Cisco, The Crow Group, Deutsche Telekom, Lantiq, Panasonic, RTX, and Sercom.

3.2 ECHONET

Model Acronym and Full Name

ECHONET (Energy Conservation and HOmecare NETwork) Detailed Requirements for ECHONET Device Objects.

Most relevant URLs, and other precise references

ECHONET Specifications Appendix “Detailed Requirements for ECHONET Device Objects” Release C, 31 May 2013,
http://www.echonet.gr.jp/english/spec/pdf_spec_app_c_e/SpecAppendixC_e.pdf

Overall description

ECHONET[10] is a largely Japan-based consortium that promotes the development of basic software and hardware for home networks that can be used for remote control or monitoring of home appliances. For this purpose the consortium developed the ECHONET specifications and established basic technology for it. The aim in doing so has been to reduce CO_2 emissions while responding to the increasing sophistication of home security and home healthcare. ECHONET further developed home network technologies on home appliances and home facility equipment, and published “the ECHONET Lite Specification” in 2011, which is easier to use than the original ECHONET specifications, and enables interworking with other standard protocols. The ECHONET Specifications Appendix “Detailed Requirements for ECHONET Device Objects” is part of the Communication Middleware Specifications of ECHONET as well as ECHONET Lite.

Description of the semantic coverage

The semantic coverage is very detailed and schematically depicted in Figure 3. The main class (superclass) is the Device Object and it is specified with all its properties, such as Operation status

[10] www.echonet.gr.jp

(ON/OFF), Installation location (location at which the device has been installed, e.g., Living room, dining room, kitchen, bathroom, etc. or free definition), Standard version information (release order of the semantic model), Fault status (indicates whether a fault has occurred in the actual device), Fault description (code values for recoverable faults, faults that require repair, or other type of faults), Identification number (unique identifier in the domain), Measured instantaneous power consumption (in Watts), Measured cumulative power consumption (in increments of 0.0001kW), Manufacturer info, Product code, Production number and date, Power saving operation setting (if the device is operating in power-saving mode), Power limit setting (maximum consumable power), Current time, Current date.

The Device Object class is then specialized in sub-classes. One example is Sensor-related device, which includes Gas leak sensor, Crime prevention sensor, Emergency button, Humidity sensor, etc. Each of these sensor-related device classes (e.g., Gas leak sensor) is further detailed specifying its properties.

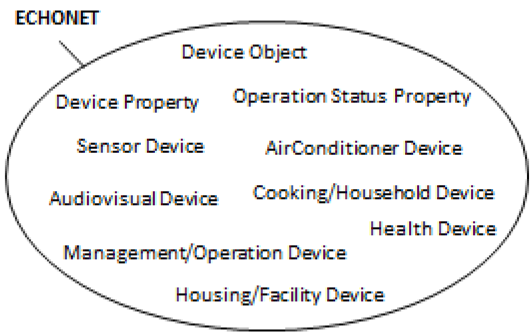

Figure 3. Visual representation of the semantic coverage of ECHONET

Other examples include:

- Air Conditioner-related device, for example, Home air conditioner, Electric fan, Dehumidifier, electric blanket, etc. Each of these Air Conditioner-related device classes (e.g., Home air conditioner) is further detailed specifying its properties.
- Housing/Facilities-related device, for example, Electrically operated shade, Electric water heater, Floor heater, etc. Each of these Housing/Facilities-related device classes (e.g., Electrically operated shade) is further detailed specifying its properties.
- Cooking/Household-related device, for example, Refrigerator, Washing machine, Clothes dryer, etc. Some of these Cooking/Household-related device classes (e.g., Refrigerator) are further detailed specifying their properties.
- Health-related device, such as Weighing machine, Clinical thermometer, Blood pressure meter, Blood sugar meter and Body fat meter. Only the Weighing Machine class is further detailed specifying its properties.
- Management/Operation-related device, such as Secure communication shared key setup node, Switch, Portable (mobile) terminal and Controller. Only the Switch class is further detailed specifying its properties.
- Audiovisual-related device, such as Display and Television. Both the Display and Television classes are further detailed specifying their properties.

Overall description of the consensus driven process leading to the model

The consortium was founded in 1997 and now has 160 members. Member have a number of benefits, including the right to view and offer opinions concerning drafts during development of the ECHONET Specification. Only the so-called "managing members" have voting rights. They are Hitachi, Ltd., Mitsubishi Electric Corp., NIPPON TELEGRAPH AND TELEPHONE CORPORATION (NTT), Panasonic Corporation, Sharp Corp., SOFTBANK TELECOM Corp., Tokyo Electric Power Company, Inc., and Toshiba Corp.

3.3 eDIANA

Model Acronym and Full Name

eDIANA (Embedded Systems for Energy Efficient Buildings) Ontology for Device Awareness

Most relevant URLs, and other precise references

D2.2-A "Ontology for Device Awareness", 30 November 2009, http://s15723044.onlinehome-server.info/artemise/documents/D22A_Ontology_for_Device_Awareness_m10_IMSML.pdf

Overall description

eDIANA[11] was an ARTEMIS[12] project running between 2009 and 2012. It aimed to address the need of achieving energy efficiency in buildings through innovative solutions based on embedded systems. The technical approach included the development of a reference model-based architecture, implemented through an open middleware including specifications, design methods, tools, standards, and procedures for platform validation and verification. The platform is designed to achieve the interoperability of heterogeneous devices at the Cell and MacroCell levels, and to provide the hook to connect the building as a node in the producer/consumer electrical grid. The architecture describes a network of composable, interoperable and layered embedded systems that will be instantiated to several physical architectures. The eDIANA Platform realisations will then cope with a variable set of location and building specific constraints, related with parameters such as climate, Cell/MacroCell configuration (one to many, one to one, etc.), energy regulations etc.

Description of the semantic coverage

D2.2 describes the eDIANA ontology, which aims at defining the universe of concepts or classes and their relations in the domain of eDIANA Platform Architecture, related to device awareness. The document first analyses middleware that considers device awareness in its specification (OSGi, KNX, ZigBee- Home Automation Public Application Profile and CORBA), then analyses different ontology languages and also describes the methodology that has been used to create the ontology. Section 5 presents the semantic structure of the ontology. The document defines three layers and for each layer a taxonomy in OWL is shown in a picture. The information and service layers ontology is actually only a taxonomy of classes. No object properties, data properties or restrictions are specified in this document. Some properties and restrictions are defined for the device layer ontology making it a proper ontology. The semantic coverage is depicted in Figure 4.

[11] http://s15723044.onlinehome-server.info/artemise/index.php
[12] http://www.artemis-project.eu/

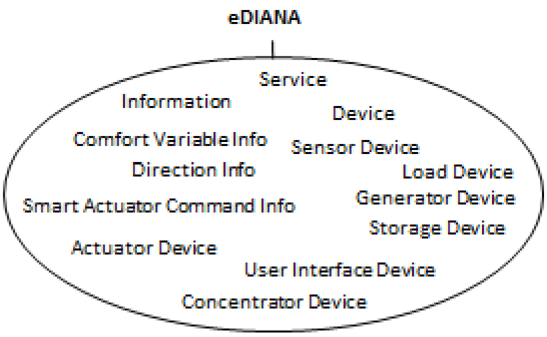

Figure 4. Visual representation of the semantic coverage of eDIANA

The three layers in the ontology are defined as information, services and devices layers. The information layer contains the different categories of information that will be referenced by the elements defined in the services layer and devices layer. They include Direction_Information, Comfort_Variable_Information (such as Humidity_Information, Luminosity_Information, Noise_Information, and Temperature_Information), and Smart_Actuator_Command_Information (such as Change_Configuration_Command_Information, Delayed_Turn_Off_Command_Information, Delayed_Turn_On_Command_Information, and Turn_Off_Command_Information, Turn_On_Command_Information).

The services layer specifies the different interfaces at a very high level (the concrete definition of the interfaces is recommended as future work in the document), including External_Services and Internal_Services. The devices layer contains different categories of devices that compose the eDIANA platform to enable device awareness services and plug-and-play services by characterizing the devices, their properties and their interfaces. They include Concentrator, Actuator, Appliance (including Generator, Load, Storage), Sensor (including Video Camera, Airflow Sensor, Gas Sensor, Humidity Sensor, Light Sensor, Power Sensor, Sound Sensor, Sun Radiation Sensor, Temperature Sensor, Fire Sensor, Movement Sensor, and Smoke Sensor), and User Interface.

Overall description of the consensus driven process leading to the model

The majority of the eDiana consortium members are based in Spain, including Acciona Infrastructures, Atos Origin, Tecnalia, Fagor, Ikerlan, I&IMS, Gaia, and Mondragon University. Other partners include STM, Philips, Elsag, Fideliz, Quintor, Infineon, VTT, Bologna University, and Sapienza University Rome. The authors of the ontology are from ESI Tecnalia and I&IMS.

3.4 EnOcean

Model Acronym and Full Name

EnOcean Alliance Equipment Profiles

Most relevant URLs, and other precise references

EnOcean Equipment Profiles (EEP), Version 2.6, 17 December 2013, http://www.enocean-alliance.org/eep/

Overall description

EnOcean[13] is a company that develops energy harvesting wireless sensors which are claimed to be maintenance free and flexible allowing cost reduction in buildings and industrial facilities. They

[13] www.enocean.com

founded the EnOcean Alliance[14], which develops and promotes self-powered wireless monitoring and control systems for sustainable buildings by formalizing an interoperable wireless communication technology. In 2012 this technology has subsequently been standardized as ISO/IEC 14543-3-10 [12]. The standard covers the OSI (Open Systems Interconnection) layers 1-3 which are the physical, data link and networking layers, and is geared to wireless sensors and wireless sensor networks with ultra-low power consumption. It also includes sensor networks that utilize energy harvesting technology to draw energy from their surroundings – for example from motion, light or temperature differences. This principle enables electronic control systems to be used that work independently of an external power supply. Full interoperability is guaranteed together with the EnOcean Equipment Profiles (EEPs) drawn up by the EnOcean Alliance.

Description of the semantic coverage

The EnOcean Equipment Profile (EEP) contains information about devices "enabled by EnOcean", including RORG (identifies the EnOcean Radio Protocol (ERP) radio telegram type), FUNC (identifies the basic functionality of the data content), and TYPE (identifies the type of device in its individual characteristics). The semantic coverage is depicted in Figure 5.

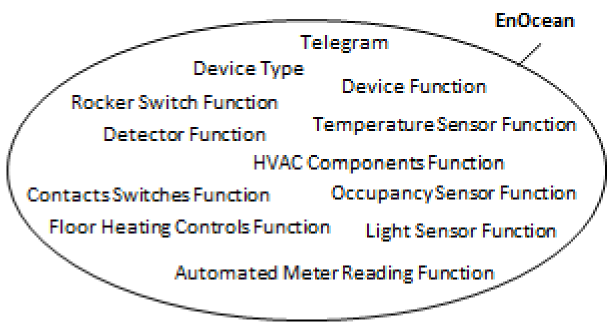

Figure 5. Visual representation of the semantic coverage of EnOcean

There are 4 types of Telegrams (RPS, 1BS, 4BS, VLD) and for each of them there are several corresponding devices functions and types.

The RPS telegram contains the following device functions: Rocker Switch, which has several channels and states, and can be further classified in 2 Rocker or 4 Rocker, Position Switch Home and Office Application, Detectors, and Mechanical Handle. Each of these functions is further divided in device types, for example, the Rocker Switch – 2 rockers function has types "01 Light and Blind Control – Application Style 1", "02 Light and Blind Control – Application Style 2", "03 Light and Blind Control – Application Style 3" and "04 Light and Blind Control ERP 2".

The 1BS telegram contains only one function and type, namely the Contacts and Switches device function with type "01 Single Input contact".

The 4BS telegram contains the following device functions: Temperature Sensors, which is further classified in types depending on the range of temperature handled, Temperature and Humidity Sensor, Light Sensor, Occupancy Sensor, Light-Temperature-Occupancy Sensor, Gas Sensor, Room Operating Panel, Controller Status with types Light controller, Temperature Controller Output, Blind Status and Extended light status, Automated meter reading (AMR) with types Counter, Electricity,

[14] www.enocean-alliance.org

Gas and Water, Environmental Applications with types Weather station, Sun Intensity, Date exchange, Time and Day exchange, Geographic position exchange, sun position and radiation, Multi-Func Sensor, HVAC components, Digital Input, energy management, Central command, Universal.

The VLD telegram contains the following device functions: Electronic switches and dimmers with energy measurement and local control, Sensors for temperature-illumination-occupancy and smoke, Light Switching + Blind Control, CO2-Humidity-Temperature-Day/Night and Autonomy, Fan Control, Floor heating controls and automated meter reading, Automated reading meter gateway, Standard valve.

Overall description of the consensus driven process leading to the model
The EnOcean Alliance is founded in 2008 and includes over 250 members and aims to create interoperability between the OEM partners of the EnOcean technology. The Alliance has 9 so-called promotor members which besides EnOcean include BSC Computer GmbH, Honeywell, OPUS greenNet, Pressac Communications, ROHM, Texas Instruments, Thermokon Sensortechnik, and Verve Living Systems.

3.5 FAN

Model Acronym and Full Name
FAN (FlexiblePower Alliance Network) FPAI (Flexible Power Application Infrastructure)

Most relevant URLs, and other precise references
HEGRID AD1305 Interface description: Interface report, Version 1.0 (final), 7th January, 2014, http://www.flexiblepower.org/downloads/ (after free registration).

Overall description
FAN[15] (The Flexiblepower Alliance Network) is a network of companies and institutions that jointly develop and manage the international FAN standard. The alliance assures the quality of the standard and monitors compatibility of devices and services that are FAN-labeled. FAN is an independent foundation. FAN develops and maintains a standard for the communication layer between devices and energy services. On the one hand, appliances indicate the minimum amount of energy they need to operate properly. On the other hand, energy services can work out when the circumstances are ideal for energy use (depending on e.g. the weather forecast and energy price). The FPAI (Flexible Power Application Infrastructure) framework can be used to flexibly support different Supply and Demand Management approaches towards end-customers. With the FPAI framework the household is managed via an FP Home Box. This box will be responsible for the negotiation between the energy service providers and the household and the coordination and management of energy resources located within the household. The FPAI application is implemented on top of the OSGi platform.

Description of the semantic coverage
The semantic coverage of FAN is depicted in Figure 6 and consists of the following main concepts:

– A Device represents a functional (hardware) component that consumes, produces, releases, or converts electricity or physical substances and that has some flexibility in its energy usage and can therefore be energy-managed;

[15] www.flexiblepower.org/

– Resources represent devices within a household or a building that can provide flexibility with regard to consumption, storage and production of energy;
– Device manager, or resource manager, describes the energetic flexibility of a device in a generic and standardized way. An energy app is only interested in exploiting energetic flexibility and not in the specifics of a washing machine, for instance. The energetic flexibility is expressed in so called Control Spaces. There are four different types of Control Spaces that cover most appliances:
    - Time shifters are resources that can shift the generation or usage of energy over a specific period of time. Examples are washing machines with a possibility to postpone the start time. Parameters in the Control Space of a Time shifter are: an energy profile and a period over which the start moment can be shifted. Another example is an electric car which needs to be charged before a certain moment (before it will be used) but the actual loading can be performed and shifted within a certain time period;
    - Buffers are resources that can temporarily consume (or produce) more energy so they will use (or generate) less energy at a later moment in time. In most cases these are thermic buffers such as heating devices or refrigerators. Examples of parameters for the Buffer Control Space are: total buffer capacity, filling, loading curve and discharge curve;
    - Storage are resources that resemble a Buffer Resource, but a Storage resource can both store and return energy. Apart from parameters describing the Buffer resource, a Storage Control Space also has parameters for storage loss;
    - Uncontrolled load/generation are type of Resources whose energy behaviour cannot be controlled (e.g. solar panels, TV, computers, etc.). For this resources only a prediction can be made for the expected consumption or production of energy. These predictions can be used in the rest of the framework to make decisions on energy control;
– An energy app receives the control spaces and decides how to exploit the energetic flexibility. As a response to a control space an energy app will send an allocation. The allocation simply contains the energy profile that a resource will have to follow. An allocation should always respect the constraints that were expressed in the control space.

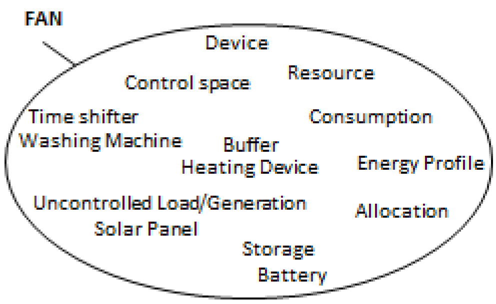

Figure 6 Visual representation of the semantic coverage of FAN

Overall description of the consensus driven process leading to the model

The FlexiblePower Alliance Network is founded in 2013 and includes TNO and Alliander. FAN aims to develop a worldwide standard to help households, businesses, manufacturers, energy companies and software suppliers to accelerate the future of sustainable energy together. FAN has participants and platinum participants. Decisions are made by the general assembly by majority of votes. Every participant has one vote and every platinum participant has five votes in the general assembly.

3.6 FIEMSER

Model Acronym and Full Name

FIEMSER (Friendly Intelligent Energy Management Systems in Residential Buildings) Data Model

Most relevant URLs, and other precise references

D5 FIEMSER Data Model, February 2011, http://www.fiemser.eu/wp-content/uploads/2011/12/D5_FIEMSER-data-model_m9_CSTmb_REVIEW.pdf

Overall description

FIEMSER ran between 2010 and 2013. The main objective of this FP7 European R&D project[16] was the development of an innovative energy management system for existing and new residential buildings, which pursues the increase of the efficiency of the energy used and the reduction of the global energy demand of the building, but without penalizing the comfort levels of the users. To the achievement of this goal, it followed two main strategies:

- Minimizing the energy demand from external resources, through the reduction of the energy consumption in the building and the correct management of local generation (heat and electricity) and energy storage equipment to satisfy the energy demand of the building, and even provide the capability to export energy to the utilities when needed.
- Interaction with the building user, in such a way as to increase the consciousness of the consumer of his energy consumption and CO_2 emissions, providing hints to make punctual changes in his behaviour without major disruptions of his comfort conditions.

To specify this energy management system, the project defined and published a system architecture (D4) [13], a data model (D5), and interface modules (D9) [14]. D5 describes the methodology used to develop a data model for Friendly Intelligent Energy Management System for Existing Residential Buildings (FIEMSER) and specifies the data model itself. The methodology followed a bottom-up approach that started from 8 specific sub-models that were afterwards integrated in a single data model. The several sub-models are described using natural language and UML diagrams.

Description of the semantic coverage

The semantic coverage of FIEMSER is depicted in Figure 7. The specific sub-models used to create the FIEMSER data model belong to the following 8 corresponding categories of data: Environmental and Contextual data (ENV), Energy-focused Building Information Model (BIM), Data from sensors (WSN), User Preferences (USR), Resources scheduling data (SCH), Advices (ADV), Energy Performance Indicators (EPI), and User access right (RGH).

The ENV data model represents the environment of the building, such as the climate, location, orientation, and economical environment (prices). Main classes are: Weather Forecast class and Day Ahead Prices class to describe the hourly evolution of, respectively, weather and energy prices, during a certain period of time.

The Energy-focused BIM data model describes the building space organization and the building resources (loads that consume energy to offer a service to the user, generators that provide part of the energy required by the building, storage devices to provide convenient energy management strategy).

[16] www.fiemser.eu

The WSN data models represents the Control device class, i.e., the devices that can be directly controlled and monitored by FIEMSER, which can be interfaced with Hardware Components (sensors or actuators), and handles a number of software and network protocols. The energy consumption of each control device is maintained and estimated.

The USR data model represents the daily planning of the building usage by the end-user using home usage profiles at the level of building zones.

The SCH data model represents the overall building energy usage planning and the individual use of resources. The main classes are: building program schedule class, temperature schedule class, resource schedule class.

The ADV data model represents the advices given to the user to improve the energy efficiency of the building (Order class, Advice class and Control Action class).

The EPI data model represents the control devices, the link with the equipment they operate upon, and the details of operations of sensors and actuators (DataLog class, Sensor class, Actuator class, Home Daily MeasurementLog class).

The RGH data model represents the (groups of) users and their different permissions to access and operate upon the FIEMSER system.

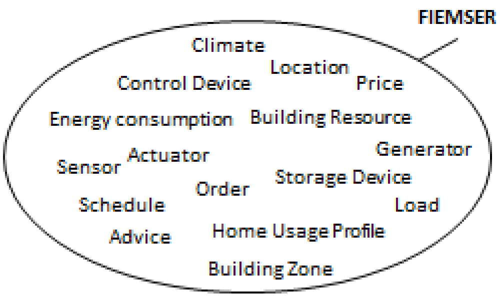

Figure 7. Visual representation of the semantic coverage of FIEMSER

Overall description of the consensus driven process leading to the model
The consortium is mainly based in France and Spain, and includes Tecnalia, Centre Scientifique et Technique du Bâtiment (CSTB), Fraunhofer Institute for Building Physics (IBP), University College Dublin, Acciona Infraestructuras SA, Tenesol SA, TP Vision, and Thales Communications SA. D5 was edited by CSTB, with input from Tecnalia, UC Dublin, Fraunhofer, and Tenesol.

3.7 FIPA

Model Acronym and Full Name
FIPA (Foundation for Intelligent Physical Agents) Device Ontology Specification

Most relevant URLs, and other precise references
FIPA Device Ontology Specification, SC00091E, 3 December 2002,
http://www.fipa.org/specs/fipa00091/SI00091E.pdf or
http://www.fipa.org/specs/fipa00091/SI00091E.html

Overall description

FIPA[17] is an IEEE[18] Computer Society standards organization that was formed in 1996 and is dedicated to promoting the industry of intelligent agents by openly developing specifications supporting interoperability among agents and agent based applications. FIPA Technical Committees (TCs) are intended to carry out the technical work of FIPA. Currently, the following TCs are tasked with work:

- Ad-Hoc
- Methodology
- Modeling
- Security
- Semantics
- Services

In 2002, the then existing FIPA Gateways TC published an ontology for describing devices and their properties. The FIPA Device Ontology Specification describes a device ontology that aims at enabling interoperability between software agents. The FIPA device ontology can be used by agents when communicating about devices.

Description of the semantic coverage

Two devices may exchange device profiles (either directly or through a brokering agency) and acquire a list of services provided by the other device. The list of services may include both hardware and software services, for example, a software component that provides access to a hardware component of the device (such as microphone, headset or GPS service). The profile needs to support the identification of services for various input and output capabilities, such as audio input and output. Agents pass profiles of devices to each other and validate them against the fipa-device ontology. For example, an agent can ask another agent whether a certain device has enough capabilities to handle some task. The classes represented in the FIPA device ontology are agent, device, profile, info-description, hw-description, connection-description, ui-description, screen-description, resolution-description, memory-description, memory-type-description, sw-description. The semantic coverage is shown in Figure 8.

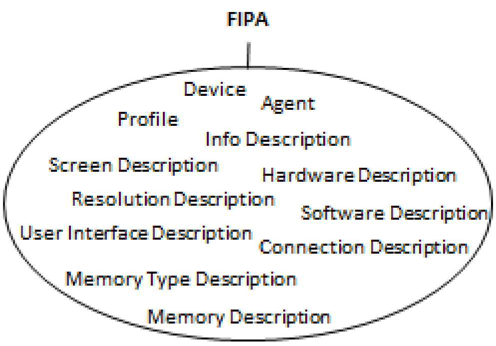

Figure 8. Visual representation of the semantic coverage of FIPA

[17] www.fipa.org
[18] www.ieee.org

Overall description of the consensus driven process leading to the model

FIPA is an open organization with free membership. When the standard was published, FIPA consisted of 56 member organizations and companies. The Gateways TC was founded in 2000 and supported by BT, EPFL, Nokia, Siemens AG, Sonera Ltd, and University of Helsinki.

3.8 HYDRA

Model Acronym and Full Name

HYDRA (Heterogeneous physical devices in a distributed architecture) MDA Design Document

Most relevant URLs, and other precise references

Deliverable D6.6 Updated MDA Design Document, version 1.0, 20 August 2009, http://www.hydramiddleware.eu/hydra_documents/D6.6_Updated_MDA_Design_Document.pdf

Overall description

HYDRA[19] was a European 6th Framework R&D project running from 2006-2010. The first objective of the Hydra project was to develop middleware based on a Service-oriented Architecture, to which the underlying communication layer is transparent. The middleware will include support for distributed as well as centralised architectures, security and trust, reflective properties and model-driven development of applications. The HYDRA middleware is designed to be deployable on both new and existing networks of distributed wireless and wired devices, which operate with limited resources in terms of computing power, energy and memory usage. It says to allow for secure, trustworthy, and fault tolerant applications through the use of distributed security and social trust components. The embedded and mobile Service-oriented Architecture is expected to provide interoperable access to data, information and knowledge across heterogeneous platforms, including web services, and support true ambient intelligence for ubiquitous networked devices.

The second objective of the HYDRA project was to develop a Software Development Kit (SDK) to be used by developers to develop innovative Model-Driven applications. The middleware developed within HYDRA has been open-sourced as LinkSmart[20], allowing developers to incorporate heterogeneous physical devices into their applications through easy-to-use web services for controlling any device. LinkSmart is still actively developed and released on 20 March 2014 its version 2.1.

Description of the semantic coverage

D6.6 explains the methodology, architecture and semantic models used in HYDRA. HYDRA aims to interconnect devices, people, terminals, buildings, etc., not only providing interoperability at a syntactic level, but also at a semantic level. This is done by combining the use of ontologies with semantic web services. Hydra relies on semantic descriptions/annotations to expose device capabilities (using ontologies) so that applications can understand these capabilities and use them. There are several ontologies developed in the project, namely:

- The Device ontology
    - Basic device information

[19] www.hydramiddleware.eu

[20] http://sourceforge.net/projects/linksmart/

- o Device services
- o Device Events
- o Device malfunctions
- o Device capabilities and state machine

– Semantic Discovery ontology
– Semantic Device ontology
– Application Specific ontology

HYDRA has done muchwork on service discovery and composition using ontologies. Most relevant for this study is HYDRA's device ontology, especially the Basic device information module, but also Device services and Device events. The semantic coverage is schematically depicted in Figure 9. It includes concepts such as Hydra application, Semantic Device, Hydra Device, Physical Device, Device Application Catalog, Device services, Device events, Device mulfunctions, etc.

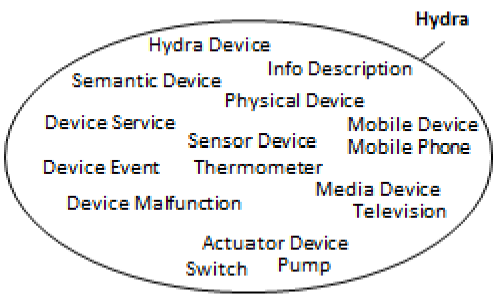

Figure 9. Visual representation of the semantic coverage of Hydra

The Basic device information module represents general device information. The HydraDevice concept presents the main ontology class. The HydraDevice is further subclassed to the model of the PhysicalDevice and the SemanticDevice, which share the common device properties (such as deviceId or location), but have different semantic interpretation and behaviour. The concept InfoDescription contains basic information about device friendly name, manufacturer data (such as manufacturer name and URL) and device model data, namely model name, model description and model number. The information is represented as OWL data type properties. The InfoDescription class is referred from the HydraDevice concept using the info OWL object property. An important part of the basic device information is the representation of device type modelled as the OWL is-a hierarchy by sub classing the PhycicalDevice concept. Further, the OWL object property hasEmbeddedDevice of SemanticDevice concept recursively refers to HydraDevice concept. This property enables the creation of models of composite devices, such as in case of HeatingSystem device used in first system prototype application. HeatingSystem can be, for example, composed of Thermometer and Pump devices.

Overall description of the consensus driven process leading to the model
The partner of the HYDRA consortium include CNet Svenska AB, The Fraunhofer Institute for Applied Information Technology, The Fraunhofer Institute for Secure Information Technology, In-JeT ApS, Priway, T-Connect S.r.l., Telefonica I+D SA, University of Aarhus, Innova S.p.A., University of Reading, Siemens IT Solutions and Services, Technical University of Kosice, and University of Paderborn. The editors of D6.6. are from CNet and Technical University of Kosice.

3.9 KNX

Model Acronym and Full Name

KNX (Konnex) Datapoint Types

Most relevant URLs, and other precise references

KNX System Specifications Interworking Datapoint Types, Version 1.07.00, 26 April 2012, http://www.knx.org/media/docs/downloads/03%20-%20KNX%20Standard/KNX%20Standard%20Public%20Documents/03_07_02%20Datapoint%20Types%20v1.07.00%20AS.zip

Overall description

KNX Association[21] is a non-profit-oriented organisation which members are manufacturers developing devices for several applications for home and building control based on KNX, like lighting control, shutter control, heating, ventilation, air conditioning, energy management, metering, monitoring, alarm/intrusion systems, household appliances, and audio/video. The association is the owner of the KNX standard. It standardizes an OSI-based network communications protocol for intelligent buildings. It defines several physical communication mediums and is designed to be independent of any particular hardware platform. The most common form of installation however is over twisted pair. A KNX Device Network can be controlled by anything from an 8-bit microcontroller to a PC, according to the needs of a particular implementation. Any product labelled with the KNX trademark are tested by KNX accredited third party test labs. During these tests, it is not only checked that the device supports the KNX protocol but that its useful data is coded according to the KNX standardized Datapoint Types. The KNX specifications, known as KNX Handbook and standardized as ISO/IEC 14543-3 [15] and CENELEC EN 50090 [16], are not freely available, but the section that specifies the Datapoint Types is.

Description of the semantic coverage

KNX does not define devices, but it is completely command based. However, the parameters in those commands are standardized and called Datapoints. There are several types of Datapoints, namely Datapoint Types for common use, Datapoint Types for HVAC, Datapoint Types for Load Management, Datapoint Types for Lighting, Datapoint Types for Systems. Combinations of data point types into a device are called Functional blocks. Many functional blocks have been defined, but only two of them have been standardized: Dimmer Actuator Basic and Sunblind Actuator Basic. The other functional blocks are not standardized because they are not tested and certified as such. A KNX certification means that all the relevant datapoint types have been implemented correctly. A functional block is generally not more than just a selection of datapoint types. Dimmer and Sunblind also contain state, which goes beyond just datapoint types. The semantic coverage of KNX is schematically depicted in Figure 10.

Overall description of the consensus driven process leading to the model

KNX Association, as of 1 March 2014, had 339 members/manufacturers from 37 countries. Companies in the Executive Board are mostly from Germany and include ABB Stotz-Kontakt GmbH, Albrecht Jung GmbH & Co. KG, Busch-Jaeger Elektro GmbH, Feller AG, GIRA Giersiepen GmbH & Co.

[21] www.knx.org

KG, HAGER Group, Insta Elektro GmbH, Kellendonk Elektronik GmbH, Merten GmbH, Schneider Electric, Siemens AG, Siemens Switzerland Ltd., and Theben AG. Siemens and HAGER deliver the president and the vice-president of the Association. The KNX standard is largely based on the communication stack of EIB (European Installation Bus), which was originally developed by Berker, Gira, Jung, Merten and Siemens AG.

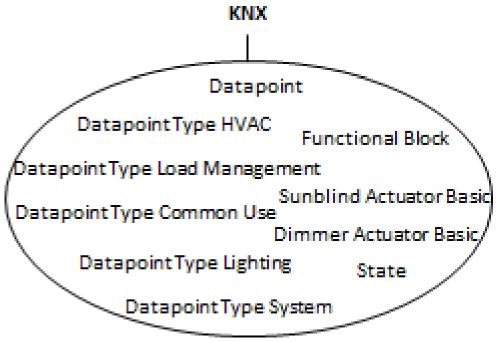

Figure 10. Visual representation of the semantic coverage of KNX

3.10 MIRABEL

Model Acronym and Full Name

MIRABEL (Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution)

Most relevant URLs, and other precise references

D7.5 “MIRABEL-ONE: Initial draft of the MIRABEL Standard, version1.0”, 22 December 2011, http://wwwdb.inf.tu-dresden.de/miracle/publications/D7.5.pdf

Overall description

MIRABEL[22] was a European 7th Framework R&D project running from 2010-2013. Its main goal was to develop an approach on a conceptual and an infrastructural level that allows energy distribution companies to balance the available supply of renewable energy sources and the current demand in ad-hoc fashion. MIRABEL worked on a concept of micro-requests with time shifts to handle the demand and supply of energy on a household level. Further, they defined methods to predict the energy supply and demand in the small (i.e., for households) and in the large and to update predictions over time. The idea is then to aggregate (and disaggregate) the micro-requests on a regional level, and to develop a scheduling approach for energy production and consumption based on aggregated requests. Energy distribution companies may use the aggregated request information to re-schedule energy demands/supplies and thus have additional means to react to shortages or an abundance of energy. They may also trade their demand requests with other energy distribution companies.

Description of the semantic coverage

The goal of D7.5 is to define a specification for modeling flexibility and the exchange of flexibility information between stakeholders in the energy domain, especially between consumers and electricity suppliers. The specification is described in terms of a generic data model for energy flexibility and messages for information exchange on flexibility offerings. The intention of this

[22] www.mirabel-project.eu/

specification is to be used as input for formal European standardization and acceptance in the electricity market. The document presents detailed data models and messages. TNO created an ontology based on this document. Its coverage is depicted in Figure 11.

The ontology consists of several concepts, some specific to the energy/smart grid domain, others more general, like time and price. The ontology describes how actors can express their energy flexibility for a specific device with respect to amount, time and price in user preferences. Each device has an energy profile that describes how much (amount) energy the device consumers and or produces over a time span. A FlexOffer will be issued by an actor. It combines the user preferences and the corresponding device energy profile.

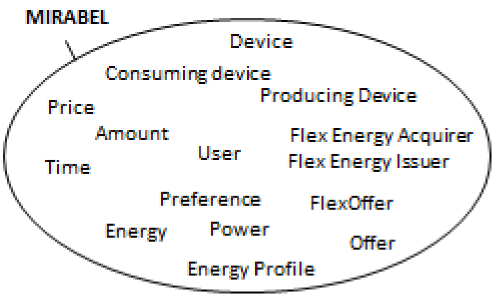

Figure 11. Visual representation of the semantic coverage of MIRABEL

Overall description of the consensus driven process leading to the model
The MIRABEL Consortium consists of six research and technology partners and two use-case partners: SAP AG, Aalborg Universitet, CRES, Energie Baden-Württemberg, INEA, the Josef Stefan Institute, the Technische Universität Dresden, and TNO. D7.5 is edited by TNO.

3.11 OMA Lightweight M2M

Model Acronym and Full Name
OMA (Open Mobile Alliance) Lightweight M2M (Machine-to-Machine) Technical Specification

Most relevant URLs, and other precise references
OMA Lightweight Machine-to-Machine Technical Specification Candidate version 1.0, 10 December 2013,
http://technical.openmobilealliance.org/Technical/release_program/docs/LightweightM2M/V1_0-20131210-C/OMA-TS-LightweightM2M-V1_0-20131210-C.pdf

Overall description
OMA[23] was formed in June 2002 by world-wide mobile operators, device and network suppliers, information technology companies and content and service providers. OMA delivers open specifications for creating interoperable services that work across all geographical boundaries, on any bearer network. OMA's specifications support the billions of new and existing fixed and mobile terminals across a variety of mobile networks, including traditional cellular operator networks and emerging networks supporting machine-to-machine device communication. OMA has developed and is developing a number of standards for managing light weight and low capability devices on a variety of networks

[23] http://openmobilealliance.org

Description of the semantic coverage
The OMA Lightweight M2M Technical Specification specifies the Lightweight M2M protocol between the server and the client that resides in a device. The target devices are resource constrained devices. The document also specifies the core set of LightweightM2M Objects. Each piece of information made available by the client is a resource, a client may have any number of resources, and these resources are organized into objects. Each object and resource supports one or more operations. There are reusable resources that are common to several objects. The objects described are: LWM2M Security, LWM2M Server, Access Control, Device, Connectivity Monitoring, Firmware, Location, and Connectivity Statistics. Each object is presented with all its resources. The XML schemas of the objects with their resources are available.

The semantic coverage is depicted in Figure 12. Besides client and server we can derive from the technical specification document: objects, resources, operations, instances, LWM2M Server object, Access Control object, Device object, Connectivity Monitoring object, Firmware object, Location object, Connectivity Statistics object. Examples of resources for the Device object are: manufacturer, modal number, serial number, firmware version, reboot, factory reset, available power sources, power source voltage, power source current, and battery level, among others.

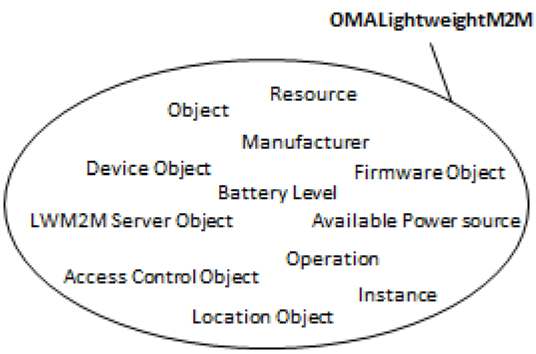

Figure 12. Visual representation of the semantic coverage of OMALightweightM2M

Overall description of the consensus driven process leading to the model
OMA has 104 members, of which 8 so-called promoter members: AT&T, Microsoft, Orange SA, BlackBerry Limited, Motorola Solutions Inc., Qualcomm Inc, Intel Corporation, and NTT DOCOMO INC. Members particularly supporting the Lightweight M2M specifications are China Mobile, China Unicom, Huawei, Intel, and ZTE.

3.12 OMS

Model Acronym and Full Name
OMS (Open Metering System)

Most relevant URLs, and other precise references
Open Metering System Specification Vol.2 – Primary Communication Issue 4.0.2, and OMS-Data Point List –RELEASE A, Annex B to Volume 2: Primary Communication Issue 4.0.2, 27 January 2014, http://oms-group.org/fileadmin/pdf/OMS-Spec_Vol2_Primary_v402.pdf and http://oms-group.org/fileadmin/pdf/OMS-Spec_Vol2_AnnexB_A031.pdf .

Overall description

The Open Metering System (OMS) specification is defined by the OMS Group [24], and focuses on an automatic meter readout system. Part of this system is a hardware system (a Multi Utility Communication, or MUC) which is used to readout different metering devices and to transfer subsets of this data to automated meter management (AMM) back office systems for billing, servicing or other purposes. Metering devices are sensors and actuators. Metering devices and AMM Systems have to follow certain protocols which are described within the specification. Communication between the meter and the MUC is called Primary Communication and can be based on DLMS/COSEM (see section 3.21.9), SML (Smart Message Language [17], a German specification), or M-Bus. M-Bus is a significant communication technology for remote reading of meters in Europe, and standardized as EN13757-x, „Communication System for Meters and Remote Reading of Meters" [18]. The standard defines wired and wireless remote reading of meters. The wireless variety (W-Mbus) is also part of the KNX standard (see section 3.9). OMS Specification Vol.2 – Primary Communication Issue 4.0.2 defines the OMS Application Protocols for Primary Communication. For M-Bus it just cites the M-Bus Application Protocol as described in EN 13757-3:2013, and restricts it by some additional rules to ensure interoperability. This includes a list of mandated and harmonized M-Bus Data Points as given by the separate Annex B document.

Description of the semantic coverage

The semantic coverage is shown in Figure 13. Metering devices are sensors and actuators. Sensors are metering devices which at least provide meter index data (current metering counter value). Basic meter are meters with minimal functionality. Current metering data are given by request or sent in regular intervals. Sophisticated meters are basic metering devices with additional features such as data logging. The metering data given by these devices could include timestamps and metering profiles of the recorded consumption data. Actuators are appliances which can limit consumption or cut-off the supply. Terms which are included in the term 'actuator' are breaker, limiter, shut-off-valve, gas valve or switch. Multi Utility Communication Controller (MUC) is a hardware system which is used to readout different metering devices and to transfer subsets of this data to AMM back office systems for billing, servicing or other purposes. Metering devices and AMM Systems have to follow certain protocols. The AMM back office system maintains a connection to several MUCs. The MUCs themselves keep the connection to several meters.

The *Open Metering System Specification- Vol.2-Primary Communication_version4.0.2* provides a classification of smart meters and other devices addressed by OMS and can be used to make a taxonomy for smart meters.

- Device Types of OMS-Meter: Electricity meter, Gas meter, Heat meter, Warm water meter (30°C ... 90°C), Water meter, Heat Cost Allocator, Cooling meter (Volume measured at return temperature: outlet), Cooling meter (Volume measured at flow temperature: inlet), Heat meter (Volume measured at flow temperature: inlet), Combined Heat / Cooling meter, Hot water meter (≥ 90°C), Cold water meter, Waste water meter.
- Device Types of other OMS-devices: Breaker (electricity), Valve (gas or water), Customer unit (display device), Communication controller, Unidirectional repeater, Bidirectional repeater, Radio converter (system side), Radio converter (meter side).

[24] www.oms-group.org

– Device Types of not certifiable device: Oil meter, Steam meter, etc. (See table 4, Open Metering System Specification- Vol.2-Primary Communication_version4.0.2)

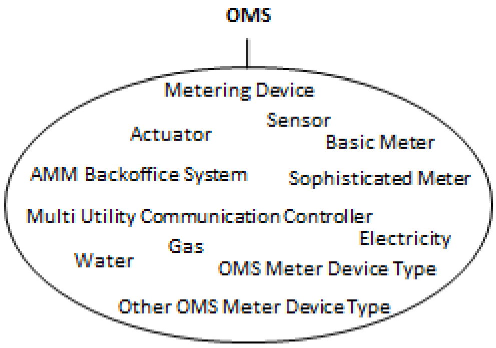

Figure 13. Visual representation of the semantic coverage of OMS

Overall description of the consensus driven process leading to the model

The vendor associations Figawa[25] and KNX are chairs in this specification creation process. Figawa is the German trade organization for water, gas, and pipeline companies. KNX Association is described in section 3.9. The goal is to guarantee a future-proof communication standard and interoperability between all the meter products: gas, water, electricity, heating.

3.13 OSGi DAL

Model Acronym and Full Name

OSGi DAL (Device Abstraction Layer)

Most relevant URLs, and other precise references

RFC-196 OSGi Alliance Device Abstraction Layer, Draft, 30 January 2014, https://github.com/osgi/design/blob/a71f2871f4ed0b97c4da79cf756a15876a61a347/rfcs/rfc0196/rfc-0196-DeviceAbstractionLayer.pdf?raw=true . This is the 9th draft of the document and it is the one we analysed. In February 2014, a new draft was published under https://github.com/osgi/design/blob/master/rfcs/rfc0196/rfc-0196-DeviceAbstractionLayer.pdf . The basic changes are: Basic device functions are moved to another RFC document, DeviceFunction renamed to Function, DeviceFunctionEvent renamed to FunctionEvent, DeviceFunctionData renamed to FunctionData.

Overall description

The OSGi Alliance[26] is a worldwide consortium founded in 1999 to create open specifications that enable the modular assembly of software built with Java technology. The OSGi technology facilitates the componentization of software modules and applications and assures remote management and interoperability of applications and services over a broad variety of devices. The alliance provides specifications, reference implementations, test suites and certification to foster a valuable cross-industry ecosystem. OSGi specifications define a dynamic component system for Java. These specifications reduce software complexity by providing a modular architecture for large-scale distributed systems as well as small, embedded applications.

[25] www.figawa.org
[26] www.osgi.org

Description of the semantic coverage
The OSGi Device Abstraction Layer document specifies a reference architecture that introduces an abstraction layer to allow the decoupling of devices and services from specific protocols. This architecture is based on a service registry in which services and device functions are registered. Section 5 of the document ("Technical solutions") provides a detailed specification of the entities and properties involved in the architecture.

The semantic coverage is depicted in Figure 14. The concept of device is central in the OSGi architecture. Devices can play different roles in their networks as events reporters, controllers etc. The dynamic behavior of a device can be mapped to the dynamic OSGi service registry, where it is registered as a device service. Device services realize a basic set of operations and provide a set of properties. Applications running in the architecture are allowed to track the device status, to read descriptive information about the device and to follow the device relations. A set of functions can belong to the device and can be found in the OSGi service registry. These functions represent the device operations and related properties in a modular way. Applications are allowed to get directly the required functions if they do not need information about the device. For example, light device is registered as a device service and there is a device function to turn on and turn off the light.

Overall description of the consensus driven process leading to the model
The OSGi Alliance consists of about 30 membership paying companies and over 100 supporter companies.. RFC-196 is edited by ProSyst Software. France Telecom, Telekom Italia, Deutsche Telekom, NTT, ProSyst, Makewave, Oracle, IBM, EnOcean, Hitachi, IS2T, NEC, Paremus, and invited researchers are member of the relevant working group within the OSGI Alliance. As part of the development process non-OSGI-members can access the specification draft and provide comments under the OSGi IPR policy. The final specification needs to be approved by all paying members of the OSGi Alliance. OSGi Alliance expects it to become final in Q3, 2014.

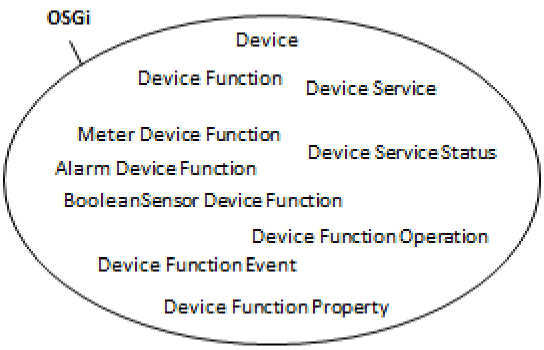

Figure 14. Visual representation of the semantic coverage of OSGi DAL

3.14 SEEMPubs

Model Acronym and Full Name
SEEMPubS (Smart Energy Efficient Middleware for Public Space) Data Format Definition

Most relevant URLs, and other precise references
Deliverable D5.1 "Data Format Definition, version 1.0", 30 September 2012, http://seempubs.polito.it/images/stories/documents/WP5/D.5.1.pdf

Overall description

SEEMPubs[27] was a European 7th Framework R&D project running from 2010-2013. Its goal was to provide control of appliances to effortlessly optimise energy efficiency usage without compromising comfort or convenience and offering decision makers strategies and tools needed to plan energy saving measures. SEEMPubS makes use of the service-oriented middleware for embedded systems being developed in the HYDRA project and uses its huge potential to create services and applications across heterogeneous devices to develop an energy-aware platform. The SEEMPubS platform is developed to provide necessary functionality and tools to add energy efficiency features to monitor dynamic sensor data in real time, taking advantage of natural resources (like daylight and solar energy) and controlling the operation of both passive and active environmental systems to ensure the best possible comfort conditions with the most efficient use of energy. Another European R&D project (ARTEMIS framework) that used a very similar approach is ME3Gas (Middleware for Energy Efficient Embedded Services & Smart Gas Meters)[28].

Description of the semantic coverage

D5.1 summarizes the architecture used in the SEEMPubS project to control building services and monitor indoor comfort conditions, electric and thermal energy consumption in a room. Two architectures are designed in order to take into account possible different types of buildings to be monitored. The first architecture is a wireless control architecture, mainly used in the Valentino Castle due to its architectural constraints (paintings, stuccos and historical structures) that did not allow destructive interventions on the buildings component. The second architecture is a wired control architecture that was mainly adopted in the modern parts of the Politecnico di Torino Campus, together with some wireless devices to monitor the electric energy consumptions of lights or other equipment (PC, printers, etc.) or to collect more detailed data of indoor air temperature distribution. Section 3 of D5.1 describes the data that are recorded from the hardware devices and processed through the SEEMPubS platform. The description categorizes the data in data related to indoor comfort conditions, energy consumptions, and spaces and building services usage. These data are represented in the deliverable using tables.

The semantic coverage is shown in Figure 15 and includes the concepts of Sensor/Device, such as Light sensor , Indoor air temperature sensor, Wireless sensors for indoor air temperature and relative humidity, Sensor of supplied air temperature, Controller, Power meter for lighting systems, Power meter for appliances, Occupancy sensor, Switch, Outdoor air temperature sensor, Indoor air temperature sensor (thermostat); Sensor number and position, e.g., Ceiling, Wall, Work plane; Measured quantity, e.g., Illuminance (lux), Indoor Air Temperature (°C), angle of rotation for manual control (°), Indoor Relative Humidity (%); Timing of data communication; Corresponding communication protocol, e.g., EnOcean, BACNet, IEEE802.15.4; Basic data processing, e.g., Average values over 15 minutes, Average hourly value; Basic data representation, e.g., Daily values, Weekly values, Monthly values, Seasonal trend, Annual values (carpet plot), Frequency distribution, and Cumulative frequency.

[27] http://seemspub.polito.it
[28] www.me3gas.eu

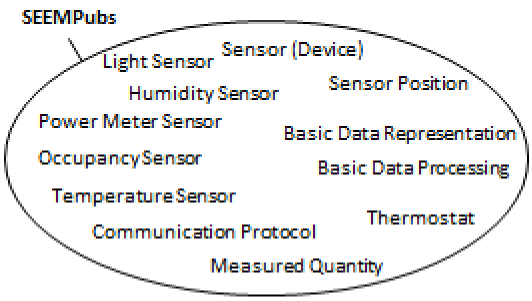

Figure 15. Visual representation of the semantic coverage of SEEMPubs

Overall description of the consensus driven process leading to the model
Project partners are Politecnico di Torino, STMicroelectronics, Centro Ricerche Fiat, Fraunhofer-FIT, CNet Svenska AB, Katholieke Universiteit Leuven, Universite Claude Bernard Lyon 1, Sinovia SA, Istituto Superiore Mario Boella, ENI Servizi. D5.1 was edited by Politecnico di Torino together with Unversite Claude Bernard Lyon 1.

3.15 SEIPF

Model Acronym and Full Name
SEIPF (Semantic Energy Information Publishing Framework)

Most relevant URLs, and other precise references
Dario Bonino, Fulvio Corno, Faisal Razzak "Enabling Machine Understandable Exchange of Energy Consumption Information in Smart Environments", Energy and Buildings 43 (2011) 1392–1402, http://dx.doi.org/10.1016/j.enbuild.2011.01.013

Overall description
The goal of the Bonino *et al* paper is enabling residential gateways to provide energy consumption information and other properties for different appliances in the house in a machine understandable format by using a Semantic Energy Information Publishing Framework (SEIPF). This information is published according to Semantic Web standards and best practices. Appliance properties are exposed according to the existing semantic modeling supported by home gateways, power consumption is modeled by introducing a new modular Energy Profile (E.P) ontology. The SEIPF framework is able to expose data both as simple RDF triples (according to Linked Data requirements) and as full ontology instances, for the benefits of applications needing intelligent processing.

Description of the semantic coverage
The goal of the Semantic Energy Information Publishing Framework (SEIPF) is enabling residential gateways to provide energy consumption information and other properties for different appliances in the house. This information is published in a machine understandable format according to Semantic Web standards and best practices. Appliance properties are represented using existing semantic models supported by home gateways, while the power consumption is modeled by introducing the Energy Profile (EP) ontology. The EP ontology models the energy consumption information about the appliance using the underlying DogOnt ontology [29], which models the domotic system of a house supporting intelligent operations. The paper claims that the EP ontology is

[29] http://elite.polito.it/dogont

published according to Semantic Web practices and an OWL version is available, but it does not provide a URL.

The semantic coverage of the EP Ontology is depicted in Figure 16. Basic concepts of this ontology are Device Profile, which describes the energy profiles of all the major device categories in the house (e.g., TV and dishwasher), and Consumption, which encodes the power consumed by an appliance in a given state. A device profile has some properties, such as the estimated and measured power consumption of a device in a state, and the unit of power for the power consumed by the appliance, expressed as using the Metric Unit class from the Measurement Units Ontology. The Consumption class also has some properties, such as the hasConsumption property that relates the device profiles and consumption instances, and the hasDevice property that relates an instance of device energy profile to a particular device. The EP Ontology is linked to the DogOnt, which has been designed along 7 main classes, corresponding to the Building Thing, Building Environment, Functionality, Command, Domotic Network Component, State, StateValue. Building Environment and Building Things are used in the EP ontology to describe the environment of the house.

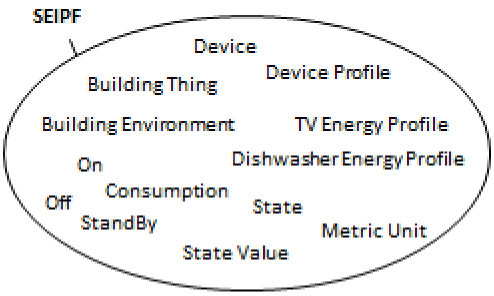

Figure 16. Visual representation of the semantic coverage of SEIPF

Overall description of the consensus driven process leading to the model
This paper reflects the work of a single research group at Politecnico di Torino.

3.16 SEP2

Model Acronym and Full Name
SEP2 (Smart Energy Profile 2.0)

Most relevant URLs, and other precise references
Zigbee Alliance / HomePlug Alliance Smart Energy Profile 2 Application Protocol Standard, ZigBee Public Document 13-0200-00, April 2013,
http://www.zigbee.org/Standards/ZigBeeSmartEnergy/ZigBeeSmartEnergy20Standard.aspx

Overall description
Consumers should be able to manage their usage and generation of energy. CSEP[30] (Consortium for SEP2 Interoperability) sees this as a critical feature of the Smart Grid and a basis of innovation for new products and services in energy management. To enable this capability, information flow between devices such as meters, smart appliances, plug-in electric vehicles, energy management systems, and distributed energy resources (including renewable energy and storage elements) must

[30] www.csep.org

occur in an open, standardized, secure, and interoperable fashion. The SEP2 specification is intended to fulfil those needs. The standard offers IP- based Home Area Network (HAN) energy management functionality and was ratified in April 2013. It addresses the following needs of the market:

- Deployments in multi-dwelling units such as apartment buildings
- Supports multiple Energy Service Interfaces into a single premises
- Control of plug in hybrid electric vehicle (PHEV) charging
- Supports any transport based on IETF IP compliant standards, including but not limited to ZigBee IP, other RF-based and Power Line Carrier (PLC)-based transports
- Supports internationally recognized standards to ensure long-term interoperability with multiple technologies

The document is drafted by the Zigbee Alliance[31] and the HomePlug Alliance[32], which are both member of CSEP, and assures interoperability between ZigBee IP, HomePlug and other IP network technologies that could adopt SEP2. They include the networks supported by the other members of CSEP, the Wi-Fi Alliance and the Bluetooth SIG. The application function sets implemented for SEP 2 have been mapped to the IEC Common Information Model [19]. Additional data beyond the IEC Common Information Model will be proposed back into IEC. SEP2 has been standardized in 2013 as IEEE 2030.5-2013 [20].

Description of the semantic coverage

This document defines the application protocol used by the Smart Energy Profile release 2.0 (SEP2) and specifies the mechanisms for exchanging application messages, the exact messages exchanged including error messages, and the security features used to protect the application messages. Clients issue requests to all devices on the network requesting resource(s) of interest. Servers hosting the requested resource(s) respond with the information necessary to access the server and its resource(s). The semantic coverage is depicted in Figure 17 and was inferred from the model presented in Section 15- Appendix B of the SEP2 document. XML schemas and UML representations are also available.

The following classes characterize the semantic coverage of SEP 2:

– Commodity Type Object , which has as example values: Electricity secondary metered value, Electricity primary metered value, Air, Natural Gas, Propane, Potable Water, Steam, Waste Water, Heating Fluid, Cooling Fluid;
– Device Category Type Object, which has as example values: Programmable Communicating Thermostat, Strip Heaters, Baseboard Heaters, Water Heater, Pool Pump, Sauna, Hot tub, Smart Appliance, Irrigation Pump, Managed Commercial and Industrial (C&I) Loads, Simple misc. (Residential On/Off) loads, Exterior Lighting, Interior Lighting, Electric Vehicle;
– Service Kind Object , which has as example values: Electricity, Gas, Water, Time, Pressure, Heat, Cooling;
– Unit Type Object , which has as example values: kWh, kW, Watts, Cubic Meters, Cubic Feet, US Gallons, Imperial Gallons, Liters; and Uom Type Object, which has as example values A (Current in Amperes (RMS)), Kelvin (Temperature), Degrees Celsius (Relative temperature), Voltage, J (Energy joule), Hz (Frequency);

[31] www.zigbee.org
[32] www.homeplug.org

– Device Status Object, which has as example values: Not operating, Operating, Starting up, Shutting down, At disconnect level;

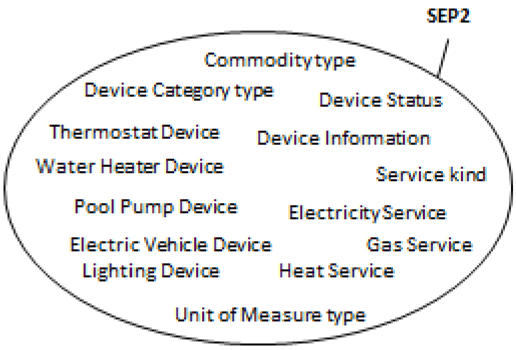

Figure 17. Visual representation of the semantic coverage of SEP2

Device Information Object, which has as example attributes : mfDate attribute (Date/time of manufacture), fHwVer attribute (Manufacturer hardware version), mfID attribute (Manufacturer's IANA Enterprise Number), mfInfo attribute (Manufacturer dependent information related to the manufacture of this device), mfModel attribute (Manufacturer's model number), mfSerNum attribute (Manufacturer assigned serial number), primary Power attribute (Primary source of powe)r, secondary Power attribute (Secondary source of power), swActTime attribute (Activation date/time of currently running software), swVer attribute (Currently running software version).

Overall description of the consensus driven process leading to the model

SEP2 is a joint production of Zigbee Alliance and HomePlug Alliance, although it seems that Zigbee Alliance had a leading role in its production, as they officially ratified it as a Zigbee standard and published it on their website. The Zigbee Alliance has about 150 participant members and a few hundred adopter members. It is governed by 10 promotor members: Comcast, Freescale, Itron, Kroger, Landis+Gyr, Legrand, Philips, Schneider Electric, Silicon Labs and Texas Instruments. The SEP2 standard has many editors and contributors from many different companies.

Not only Zigbee Alliance and HomePlug Alliance are member of CSEP. Also Wi-fi Alliance and Bluetooth SIG are. CSEP is not responsible for drafting and maintaining the standard though. The members of the Consortium for SEP 2 Interoperability are working together to develop common testing documents and processes for certifying SEP 2 interoperability to ensure interoperability of SEP 2 products.

3.17 SmartCoDE

Model Acronym and Full Name

SmartCoDE (Smart Control of Demand for Consumption and Supply to enable balanced, energy-positive buildings and neighbourhoods) Model of Local Energy Resource Cluster

Most relevant URLs, and other precise references

Deliverable D1.1.2 “Model of local energy resource cluster”, 31 December 2012, https://www.fp7-smartcode.eu/system/files/page/d-1.1.2.pdf

Overall description

SmartCoDE[33] is a European 7th Framework R&D project running from 2009-2013. The objective of SmartCoDe is to enable the application of demand side management and smart metering in private and small commercial buildings and neighbourhoods by

- Developing new methods for automated energy management that specifically consider the requirements of Energy using Products in homes / offices and local renewable energy providers such as information security and dependability.
- Developing an inexpensive (<3€) hardware/software implementation that can be integrated into arbitrary Energy using Products, providing them with the ability to communicate and to remotely control its use of power.
- Demonstration of technical and economic feasibility and benefit of intelligent energy management in buildings and neighbourhoods with an initial focus on electric lighting.

This project aims at providing a wireless communication infrastructure for the demand side management of energy in the domestic sector. Wireless sensor/actor nodes are integrated into appliances to enable remote control by an Energy Management Unit (EMU). SmartCoDe builds on the ZigBee wireless standard. D1.1.2 provides an extensive explanation of the SmartCoDE classifications. In addition to the classification of Energy Using Products (EuPs), also a classification of Local Energy Providers (LEPs) into 4 classes is presented.

Description of the semantic coverage

The semantic coverage is depicted in Figure 18 and covers the classification of Energy Using Products (EuPs) that characterize the SmartCoDe project. The Energy Using Products are divided in the following classes:

– SKDSVC class, namely schedulable service, which provides a service that runs for a certain time and can be scheduled within a certain time span. Examples of SKDSVC are washing machine, dryer, dishwasher, baking machine;
– VSTSVC class, namely virtually storable service, which provides an inert service that can serve as a virtual storage. Examples of VSTSVC are Fridge, Freezer, HVAC, Water-boiler;
– VARSVC class, namely variable service, which provides a service that might vary due to user interaction and/or daytime. Examples of VARSVC are lighting controlled by luminance level (e.g. in garden, at entrance), dimmable lighting, blinds;
– ETOSVC class, namely event-timeout controlled service, which provides a service such that the device is switched on and kept on by sensor events, and switched off in absence of sensor event. Examples are lighting controlled by presence detector (e.g. on corridor);
– COMCON class, namely complete control, charging and using up power decoupled; latter only restricted w.r.t. time slots & minimal service. Examples are robot vacuum, robot lawn-mower;
– CHACON class, namely charge control, charging and using up power decoupled; latter is mostly (or solely) user-dependent. Examples are battery & cellphone chargers, hand-held vacuum, emergency backup storages;
– CUSCON class, namely custom control, when the device does not fit into other classes, therefore custom control by user and/or EMU. Examples are HiFi, PC, Oven.

[33] www.fp7-smartcode.eu

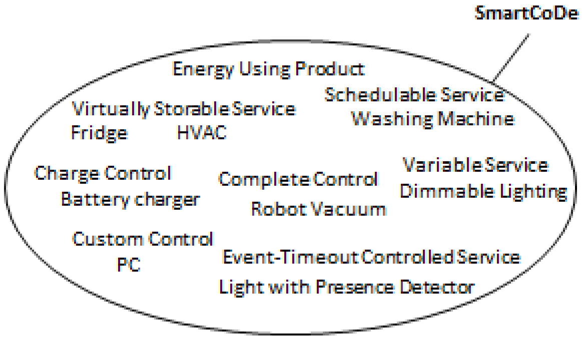

Figure 18. Visual representation of the semantic coverage of SmartCoDe

SmartCoDe also provides a classification of Local Energy Providers (LEPs), which are divided into the ENGRID class, namely energy grid, which is a conventional energy provider, the VOLAEP class, namely volatile energy provider, which is an energy source that depends on weather, day time, etc., the ENSTOR class, namely energy storage, which is an energy source that needs to be charged, and the LENGEN class, namely local energy generator, which is an energy source that transforms fuel to energy.

Overall description of the consensus driven process leading to the model

The partners of SmartCoDE include Edacentrum GmbH, Infineon Technologies Austria AG, Vienna University of Technology, Ennovatis GmbH, Tridonic GmbH & Co KG, Ardaco, a.s., Quiet Revolution Ltd, and University of Novi Sad. The project also has many associate partners, including BSH Bosch und Siemens Hausgeräte GmbH, BuildDesk Austria GmbH, Next Energy e.V., SMA Solar Technology AG, Q.met GmbH and TELEFUNKEN Semiconductors. The editors of D1.1.2 are from TU Vienna, Edacentrum, and Ennovatis.

3.18 UPnP

Model Acronym and Full Name

UPnP (Universal Plug and Play) Device Architecture and Home Automation Device Control Protocols (DCPs)

Most relevant URLs, and other precise references

UPnP Device Architecture 1.1, http://upnp.org/specs/arch/UPnP-arch-DeviceArchitecture-v1.1.pdf

The UPnP Home Automation DCPs consist of 4 Device descriptions with corresponding Service description. 3 Devices are relevant for this project:

- SolarProtectionBlind:1, http://upnp.org/specs/ha/solarprotectionblind1/
- HVAC:1, http://upnp.org/specs/ha/hvac/
- Lighting Controls:1, http://upnp.org/specs/ha/lighting/

Overall description

UPnP[34] is a client/server based interoperability framework for devices and services in a relatively small-scale best-effort IP subnetwork. It distinguishes three logical entities in the network: UPnP Services, which represent the service functionality of a device, UPnP Devices, which act as services servers, and UPnP Control Points (CPs), which act as clients for controlling the services. For clarity,

[34] www.upnp.org

UPnP Devices are not the physical devices but the UPnP server software running on them, providing UPnP Services to UPnP CPs. UPnP defines Simple Service Discovery Protocol (SSDP), SOAP, and General Event Notification Architecture (GENA) for discovery, control, and eventing, respectively. Device and service descriptions are expressed and partially standardized in XML templates, the so-called Device Control Protocols (DCPs). The Device Architecture and many DCPs have been standardized in ISO/IEC as ISO/IEC 29341-x-y [21].

There are DCPs for the following device categories: Audio/Video, Basic, Device Management, Home Automation, Networking, Printer, Remote Access, Remoting, Scanner, Sensor Management, and Telephony. There are also a number of add-on service standardized, such as DataStore:1, DeviceProtection:1, EnergyManagement:1, Low Power:1, ContentSync:1, Device Security:1, Security Console:1, and Quality of Service:3. The Home Automation DCPs are most relevant to this project. The Sensor Management DCPs provide very limited semantic assets for specific sensors and actuators. The EnergyManagement and LowPower DCPs only concern management of low-power states of devices.

Description of the semantic coverage
The UPnP Device Architecture describes the protocols for discovery, description, control, eventing and presentation. Two general types of devices are defined, namely controlled devices, or simply devices, and control points. A controlled device has the role of a server, responding to requests from control points. The pre-requisite for a device or control point is the *IP addressing* using the DHCP protocol to obtain an IP address. Once the IP address is given, the 1st step is the *discovery*, in which a device advertises its services to the control points in the network and, vice versa, a control point searches for devices of interest. The discovery message contains data about the device type, device ID and a pointer to more detailed info. The 2nd step is the *description* that allows the control points in the network to learn about a device and its capabilities, and how to interact with this device. The description is specified in XML and contains vendor specific manufacturer info (model name and number, serial number, manufacturer name, website, etc.), and a list of any embedded devices or services. For each service, the description contains commands (or actions) to which the service responds, parameters (or arguments) and variables that model the device state (data type, range, events). The 3rd step is the *control* used by a control point to send actions to a device's services. To do this, a control point sends a suitable control message in XML to the service URL provided in the device description. The device returns action-specific values that may enforce changes in the variables that describe the run-time state of the service. The 4th step is the *eventing* that allows to subscribe and/or listen to changes in the state of variables for a specific service of a device. There is an option that allows subscription to events and a multicasting option. Event messages (also in XML) contain the names of one or more state variables and the current value of those variables. The 5th step is the presentation that is used by a control point to retrieve the URL from which it is possible to control the device and/or view the device status.

The semantic coverage of UPnP is shown in Figure 19. UPnP covers three type of devices (solar protection blind, HVAC system and HVAC_Zone Thermostat) and several services (Two Way Motion Motor service, HVAC_User Operating Mode service, HVAC_Setpoint Schedule service, HVAC_Fan Operating Mode service, Fan Speed service, Temperature Sensor Service, Control Valve service, House Status service).

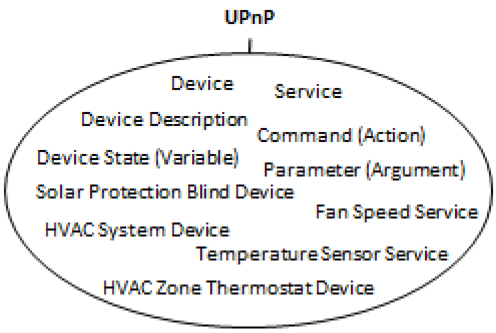

Figure 19. Visual representation of the semantic coverage of UPnP

Overall description of the consensus driven process leading to the model
The UPnP Forum, founded in 1999, consists of many hundreds of members, most of them Implementer Members and Basic Members. The Steering Committee members are the most influential and currently consist of CableLabs, Cisco Systems Inc., Intel, LG Electronics, PV, Samsung, TPVision, and ZTE. The Home Automation DCPs were drafted by Somfy, Siemens, and Honeywell.

3.19 W3C SSN

Model Acronym and Full Name
W3C (World Wide Web Consortium) SSN (Semantic Sensor Network) Ontology

Most relevant URLs, and other precise references
Semantic Sensor Network Ontology, http://www.w3.org/2005/Incubator/ssn/ssnx/ssn (2011).

Overall description
The World Wide Web Consortium (W3C)[35] has initiated the Semantic Sensor Networks (SSN) Incubator Group (which later became Community Group) to develop the Semantic Sensor Network ontology which can model sensor devices, systems, processes, and observations. The SSN ontology enables expressive representation of sensors, sensor observations, and knowledge of the environment. It is encoded in OWL and has begun to achieve broad adoption and application within the sensors community. It is currently being used by various organizations, from academia, government, and industry, for improved management of sensor data on the Web, involving annotation, integration, publishing, and search. The latest version was published in 2011.

Description of the semantic coverage
The SSN ontology is an OWL ontology that provides a framework to describe sensors, observations and related concepts. It does not describe domain concepts, such as time and locations, since these concepts are intended to be included from other ontologies via OWL imports. A sensor is a specific device whose purpose is to report measurements and observation real world phenomena. A sensor is different in nature from other types of devices such as actuators, because of its event based behaviour and the temporal relationships that need to be considered. The SSN ontology is a basis for reasoning about the measurements that can ease the development of advanced applications. For instance, when reasoning about sensors, constraints such as power restriction, limited memory, variable data quality need to be taken into account. It is possible to reason either about individual

[35] www.w3.org

sensors as well as about the connection of a number of sensors. The semantic coverage of the SSN ontology is shown in Figure 20.

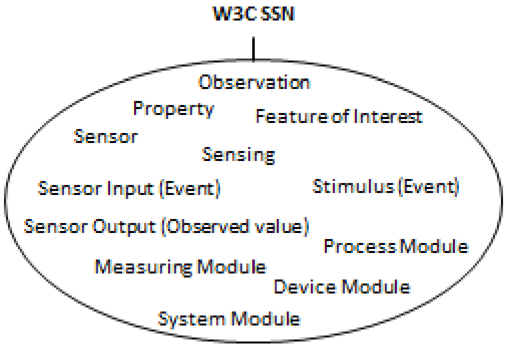

Figure 20. Visual representation of the semantic coverage of W3C SSN

The SSN ontology is composed by several modules, including a module imported from the DUL ontology to define some foundational concepts. These modules are the following:

- DUL module, which represents Designed Artifact, Event, Information Object, Method, Object, Physical Object, Process, Quality, Region, Situation;
- Skeleton module, which represents
    - Feature Of Interest, i.e., an abstraction of real world phenomena, such as thing, person, event;
    - Observation, i.e., a Situation in which a Sensing method has been used to estimate or calculate a value of a Property of a Feature Of Interest;
    - Property, i.e., an aspect of an entity that is intrinsic to and cannot exist without the entity and is observable by a sensor;
    - Sensing, i.e., a process that results in the estimation, or calculation, of the value of a phenomenon);
    - Sensor, i.e., any entity that can follow a sensing method and thus observe some Property of a Feature Of Interest. Sensors may be physical devices, computational methods, a laboratory setup with a person following a method, or any other thing that can follow a Sensing Method to observe a Property;
    - Sensor Input, i.e., an Event in the real world that triggers the sensor;
    - Sensor Output, i.e., a sensor outputs a piece of information (an observed value), the value itself being represented by an Observation Value),
    - Stimulus (an Event in the real world that 'triggers' the sensor. The properties associated to the stimulus may be different to eventual observed property. It is the event, not the object that triggers the sensor)
- System module, which represents systems;
- Process module, which represents Input, Output and Process;
- Measuring module, which represents Sensing Device, Sensor Data Sheet;
- Measuring Capability module, which represents Accuracy, Detection Limit, Drift, Frequency, Latency, Measurement Capability, Measurement Property, Measurement Range, Precision, Resolution, Response Time, Selectivity, Sensitivity;
- Deployment module, which represents Deployment, Deployment Related Process;
- Platform Site module, which represents Platform;

- Operating Restriction module, which represents Maintenance Schedule, Operating Property, Operating Range, Survival Property, Survival Range, System Lifetime;
- Data module, which represents Observation Value;
- Time module, which represents end Time and start Time;
- Constraint Block module, which represents conditions
- Device module , which represents devices;
- Energy Restriction module, which represents Battery Lifetime, Operating Power Range.

Overall description of the consensus driven process leading to the model

The editors of the SSN ontology are affiliated to CSIRO, Wright State University, University of Surrey, Universidad Politécnica de Madrid, Monterey Bay Aquarium Research Institute, Fraunhofer Gesellschaft, Pennsylvania State University, The Open University, University of Southampton, Open Geospatial Consortium, DERI at the National University of Ireland, Ericsson, Boeing, Fundacion CTIC, and others.

3.20 Z-Wave

Model Acronym and Full Name

Z-Wave Application Layer

Most relevant URLs, and other precise references

Z-Wave Technical Basics Chapter 4 "Application Layer", 1 June 2011,
http://www.domotiga.nl/attachments/download/1075/Z-Wave%20Technical%20Basics-small.pdf

Overall description

The Z-Wave protocol is a wireless RF-based communications technology designed specifically for control, monitoring and status reading applications in residential and light commercial environments. The protocol is specified by Z-wave Alliance[36] and the specifications are not publicly available. Various papers and text books describe in the technology in some detail though. It is a low- powered RF communications technology that supports full mesh networks without the need for a coordinator node. It operates in the sub-1GHz band, is designed specifically for control and status apps, and supports data rates of up to 100kbps. The application layer specification defines what and why two Z-Wave nodes communicate with each other, and contains the relevant semantics.

Description of the semantic coverage

Each device in a home or office can either control other devices or being controlled by other devices. Controlling devices are called Controllers, reporting devices are called Sensors, and controlled devices are called Actuators. It is also possible to combine a logical sensor controller or actor function within one physical device. Actors switch either digital (on / off for an electrical switch) or analogue signals (0 %. 100 % for a dimmer or venetian blind control). Sensors deliver either a digital signal (door, glass breaking, motion detector, window button on the wall) or an analogue signal (temperature, humidity, power). Z-Wave devices on the market can be categorized into one of the following function groups:

[36] www.z-wavealliance.org

– Electrical switches are designed either as plug in modules for wall outlets or as replacement for traditional wall switches (digital actors). It's also possible to have these actors already built into certain electrical appliances such as electrical stoves or heaters.
– Electrical dimmers, either as plug in modules for wall outlets or as replacement for traditional wall switches (analogue actors)
– Motor control, usually to open or close a door, a window, a window sun blind or a venetian blind (analogue or digital actors)
– Electrical Display or other kind of signal emission such as siren, Led panel, etc (digital actors)
– Sensors of different kind to measure parameters like temperature, humidity, gas concentration (e.g. carbon dioxide or carbon monoxide) (analogue or digital sensors)
– Thermostat controls: either as a one knob control or using a temperature display (analogue sensors)
– Thermostats controls such as TRVs (Thermostat Radiator Valves) or floor heating controls (analogue or digital actors)
– Remote Controls either as universal remote control with IR support or as dedicated Z-Wave Remote Control with special keys for network functions, group and/or scene control
– USB sticks and IP gateways to allow PC software to access Z-Wave networks. Using IP communication these interfaces also allow remote access over the internet

All communication within the Z-Wave network is organized in Command Classes, which are a group or commands and responses related to a certain function of a device. The Basic command class is the smallest common denominator of all Z-Wave devices. Every Z-Wave device must support the Basic command class. Device classes are organized as a hierarchy with three layers: 1) Every device must belong to a Basic device class; 2) Devices can be further specified by assigning them to a Generic device class; 3) Further functionality can be defined as assigning the device to a Specific device class. In case the Z-Wave device is assigned to a specific device class, it is required to support a set of command classes as functions of this specific device class. These required command classes are called Mandatory command classes and they are individual of certain generic and specific device classes. Besides the mandatory device classes, Z-Wave devices can support further Optional command classes. They may be very useful but the standard does not enforce the implementation of these classes. With Z-Wave it is not only possible to operate individual actions with appliances such as lights, heating and window blinds, but also create Scenes like "Leave for Work", and select what you want to happen in your home, when you leave for the day. Also it is possible to create Events, for example, when a motion detector is tripped, a light can come on for 5 minutes. There is a Timer setting to set the lights or the thermostat to go on or off at a certain time. The semantic coverage of Z-wave is schematically depicted in Figure 21.

Overall description of the consensus driven process leading to the model
The Z-Wave Alliance was founded in 2005. It is a consortium of over 250 independent manufacturers as of 2013, who have agreed to build wireless home control products based on the Z-Wave standard. Principal members include ADT, GE/Jasco, Evolve, Ingersoll-Rand, Linear, FAKRO and Sigma Designs. Z-Wave was developed by a Danish startup called Zen-Sys that was acquired by Sigma Designs in 2008.

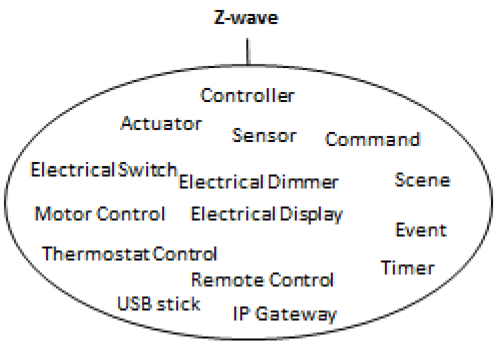

Figure 21. Visual representation of the semantic coverage of Z-wave

3.21 Other relevant bodies and projects

3.21.1 Adapt4EE

Most relevant URLs, and other precise references

D3.2 Adapt4EE Middleware Specification, Ontology and Semantic Components, May 2013, http://www.adapt4ee.eu/adapt4ee/files/document/deliverables/Adapt4EE-Deliverable-D3.2.pdf . Edited by Fraunhofer, CERTH, and Technical University Kosice

Overall description

Adapt4EE[37] is a European 7th Framework R&D project running from 2011-2015. It aims to develop and validate a holistic energy performance evaluation framework that incorporates architectural metadata (Building Information Model, BIM), critical business processes (BPM) and consequent occupant behaviour patterns, enterprise assets and respective operations as well as overall environmental conditions. The Adapt4EE framework, having as a central point of reference the occupancy behaviour (presence and movement) will align energy consumption points to all interrelated enterprise aspects (business processes, enterprise assets and utility state and operations). As part of the work, Adapt4EE will develop an enhanced semantic enterprise model that treats, learns and manages the enterprise environment as an intelligent agent, perceives environmental state using multi-type sensors and information modalities. The Adapt4EE Model will incorporate business processes and occupancy data. It will also constitute a formal model for enterprise energy performance measuring, monitoring and optimization. The model will be calibrated during the training phase based on sensor data captured during operation and then applied and evaluated in real-life every day enterprise Operations. More specifically the Adapt4EE Enterprise Models will allow for the proactive identification of optimum local adaptations of enterprise utility operations, based on predictions of possible occupancy patterns and respective business operations and energy profiles. D3.2 "Adapt4EE Middleware Specification, Ontology and Semantic Components" contains semantic assets. It is edited by by Fraunhofer, CERTH, and Technical University Kosice.

Description of the semantic coverage

D3.2 describes the Adapt4EE middleware architecture, its components, its interactions with other modules in the system, and in particular the ontology representing the information used by the modules. The LinkSmart Middleware is used to integrate existing sensor and building management technology systems with the technologies developed in Adapt4EE. Core concepts such as LinkSmart-

[37] www.adapt4ee.eu/

enabled Device, LinkSmart Device, Gateway, LinkSmart Manager, and Device Discovery are defined. Subsequently the LinkSmart Device Ontology is presented that contains knowledge about device classes, their properties and services offered. De deliverable also includes an example of the semantic model in OWL for a use case, including a table of the classes and properties in the example.

Of the Adapt4EE Ontology, the events part and the BIM model are the most relevant to our project. The semantic coverage is depicted in Figure 22, and includes Events (sensor events and context events), LinkSmart-enabled Device, LinkSmart Device, Gateway, LinkSmart Manager, Device Discovery. The semantic coverage is obviously partially overlapping with the result from the HYDRA project. From the LinkSmart Device Ontology we derive:

- Device Classifications of LinkSmart Devices. A LinkSmart Device is the software representation of a LinkSmart-enabled physical device. Type of devices are D0 Device, D1 Device, D2 Device, D3 Device, and D4 Device. This classification scheme helps developers to decide how a specific device is to be integrated into a network.
- Runtime Architecture. LinkSmart facilitates communication among devices via a P2P overlay network. The basic LinkSmart component enabling network communication is the NetworkManager. Inside a LinkSmart network, unique Internet Of Things Identifiers (IoTID-s) identify all devices and services.
- Event Management. The Event Manager implements a publish/subscribe mechanism on the level of Web Services. The LinkSmart Event Manager provides decoupling in space and synchronization through a content-based publish/subscribe mechanism. In this type of publish/subscribe, subscribers subscribe on topics and receive events that are published by publishers on that topic through a notification mechanism.

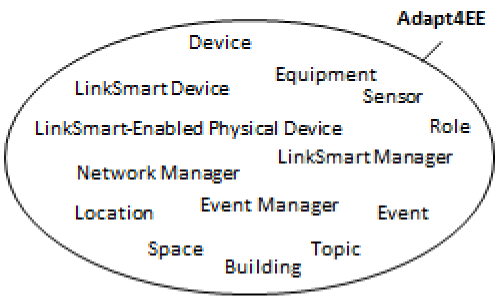

Figure 22. Visual representation of the semantic coverage of Adapt4EE

3.21.2 Agora

Most relevant URLs, and other precise references

http://www.reseau-domiciliaire.fr/home

Overall description

Agora was born when several French companies joined forces to design and distribute components, products and terminals that would communicate with services to provide better “smart home” living. The idea was to jointly review all ways to enable domestic technologies to communicate, interact and cooperate. The partners’ shared goal was to provide residents of “smart homes” with more fluid, more economical, more efficient services by building a bridge (which the consortium calls an “Agora bus”) linking everything together. So far, the consortium has been able to build prototypes of the

Agora bus based on existing technologies, including many discussed in this document, such as UPnP, HGI, and Broadband Forum. No additional semantic assets were defined.

3.21.3 AIM*

Most relevant URLs, and other precise references

http://www.ict-aim.eu/

Overall description

AIM[38] was a European 7th Framework R&D project running from 2008-2010. AIM's main objective was to foster a harmonised technology for profiling and managing the energy consumption of appliances at home. The goal was to introduce energy monitoring and management mechanisms in the home network and provide a proper service creation environment to serve virtualisation of energy consumption, with the final aim of offering users a number of standalone and operator services. The main idea was to forge a generalised method for managing the power consumption of devices that are either powered on or in stand-by state. The AIM technology was aimed at white goods (refrigerators, kitchens, washing machines, driers), communication devices (cordless phones and wireless communication devices for domestic use) and audiovisual equipment (TV Sets and Set-top-boxes). The project did not produce semantic assets up and above the ones defined elsewhere in this document. The project partners in AIM were EURESCOM, France Telecom, KELETRON, CEFRIEL, Politecnico di Milano, INDESIT, Döbelt Datenkommunikation, Lantiq, Power Plus Communications, Philips Electronics Nederland, and BlueChip Technologies.

3.21.4 BACnet

Most relevant URLs, and other precise references

BACnet - A Data Communication Protocol for Building Automation and Control Networks - Overall description, ANSI/ASHRAE Standard 135-2012, Chapter 12 “Modeling Control Devices as a Collection of Objects” , http://www.techstreet.com/ashrae/products/1852610,

Overall description

BACnet is a standard data communication protocol that enables interoperability between different building systems and devices in building automation and control applications. It was designed to allow communication of building automation and control systems for applications such as heating, ventilating, and air-conditioning control, lighting control, access control, and fire detection systems and their associated equipment. Its development started in 1987 and it was first standardized by the ASHRAE BACnet Committee (SSPC 135)[39] in 1995, and later became part of the ISO-EN-16484 suite [22]. It is promoted by the BACnet International[40] organization. Key promoter companies include Siemens, Honeywell, Delta Controls, Reliable Controls, Johnson Controls, Trane, Automated Logic, Lutron, and others. Chapter 12 of the BACnet standard defines 54 "objects", which are basic devices or device components. Every object has a required set of properties.

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[38] www.ict-aim.eu/

[39] www.bacnet.org/

[40] www.bacnetinternational.org

Description of the semantic coverage

The BACnet Standard addresses Fire, Security, Lighting, HVAC, Vertical Transport (elevators) products, among others. A BACnet device is often comprised of a microprocessor-based controller and software combination that is designed to understand and use the BACnet protocol. A BACnet device is typically a controller, gateway, or user interface. Every BACnet device contains a device object that defines certain device information, including the device object identifier or instance number. All information within an interoperable BACnet device is modeled in terms of one or more information objects. Each object represents some important component of the device, or some collection of information that may be of interest to other BACnet devices. A BACnet property conveys information about a BACnet object. Objects have a collection of properties, based on the function and purpose of the object. BACnet services are formal requests that one BACnet device sends to another BACnet device to ask it to do something. Services are grouped into five categories of functionality, namely object access (read, write, create, delete); device management (discover, time synchronization, initialize, backup and restore database); alarm and event (alarms and changes of state); file transfer (trend data, program transfer); and virtual terminal (human machine interface via prompts and menus). The semantic coverage is schematically depicted in Figure 23.

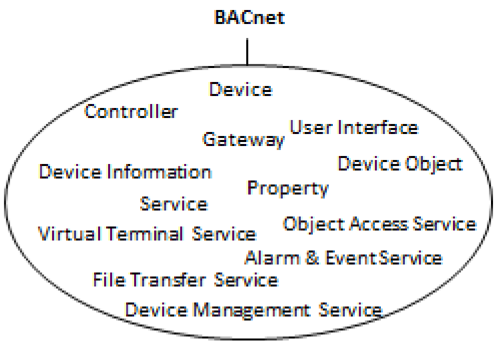

Figure 23. Visual representation of the semantic coverage of BACnet

3.21.5 Broadband Forum

Most relevant URLs, and other precise references

Broadband Forum SD-282 "Control Signaling Device Abstraction Layer", http://www.broadband-forum.org/technical/technicalwip.php

Overall description

Broadband Forum[41] develops multi-service broadband packet networking specifications addressing interoperability, architecture and management. Its work is directed at enabling home, business and converged broadband services, encompassing customer, access and backbone networks. The Broadband Forum issues Technical Reports (TR), which are prepared internally in Study Document (SD) before becoming Working Texts and finally TRs. One of the SDs the Broadband Forum currently is working on is SD-282 Control Signaling Device Abstraction layer. The document is still under development and its contents has not yet been published.

Description of the semantic coverage

SD-282 defines a Control Signaling and Device Abstraction layer that provides applications access to any M2M network of devices without the burden of understanding the communication technology of

[41] www.broadband-forum.org

each device. Application of the Control Signaling and Device Abstraction layer is possible in several domains with different types of devices (camera device, sensor device, light device, monitor device, medication device) and associated protocols, and the general concepts of devices, objects, services, discovery, methods, parameters, state. This semantic coverage is schematically depicted in Figure 24.

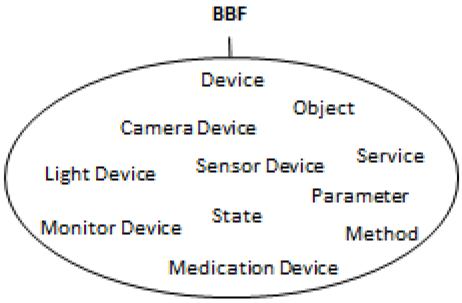

Figure 24. Visual representation of the semantic coverage of BBF

3.21.6 CECED

Most relevant URLs, and other precise references

- PI Standard 15.0, 21 March 2014, http://www.picertified.com/download/xml_download/Lang_PI15_0_EN_all.xml
- EDI-WHITE Final Messages, http://www.ceced.eudata.be/ICECED/easnet.dll/ExecReq/Search?eas:parent_id=201013 , 5 April 2006.

Overall description

CECED[42] is the European Committee of Domestic Equipment Manufactures, or the trade organization of white good manufacturers. They have executed a number of project to develop a protocol to make intelligent energy management a reality. The most relevant for this project are the projects EDI-WHITE and PI. PI is about standardizing a template for product information for cataloguing purposes. This template is continuously updated. The EDI-WHITE project finished in 2006 and standardized messages for electronic data interchange with suppliers, forwarders, banks and customers. EDI-WHITE is basically a subset of the UN/EDIFACT standard on United Nations/Electronic Data Interchange For Administration, Commerce and Transport[43]. Other projects that CECED is doing in the field op protocol standardization are EDI-Service and IRIS. EDI-Service is an electronic commerce standard for the after-sales service market, again based on UN/EDIFACT. IRIS is a standardized common language for exchanging repairing information among countries. CECED members are Arcelik, Ariston Thermo Group, BSH Bosch und Siemens Hausgeraete GmbH, Candy Hoover Group, DAIKIN Europe NV, de Longhi SpA, AB Electrolux, FAGOR Group, GORENJE d.d., INDESIT Company SpA, LG Electronics, LIEBHERR Hausgeraete, Miele & Cie. KG, Philips Consumer Lifestyle NV, Samsung Electronics, Groupe SEB, and Vorwerk Elektrowerke GmbH & Co. KG.

Description of the semantic coverage

A visual representation of the semantic coverage of CECED is provided in Figure 25. The CECED's EDI-WHITE project standardizes messages such as order, order response, order change, invoice, dispatch

42 www.ceced.org
43 www.unece.org/trade/untdid/welcome.html

advice, price catalogue, remittance advice, receiving advice, transport instruction, sales and stock report, partner identification, delivery forecast and schedule and just in time delivery.

The CECED's PI Standard for Product Information aims at standardizing product information for cataloguing purposes. The white goods product groups in the PI catalogue include: Accessories, Built-in coffee machines, Cookers and Double Cookers , Dishwashers, Freezers, Fridge/Freezers combinations, Hobs, Hoods, Microwave Ovens, Modules (fryers, grills, hobs scales and sinks), Outdoor Grills, Ovens and Double Ovens , Plate warmers, Refrigerators, Side-by-Side, Steam Ovens, Steamers, Tumble Dryers, Vacuum Cleaners, Washer-Dryers, Washing Machines, Water Machines, Wine-storage.

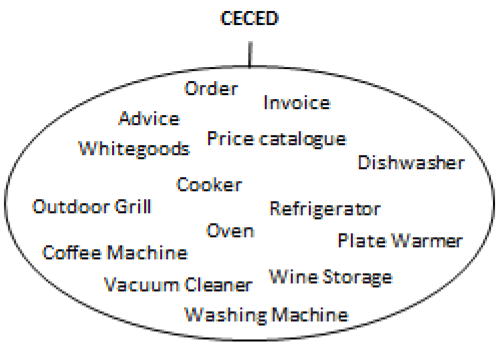

Figure 25. Visual representation of the semantic coverage of CECED

3.21.7 CEN/CLC/ETSI Smart Grid CG M490

Most relevant URLs, and other precise references

- CEN-CENELEC-ETSI Smart Grid Coordination Group "First Set of Standards", November 2012, ftp://ftp.cen.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/First%20Set%20of%20Standards.pdf
- CEN-CENELEC-ETSI Smart Grid Coordination Group "Smart Grid Reference Architecture", November 2012, ftp://ftp.cencenelec.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/Reference_Architecture_final.pdf

Overall description

In March 2011, the European Commission issued the Smart Grid Mandate M/490 [23] which was accepted by the three European Standards Organizations (ESOs), CEN, CENELEC and ETSI in June 2011. M/490 requests the ESOs to develop a framework that enables the ESOs to perform continuous standard enhancement and development in the smart grid field. In order to perform the requested work, the ESOs combined their strategic approach and established the CEN-CENELEC-ETSI Smart Grid Coordination Group (SG-CG) in July 2011. SG-CG is responsible for coordinating the ESOs reply to M/490. In 2012, the SG-CG produced a number of reports, which obtained approval from the ESOs. Among them are the Smart Grid Reference Architecture, and a First Set of Standards. The latter shows a first list of standards, enabling or supporting the deployment of Smart Grid systems in Europe. The list includes standards such as EN 13757 [18] (see section 3.12), EN 50090 [16] (see section 3.9), EN 14908 [24] (see section 3.21.18), IEC 61968 [19] (see section 3.16), and IEC 62056-53 [25] (see section 3.21.9). The document does not produce new semantic assets up and above the standards listed. The Smart Grid Reference Architecture document describes a technical reference architecture for European smart grids. In section 8.3.3 it discusses data models for the related information architecture. It concludes that besides the in our section 3.16 already referenced [19] also IEC 61850 [26] is relevant. However, IEC 61850 applies to electrical substations and is therefore out of the scope of this project. We therefore conclude that we have covered all the relevant semantics from the smart grid field in the various sections throughout this chapter.

3.21.8 CoAP

Most relevant URLs, and other precise references

Constrained Application Protocol (CoAP), draft-ietf-core-coap-18, 28 June 2013, https://datatracker.ietf.org/doc/draft-ietf-core-coap/ .

Overall description

CoAP is a specialized web transfer protocol for use with constrained nodes and constrained (e.g., low-power, lossy) networks. The nodes often have 8-bit microcontrollers with small amounts of ROM and RAM, while constrained networks such as 6LoWPAN [27], often have high packet error rates and a typical throughput of 10s of kbit/s. The protocol is designed for M2M applications such as smart energy and building automation. It is defined as a subset of REST (REpresentational State Transfer) common with HTTP. It does not specify or standardize the contents of the messages. An example of a CoAP message exchange is given: The client sends a Confirmable GET request for the resource coap://server/temperature to the server. A response is returned in the Acknowledgement message that acknowledges the Confirmable request, including a Payload of "22.3 C". The URI scheme semantics still need to be standardized, but can be easily constructed from existing XML data models as given for other M2M networks. This draft standard is final and is in the process of becoming an IETF Proposed Standard RFC. The editors are from Sensinode and University of Bremen.

3.21.9 DLMS/COSEM

Most relevant URLs, and other precise references

Companion Specification for Energy Metering: COSEM interface classes and OBIS identification system, DLMS User Association, 27 August 2013, http://dlms.com/PASSWORD/Books/Blue_Book_11th_edition.pdf , also called “Blue Book”. Available for members only. A free excerpt is available at http://dlms.com/documents/Excerpt_BB11.pdf , which is what we used for our analysis. Part of the COSEM standard is an Object Identification System (OBIS). Its latest version (2.3, October 2005, with a corrigendum published in April 2006) can be found here: http://dlms.com/documents/members/OBIS_list_v2.3_GK051026.zip

Overall description

DLMS/COSEM (Device Language Message Specification / COmpanion Specification for Energy Metering) is a world-wide standard that specifies smart meter functionality. It is developed and maintained by the DLMS User Association[44]. DLMS is a generalized concept for abstract modelling of communication entities. It is a middleware protocol that can be applied on various physical layer technologies, such as Zigbee, M-bus, but also Internet. It is designed to support messaging to and from (energy) distribution devices in a computer-integrated environment. It is an international standard published as IEC 61334-4-41 [28]. Applications like remote meter reading, remote control

[44] www.dlms.org

and value added services for metering any kind of energy, like electricity, water, gas or heat are supported.

COSEM (Companion Specification for Energy Metering) sets the rules, based on existing standards, for data exchange with energy meters. It is designed for use with DLMS but can also be applied to other protocols. COSEM achieves this by using object modelling techniques to model all functions of the meter, without making any assumptions about which functions need to be supported, how those functions are implemented and how the data are transported. The formal specification of COSEM interface classes forms a major part of COSEM. To process and manage the information it is necessary to uniquely identify all data items in a manufacturer-independent way. Therefore, the definition of OBIS (Object Identification System) is an essential part of COSEM. OBIS is standardized as IEC 62056-61 [29]. DLMS/COSEM is standardized as IEC 62056-53 [25] and IEC 62056-62 [30], of which the latter matches the Blue Book specifications.

The DLMS User Association has 281 members (29 April 2014), which are mostly Full Members having one vote. In October 2011, the Management Committee of DLMS User Association consisted of representatives of Électricité de France R&D, ERDF, ITRON ITALIA SpA, GNARUS ENGINEERING Services Ltd., IBERDROLA, Elster GmbH, Görlitz AG, Landys+Gyr (Europa) AG, SAGEM Communication, and ISKRAEMECO d.d..

Description of the semantic coverage
COSEM is an extensive and complex specification whose semantics cannot be straightforward captured. Chapter 1 gives an introduction on the DLMS/COSEM system, Chapter 4 (especially section 4.2) presents the COSEM Interface Object Classes and specifies the logical names of the objects. The semantic coverage is shown in Figure 26.

A COSEM Physical device contains COSEM Logical Device(s) and must contain a Management Logical Device. A Logical device must have a Logical Device Name (LDN), and contains some objects (Associations objects and Application objects), but also holding parameters and measurement values. The naming system is based on OBIS, the Object Identification System: each logical name is an OBIS code. There are OBIS values groups (A,B,C,D,E,F) and for example, the group A has values:

- 0: Abstract Object
- 1: Electrical Related Object
- 4: Heat Cost Allocator Related Object
- 5: Cooling Related Object
- 6: Heat Related Object
- 7: Gas Related Object
- 8: Cold Water Related Object
- 9: Hot Water Related Object

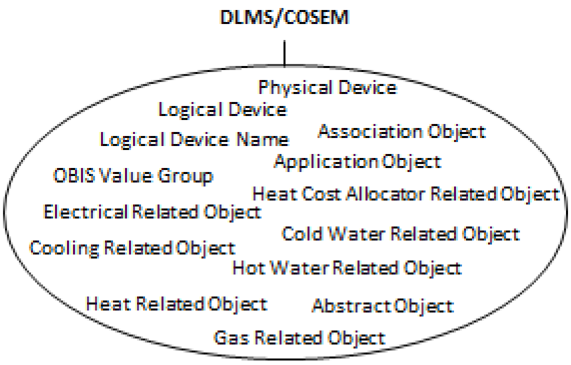

Figure 26. Visual representation of the semantic coverage of DLMS/COSEM

3.21.10 DEHEMS

Most relevant URLs, and other precise references

Nazaraf Shah, Kuo-Ming Chao, Tomasz Zlamaniec, Adriana Matei, "Ontology for Home Energy Management Domain", Digital Information and Communication Technology and Its Applications, Communications in Computer and Information Science, Volume 167, 2011, pp 337-347. http://dx.doi.org/10.1007/978-3-642-22027-2_28 .

Overall description

The Digital Environment Home Energy Management System (DEHEMS) [45]project is a European 7th Framework R&D project running from 2008-2011, looking at how technology can improve domestic energy efficiency. The intention was to develop and test a home energy management system for the home market using Living Labshttp://www.dehems.eu/living-labs in 5 cities across Europe.

Description of the semantic coverage

In Reference [31] the authors of *Ontology for Home Energy Management Domain* describe a system for intelligent energy management for home appliances that uses house hold profiles and energy consumption profiles of electrical appliances to provide households with effective advice on their energy consumption thereby enabling them to take focused and effective actions towards efficient energy use. Energy profiles are used to detect and diagnose abnormalities in energy consumption and recommend remedial actions to household in order to remove or minimize the effect of abnormalities. The encoding of the knowledge is distributed among rules (using Jess as rule base system) and a domain ontology. The domain concepts are used as runtime facts of the rule base system on which rules operate. The pieces of advice like what action to perform are encoded in an ontology. All pieces of advice within ontology are linked to hierarchy of energy consumption activities. The *Ontology for Home Energy Management Domain* paper subsequently describes the DEHEMS ontology as an extension of the SUMO ontology and provides some excerpts of the ontology. From this we can extrapolate the semantic coverage shown in Figure 27, which includes Device, Electrical appliances, Household appliances, Cleaning appliances, Laundry appliances, Washing machine, Energy saving tips, Energy star, Energy Consumed, Spin performance, Spin speed, Wash performance, Brand name, Standby wattage, Wattage, Number of washing programs, EU Energy label class, and Energy Star rating.

[45] www.dehems.eu

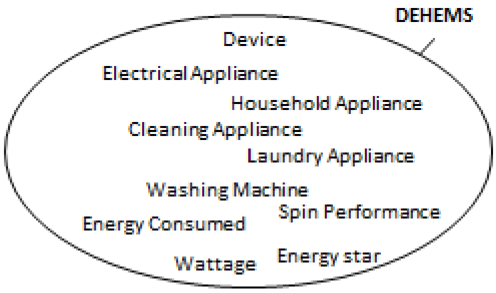

Figure 27. Visual representation of the semantic coverage of DEHEMS

3.21.11 ebbits

Most relevant URLs, and other precise references

Ebbits ontology, D3.2 "Vertical and horizontal business vocabularies", http://www.ebbits-project.eu/downloads.php?cat_id=1&download_id=27 , D4.3 "Coverage and scope of a semantic knowledge model", http://www.ebbits-project.eu/downloads.php?cat_id=1&download_id=28 , D4.5 "Analysis and design of semantic interoperability mechanisms", http://www.ebbits-project.eu/downloads.php?cat_id=1&download_id=47, and D7.2 "Event and data structures, taxonomies and ontologies", http://www.ebbits-project.eu/downloads.php?cat_id=1&download_id=31.

Overall description

The *ebbits* project[46] is a 7th Framework European R&D project, running from 2010-2014, which does research in architecture, technologies and processes, which allow businesses to semantically integrate the Internet of Things into mainstream enterprise systems and support interoperable end-to-end business applications. It will provide semantic resolution to the Internet of Things and hence present a new bridge between backend enterprise applications, people, services and the physical world. The *ebbits* platform features a Service oriented Architecture (SoA) based on open protocols and middleware, effectively transforming every subsystem or device into a web service with semantic resolution. nhe *ebbits* platform thus is expected to enable the convergence of the Internet of People (IoP), the Internet of Things (IoT) and the Internet of Services (IoS) into the "Internet of People, Things and Services (IoPTS)" for business purposes. Another 7th Framework European R&D project taking a similar approach is BEMO-COFRA (Brazil-Europe - Monitoring and Control Frameworks)[47]

Description of the semantic coverage

The ebbits deliverables D3.2, D4.3, D4.5, D7.2 discuss vocabularies, semantic models, ontologies, etc., but are not beneficial to define a precise semantic coverage. The ebbit ontology is based on the HYDRA ontology, which is extensively described in the ebbits deliverables. Some deliverables (D4.5: pages 21-22, and D7.2) contains some excerpts which cover the concepts of Service, Device, Sensor (Thermometer, RFID tag), Event, State, Sensing, Alert, and Measurement, which we have used to define the semantic coverage depicted in Figure 28.

46 www.ebbits-project.eu
47 www.bemo-cofra.eu

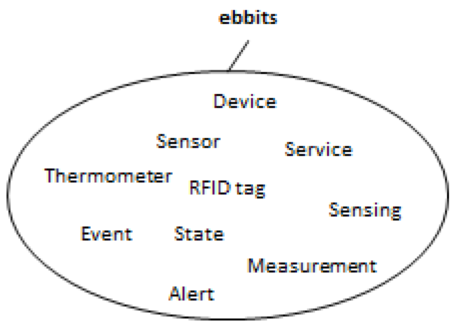

Figure 28. Visual representation of the semantic coverage of ebbits

3.21.12 Energy@Home

Most relevant URLs, and other precise references

Energy@Home Data Model, version 0.9, revision 0.5, 3 February 2014, http://www.energy-home.it/Documents/2014-02-dm/E@h_data_model_v0.9.pdf

Overall description

Energy@home is a collaborative project between Electrolux, Enel, Indesit Company and Telecom Italia. The aim of the project is to develop a communication infrastructure that enables provision of Value Added Services based upon information exchange related to energy usage, energy consumption and energy tariffs in the Home Area Network (HAN). The communication infrastructure enables cooperation between the main devices involved in residential energy management, namely electronic meter, smart appliances, smart plugs, home residential gateways and customer interfaces.

Description of the semantic coverage

The definition of the Energy@Home data model is based on the ZigBee SEP2 specification. Energy@Home identified missed functionalities and attributes in the ZigBee SEP2 specification and submitted them to the ZigBee Alliance. The parts added to the SEP2 specification by Energy@Home consist of an Appliance Identification Package, an Appliance Events and Alerts Package, an Appliance Statistics Package, an Appliance Control Package, an On/Off Package, and a Power Profile Package. Also describes the Metering, Pricing and Time function sets were expanded compared to the original ZigBee SEP2 specification.

The semantic coverage of Energy@Home is shown in Figure 29. The Home Area Network (HAN) is used for communication between devices within the home such as sensors, smart plugs, smart thermostats and household appliances. A Smart appliance is an appliance connected in the HAN with some intelligence to cooperate with the other home actors in order to provide new services to the consumer. Smart plug is a device that typically has a power meter to calculate the power/energy consumption of the connected load and can be used to remotely power on/off the load. Customer Interfaces are physical devices (logical components) that can be visualized by a PDA, a pc or a Smart Phone. The Load profile is the variation in the electrical load versus time, and is specialized by the Power profile concept, which represents the variation of power consumption of an electrical load versus time. The Appliance Power Profile specializes the power profile with information about the energy consumption of an appliance (load profile related to its cycles) and some information for load shedding or load shifting its usage. Load Shedding is as method of reducing demand on the energy generation system by temporarily rationing distribution of energy to different geographical areas.

Load Shifting is an electric load management technique to shift the pattern of energy use of a device (load profile), moving demand from the peak hours to off-peak hours of the day. Peak demand or peak load describes a period in which electrical power is expected to be provided for a sustained period at a significantly higher than average supply level. Peak demand fluctuations may occur on daily, monthly, seasonal and yearly cycles. An Energy Cost Algorithm is used to obtain the price of energy at a given time (e.g. € per kWh from 08:00 to 19:00) replicating the conditions applied by the Energy Retailer. An Energy Regulation Algorithm defines the strategy for coordinating Smart Appliances behavior, in order to reach energy consumption or cost optimization and to guarantee the overall performance of the system, using as inputs the global energy consumption, its cost, Appliances Power Profile and their status. Main control techniques involved in the Energy Regulation algorithm are load shifting and shedding.

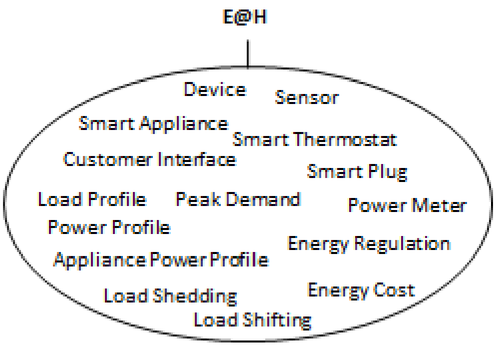

Figure 29. Visual representation of the semantic coverage of Energy@Home

3.21.13 ENERsip

Most relevant URLs, and other precise references

ENERsip deliverables for WP3 "M2M for ADR Infrastructure", https://sites.google.com/a/enersip-project.eu/enersip-project/results/deliverables/wp3

Overall description

ENERsip (ENERgy Saving Information Platform for generation and consumption networks)[48] was a European 7th Framework R&D project running from 2010-2012. The main objective of the ENERsip project was to create an adaptive, intelligent and open service-oriented platform that allows end users to optimise, in near real-time, and to save energy by remotely monitoring, controlling and coordinating power generation and consumption in neighbourhoods with residential and commercial buildings. The objective is both short-term, with respect to development and testing of prototypes, and also long-term, with respect to adoption of service-oriented compliant and energy efficiency solutions. Methods for measuring effectiveness and quality of proposed solutions were to be selected and/or developed as part of the pilot and validation phase. D3.2 of the project defined M2M communication middleware interfaces to integrate with M2M Concentrators, to monitor third party Sensors and actuators, different elements of the Power distribution infrastructure and applications. The middleware platform is said to provide open interfaces, based on the SOA paradigm, to allow integration between the different components of the ENERsip architecture to enable data exchange and monitoring of the different elements of the Power distribution infrastructure and applications. D3.2 has not been made publicly available.

[48] https://sites.google.com/a/enersip-project.eu/enersip-project/

3.21.14 eu.bac

Overall description

Eu.bac[49] is the European Building Automation Controls Association. It is an industry association which mission includes:

- Influence the development and effective implementation of EU directives and regulation, in order to achieve the optimal balance of controls and automation systems & services in new and existing homes and buildings
- Advocate the benefits of balancing controls and automation systems & services; validate outstanding technology; and establish best practices
- Drive European and worldwide industrial standards for the benefit of the industry
- Initiate quality standards through audits, certificates or labels to endorse quality and energy efficiency products and systems & services

The eu.bac Homes sector group represents European manufacturers of control and balancing equipment for residential properties. The long term aim of the group is to ensure that all homes in Europe benefit from appropriately controlled and balanced heating, cooling, ventilation and hot-water systems. An important part of their work is certification. Home Controls and Building automation Controllers with the eu.bac Certification Mark and eu.bac Energy Efficiency Label demonstrate proven quality and energy efficiency according to European standards and directives. The certification tests against the standards EN 15500 [32], EN 15232 [33], EN 16484-2/3 [22] (see section 3.21.4), EN 50090 [16] (see section 3.9) and EN 14908 [24] (see section 3.21.18). No additional semantic assets are defined by eu.bac. eu.bac has 26 member organizations, of which Schneider Electric, Honeywell, Belimo, Siemens, Danfoss, and Sauter are in the board.

3.21.15 HGI

Overall description

The HGI[50] publishes requirements for digital home building blocks. Those building blocks are the hardware and software in the digital home that connect consumers and services. They include home gateways, home networks, and home network devices. Currently the HGI is constructing a *Smart Home Appliance (Device) Model Template,* to be published as GD-042[51]. It is supposed to accompany RD-036, which will describe HGI's Smart Home Architecture and System Requirements.

Description of the semantic coverage

GD-042 outlines a list of the representations in XSD/XML or OWL/RDF currently provided by other parties, rather than providing an HGI specification. A common Device Model Template is proposed to specify device capabilities. Part of this template are Services (interfaces), Actions (operations), Device classes (types), Device instances with some attributes (i.e., name, manufacturer, model name, model number, universal product code) , States (state variables), and Events (asynchronous info). The semantic coverage of HGI is shown in Figure 30.

[49] www.eubac.org
[50] www.homegatewayinitiative.org
[51] http://www.telecomitalia.com/content/dam/telecomitalia/it/archivio/documenti/Innovazione/HotTopic/Casa%20connessa/Overall%20slide%20pack%20BBWF%202013_final.pdf

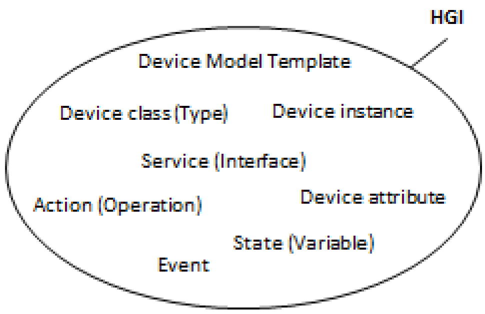

Figure 30. Visual representation of the semantic coverage of HGI

3.21.16 IFC

Most relevant URLs, and other precise references

IFC4 (Industry Foundation Classes 4) Specifications (March 2013): http://www.buildingsmart-tech.org/ifc/IFC4/final/html/index.htm . Also available for download (after free registration) at http://www.buildingsmart-tech.org/downloads/ifc/ifc4/ifc4-html-documentation-68mb .

Overall description

Industry Foundation Classes are standards for the use of object technology in construction and facilities management. They are produced by buildingSMART[52], an international organisation which aims to improve the exchange of information between software applications used in the construction industry. In 1995, the founding members were Autodesk, AT&T, ARCHIBUS, Carrier Corporation , Hellmuth, Obata & Kassabaum (HOK), Honeywell, Jaros Baum & Bolles, Lawrence Berkeley Laboratory, Primavera Systems, Softdesk, Timberline Software Corp, and Tishman Research Corp. Today the organization consists of 15 regional chapters with their own membership, and an International Council made up of 31 members from the regional chapters.

IFC represent an open specification for Building Information Modeling (BIM) data that is exchanged and shared among the various participants in a building construction or facility management project, between applications developed by different software vendors without the software having to support numerous native formats. The latest version of IFC, IFC4, incorporates several extensions of IFC in building, building service and structural areas; enhancements of geometry and other resource components; various quality improvements; fully integrated simple ifcXML specification; and a new documentation format. It is standardized as ISO 16739 [34].

Description of the semantic coverage

The semantic coverage is shown in Figure 31. The IFC specification is structured in Data item names for types, entities, rules and functions, Attribute names within an entity, Property set definitions, and Quantity set definitions. The IFC specification consists of the following four conceptual layers:

– Resource layer, which is the lowest layer and includes all individual schemas containing resource definitions, those definitions do not include an globally unique identifier and shall not be used independently of a definition declared at a higher layer. Examples of resources are DateTime, Material, Actor, Profile, Geometry, Measure, Property, Quantity, Topology, Utility, Cost, Presentation, Constraint, Approval, Structural Load.

[52] www.buildingsmart.org/

– Core layer, which includes the kernel schema and the core extension schemas, containing the most general entity definitions, all entities defined at the core layer, or above carry a globally unique id and optionally owner and history information. Core layers are Control Extension, Product Extension and Process Extension.
– Interoperability layer, which includes schemas containing entity definitions that are specific to a general product, process or resource specialization used across several disciplines, those definitions are typically utilized for inter-domain exchange and sharing of construction information. The interoperability layer consists of Shared building services elements, Shared components elements, Shared building elements, Shared management elements, Shared facilities elements.
– Domain layer, which is the highest layer and includes schemas containing entity definitions that are specializations of products, processes or resources specific to a certain discipline, those definitions are typically utilized for intra-domain exchange and sharing of information. Domain layer contains Building Controls domain, Plumbing Fire Protection Domain, Structural Elements domain, Structural Analysis domain, HVAC domain, Electrical Domain, Architecture domain, Construction management domain.

The IFC is a an extensive and complex specification that covers many domains that are not of interest for our study, except for the HVAC domain, which is represented in the *IfcHvacDomain* schema and whose scope is defined as:

– The segments, fittings and connections that constitute duct and piping distribution systems typically used for building services, such as for air conditioning, ventilation and exhaust-air systems; chilled water, steam and heating hot water, potable water, waste, natural gas and LPG systems, etc.
– Equipment typically used in building services systems, such as boilers, chillers, fans, and pumps and the vibration isolation associated with these components.
– Terminal and flow control devices, such as air vents and grilles, variable air volume modulators, valves, and dampers.

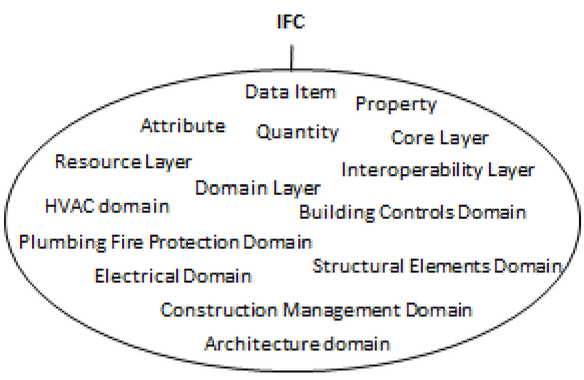

Figure 31. Visual representation of the semantic coverage of IFC

3.21.17 LightingEurope

Most relevant URLs, and other precise references

IES TM-23-11 “Lighting Control Protocols”, Illuminating Engineering Society of North America (IES 2011), http://www.ies.org/PDF/Store/TM-23-11_FINAL.pdf

Overall description
LightingEurope emphasizes the importance of control in the lighting domain, where control refers to the systems or commands that regulate the intensity of electric luminaires in response to some stimulus or action on the part of the building occupants. This stimulus can be direct, e.g., the moving of a switch from one position to the other that completes an electrical circuit and causes the luminaires to energize, or it can be less direct, e.g. in case of occupancy, time, motion, and the presence or absence of daylight. One of the documents LightingEurope has produced is IES TM-23-11 “Lighting Control Protocols”. It identifies 17 different protocols being used for lighting control today, on 4 different physical layers. The protocols are widely varying where some have specified their semantics (e.g. Zigbee Light Link[53]) whereas others are still under development (e.g. DALI[54]). With IES TM-23-11, LightingEurope aims to “encourage greater coordination among disciplines and allow the continued integration of lighting control with other major building systems. Greater integration will ultimately lead to more efficient and healthier buildings enhancing the experience of the built environment for more people”.

Description of the semantic coverage
Section 2 of IES TM-23-11 subsequently describes the core concepts and terms related to lighting in order to provide a common vocabulary. Section 3 presents a basic architecture that is common for controlling the light output of a luminaire or light source. This architecture consists of components (such as user initiated devices and power controllers), interfaces and signals. Examples of user initiated devices are Switch and Wallbox Dimmer. There are also initiating devices such as occupancy sensors. Examples of power controllers are Ballast, Driver and Transformer. There are different types of light sources, such as incandescent lamp, fluorescent lamp, and LED lamp, which require different input forms from the user device and different type of power controllers. The semantic coverage of LightingEurope is shown in Figure 32.

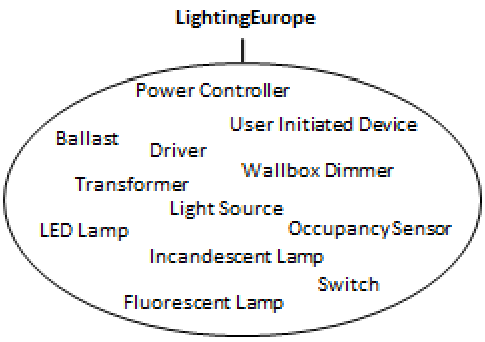

Figure 32. Visual representation of the semantic coverage of LightingEurope

3.21.18 LonWorks

Most relevant URLs, and other precise references
LonMark Device Classes and Functional Profiles,
http://www.lonmark.org/technical_resources/resource_files/spid_master_list#DeviceClasses

[53] http://zigbee.org/Standards/ZigBeeLightLink/Overview.aspx
[54] www.dali-ag.org

Overall description

LonWorks is a networking platform created to address the needs of control applications used for the automation of various functions within buildings, such as lighting and HVAC. It is a peer to peer network in which all devices speak to each other. The platform is built on a protocol created by Echelon Corporation for networking devices over media such as twisted pair, powerlines, fiber optics, and RF. The communications protocol, twisted pair signaling technology, power line signaling technology, and Internet Protocol (IP) compatibility standard were standardized in 2008 as ISO/IEC 14908-1, -2, -3, and -4 [24].

LonMark International[55] is a global membership organization created to promote and advance the business of efficient and effective integration of open, multi-vendor control systems utilizing ISO/IEC 14908-1 and related standards. LonMark establishes interoperability guidelines by profiling the interfaces to a device's functions at the exchange level, and certifies manufacturers' products accordingly.

Description of the semantic coverage

Each device or node contains a microprocessor to communicate the protocol to each other device. On the LonMark website we could find a list of device classes for defining the sematic coverage of LonWorks, which is shown in Figure 33.

Access/Intrusion/Monitoring devices, Automated Food Service devices, Energy Management devices, Fire & Smoke Devices, Gateways devices (Telephone Gateway, Internet Gateway, etc.), Generic Actuators, Generic Controllers, Generic Human-Machine Interfaces (Remote Control, Panel Interface), HVAC devices (VAV Controller, Fan Coil Unit Controller, Roof Top Unit Controller, Chiller, Thermostat, Pump Controller, Unit Heater, etc.), I/O devices, Industrial devices (e.g., Filtration Systems and Power Supply), Lighting (e.g., Dimmer, Lamp actuator, Occupancy controller, Switch, Lighting controller), Motor Controls (e.g., Variable-Speed Motor Drive, Sunblind Actuator, Sunblind Controller), Network Infrastructure devices, Programmables devices, Refrigeration devices (Defrost Controller, Evaporator Controller, Refrigeration Thermostat Controller, Railheat Controller), Semiconductor Fabrication, Sensors (e.g., Light Sensor, Global Solar Radiation Sensor, Time Sensor, Pressure Sensor, Temperature Sensor, Occupancy Sensor, etc.), Transportation (e.g., door controls and electric vehicles), Vertical/Conveyer Transportation (Elevator), Whitegoods (Clothes-e.g., Clothes Dryer, Cooking-e.g., oven, Storage-e.g., refrigerator, Miscellaneous-e.g., dishwasher), Wiring Devices (e.g., Hardwired Gas Detection Shutdown and Hardwired Fire Alarm Shutdown).

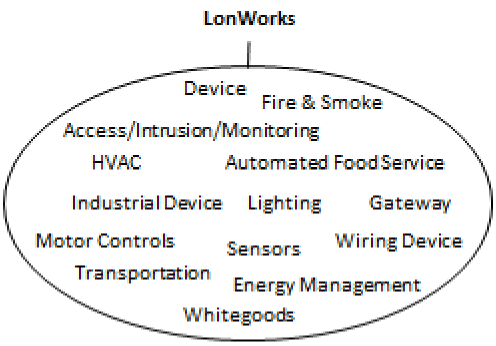

Figure 33. Visual representation of the semantic coverage of LonWorks

[55] www.lonmark.org

3.21.19 oBIX

Most relevant URLs, and other precise references

OASIS, obix-v1.1-csprd02, Committee Specification Draft 02 /Public Review Draft 02, 19 December 2013, http://docs.oasis-open.org/obix/obix/v1.1/csprd02/obix-v1.1-csprd02.pdf

Overall description

oBIX (OASIS Open Building Information eXchange Technical Committee)[56] is an industry-wide initiative to define XML- and web-services-based mechanisms for building control systems. The scope of the OASIS (Organization for the Advancement of Structured Information Standards) Open Building Information Exchange (oBIX) TC is to develop a publicly available web services interface specification that can be used to obtain data in a simple and secure manner from HVAC, access control, utilities, and other building automation systems, and to provide data exchange between facility systems and enterprise applications. In addition, the TC will develop implementation guidelines, as needed, to facilitate the development of products that use the web service interface. oBIX defines a common information model to represent diverse M2M systems and an interaction model for their communications. The current version is 1.1. The current oBIX mailing list consists of representatives of Cisco Systems, Continental Automated Buildings Association (CABA), IBM, William Cox, Institute of Computer Aided Automation, NEXTDC Ltd., Schneider Electric Industries SAS, TIBCO Software Inc., Trane, Tridium, University of North Carolina at Chapel Hill, and US Department of Defense (DoD).

Description of the semantic coverage

The common information model represents Objects that can be extended through the so-called Contracts. Contracts are standard OBIX objects used as a template or patterns. The oBIX standard addresses building control systems, such as Heating and Cooling (HVAC), Lighting, Security, Energy Management, and Life/Safety Alarms. Different type of data, from simple to complex are considered, for example, the room temperature of the lobby (simple), the list of people currently in East Wing with time of entry (lengthy), the current state of all systems across an entire university campus (complex), and the variation of internal humidity of sports hall over the last 6 months (reports). Simple data follows the International Unit of Measurement System, i.e., Mass in kilograms, Length in meters, Time in second, etc., and more complex data structures are built from these. Data is accessed at a Datapoint and exposed by a Point Service, Datapoints are revealed by a Discovery Service, Data trends are reported by a History Service, Critical events are signaled by the Alarm Service. The semantic coverage is shown in Figure 34.

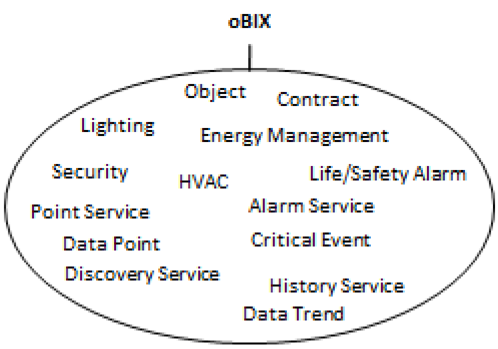

Figure 34. Visual representation of the semantic coverage of oBIX

[56] www.obix.org , https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=obix

3.21.20 SensorML

Most relevant URLs, and other precise references

OGC SensorML: Model and XML Encoding Standard, v2.0.0, 4 February 2014, https://portal.opengeospatial.org/files/?artifact_id=55939 . Here we analysed an older version: OpenGIS Sensor Model Language (SensorML) Implementation Specification, v1.0.0, 17 July 2007.

Overall description

Sensor Model Language (SensorML)[57] is an initiative part of the Sensor Web Enablement (SWE) [58]activity of OGC (Open Geospatial Consortium)[59] for establishing a "sensor web" through which applications and services should be able to access sensors of all types over the Web. The aim of SensorML is to define processes and processing components associated with the measurement and post-measurement transformation of observations. SensorML provides standard models and an XML encoding for describing any process, including the process of measurement by sensors and instructions for deriving higher-level information from observations. Processes described in SensorML are discoverable and executable. All processes define their inputs, outputs, parameters, and method, as well as provide relevant metadata. SensorML models detectors and sensors as processes that convert real phenomena to data.

The document we analyzed specifies the models and XML encoding for the core SensorML, as well as the definition of several SWE Common data components of the SWE framework (the specification of SWE Common data components is out of our scope). The document also gives an informal description of the SensorML components and the common data components of SWE in natural language. It also provides UML diagrams that can be used as basis to build ontologies and should be used as such, as recommended in the specification. Also XML schemas and example instances are provided.

Description of the semantic coverage

The essential elements of SensorML strongly overlap with the SSN ontology and are schematically depicted in Figure 35. These elements are:

- Phenomenon - A physical property that can be observed and measured, such as temperature, gravity, chemical concentration, orientation, number-of-individuals;
- Observable property - A parameter or a characteristic of a phenomenon subject to observation;
- Observation - An act of observing a property or phenomenon, with the goal of producing an estimate of the value of the property;
- Measurement - An observation whose result is a measure;
- Component - Physical atomic process that transforms information from one form to another. For example, a Detector typically transforms a physical observable property or phenomenon to a digital number. Example Components include detectors, actuators, and physical filters;
- System- Composite physically-based model of a group or array of components, which can include detectors, actuators, or sub-systems. A System relates a process to the real world and therefore provides additional definitions regarding relative positions of its components and communication interfaces;

[57] www.ogcnetwork.net/SensorML
[58] www.ogcnetwork.net/SWE
[59] www.opengeospatial.org

– Process Model- Atomic non-physical processing block usually used within a more complex Process Chain. It is associated to a Process Method which defines the process interface as well as how to execute the model. It also precisely defines its own inputs, outputs and parameters;
– Process Chain- Composite non-physical processing block consisting of interconnected sub-processes, which can in turn be Process Models or Process Chains. A process chain also includes possible data sources as well as connections that explicitly link input and output signals of sub-processes together. It also precisely defines its own inputs, outputs and parameters;
– Process Method- Definition of the behavior and interface of a Process Model. It can be stored in a library so that it can be reused by different Process Model instances (by using 'xlink' mechanism). It essentially describes the process interface and algorithm, and can point the user to existing implementations;
– Detector- Process Model profile that represents an atomic component of a Measurement System defining sampling and response characteristic of a simple detection device. A detector has only one input and one output, both being scalar quantities. More complex Sensors such as a frame camera which are composed of multiple detectors can be described as a detector group or array using a System or Sensor. In SensorML a detector is a particular type of Process Model;

Sensor- Specific type of System representing a complete Sensor. This could be for example a complete airborne scanner which includes several Detectors (one for each band).

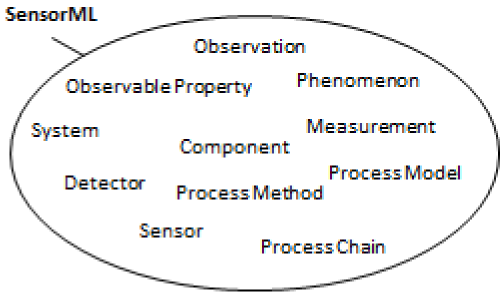

Figure 35. Visual representation of the semantic coverage of SensorML

3.21.21 SESAME

Most relevant URLs, and other precise references

Slobodanka Tomic, Anna Fensel, Tassilo Pellegrini, “SESAME Demonstrator: Ontologies, Services and Policies for Energy Efficiency”, in Proceedings of the 6th International Conference on Semantic Systems I-SEMANTICS 2010, 1-3 September 1-3, Graz, Austria, http://dx.doi.org/10.1145/1839707.1839738

Overall description

SESAME Demonstrator: Ontologies, Services and Policies for Energy Efficiency is a publication in the context of the SESAME[60] project, which uses semantic modelling and reasoning to support home owners and building managers in saving energy and in optimizing their energy costs, while maintaining their preferred quality of living. The SESAME project (running from September 2009 to November 2010) was an international research collaborative project of Forschungszentrum Telekommunikation Wien GmbH, E-Smart Systems d.o.o., eSYS Informationssysteme GmbH (Austria), EZAN – Experimental Factory of Scientific Engineering, Upper Austria University of Applied Sciences,

[60] http://sesame.ftw.at

and Semantic Web Company GmbH. It resulted in a technical solution that actively assists end-consumers to make well-informed decisions and control regarding their energy consumption. The SESAME solution is a full-fledged prototype covering a sensor and smart metering solution that can be installed in the house, equipped with the semantic software and user interfaces performing reasoning and control of the house on the basis on defined policies, sensor inputs and interactions. The cited paper gives an overview of the system, which encodes domain knowledge in an RDF/OWL ontology (not publicly available) that is then used to create SWRL (Semantic Web Rule Language) rules for more advanced reasoning.

Description of the semantic coverage

The semantic coverage is shown in Figure 36. The SESAME ontology includes a number of general concepts such as resident and location, and concepts specific to the automation and the energy domains, such as Device, Tariff, Energy Usage Profile, Account. The Device class is further specialized to model an Appliance, Sensor, or UI device. Properties in the device model are consumption per hour, peek power, the switch on/off status but also the required state "to be switched on/off". The property "canBeStarted" models the state of the devices whose activation can be scheduled, e.g., a filled washing machine. The central function-level concept in the SESAME ontology it the Configuration class, which has two the subclasses Activity (automation activity) and EnergyPolicy. A Configuration connects Appliance, Sensor and UI Device into a joint task. The Configuration can provide regulation of different types, e.g. regulation on time, occupancy of location, threshold value.

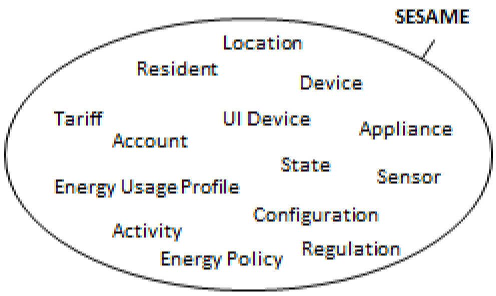

Figure 36. Visual representation of the semantic coverage of SESAME

3.21.22 TIBUCON

Most relevant URLs, and other precise references

TIBUCON D2.3 High Level Data Models and Message Structures, http://www.tibucon.eu/docs/D2%203%20High%20Level%20Data%20Models%20and%20Message%20Structures%20V1.0.pdf

Overall description

TIBUCON[61] (self-powered wireless sensor network for HVAC system energy improvement – Towards Integral BUilding CONnectivity) is a European 7th Framework R&D project which proposes a solution for an easy to deploy and easy to maintain building environment monitoring. It is based on a Wireless Sensor Network (WSN) that consists of spatially distributed autonomous sensors with the objective of monitoring physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, and cooperatively send their data through the network to a main location. D2.3

[61] www.tibucon.eu

describes the standards used at the upper levels of the WSN protocol stack. Only the application layer is in the scope of our analysis.
TIBUCON is a collaboration of Mostostal Warszawa S.A., Tekniker-IK4, Giroa, University of Southampton, Katholieke Hogeschool Kempen, and E&L Architects. D2.3 was edited by Tekniker-IK4.

Description of the semantic coverage
The Tibucon approach uses DPWS (Devices Profiles for Web Services) and SensorML schemas. Section 3 should elaborate on the TIBUCON data models, but it only gives an overview of SensorML purposes and no data models are actually presented. Annex-A gives 3 examples of SensorML XML schemas adapted for TIBUCON in which some headers "have been omitted for simplicity". These schemas represent temperature sensor, humidity sensor and remaining battery monitoring. The rest of the semantic coverage is completely overlapping with SensorML. The semantic coverage is shown in Figure 37.

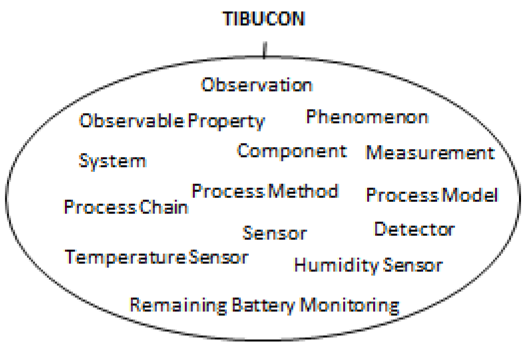

Figure 37. Visual representation of the semantic coverage of TIBUCON

3.21.23 VoCamp

Overall description
VoCamp (Vocabulary Camp)[62] is a series of informal events where people can spend some dedicated time creating lightweight vocabularies/ontologies for the Semantic Web/Web of Data. The emphasis of the events is not on creating the perfect ontology in a particular domain, but on creating vocabs that are good enough for people to start using for publishing data on the Web. The 5th VoCamp took place in Kaiserslautern (Germany) from 13-14 June 2013, where scientific foundations for standardization of M2M communication for energy management of Energy using and producing Products (EupP) in buildings and its environments were discussed. Major contributions were from research projects (FP7) SmartCoDe (TU Kaiserslautern), Adapt4EE, industry stakeholders, ETSI, and CENELEC as standardization bodies, and the European Commission. Presentations are mad available by the conference organizer, but have not yet been uploaded to the conference website, http://cps.cs.uni-kl.de/vocamp

[62] http://vocamp.org

4. Visual representation of key terms

The term asset is used in this deliverable in a broad sense, since it refers to a source that can present a project, a set of documents, an ISO standard, a working group, a committee, a paper, a homepage (of a wiki, or of any other website) that is somehow related to energy management and/or home appliances. Therefore, an asset may refer to one well-defined single ontology, but in most cases is a pointer to a set of multiple documents, several related standards and distinct articles on a web site or wiki, from which a single ontology should be derived.

In order to support the stocktaking task with an overall representation that could help the reader in visualizing the key terms used by different assets , we have created the visual representation in Figure 38, which schematically depicts between 10 and 15 key terms for each asset[63]. This visualization is intended to be an initial step towards the definition of a common semantics for the smart appliances domain. As such, it should be considered as a preliminary and partial result that will be taken as input in the following task of our study, namely creating ontologies based on an accurate semantic analysis. Figure 38 also shows some overlaps (in red and capital letters, in the middle of the figure). We acknowledge that this visualization does not provide a precise semantic representation of the considered assets nor of their overlaps and differences. Ambiguities and inconsistencies are possible. For example, two assets may use the same term with a different meaning and consequently they will result in the overlaps of Figure 38, although in reality they do not share the same semantics. These ambiguities issues will be addressed in WP2 when creating accurate ontologies for the assets in the short list. Figure 38 only gives an indication of the linguistic overlap between key terms used by different assets, but with no guarantee that multiple uses of the term *Device*, for example, actually mean the same thing.

The overlaps in Figure 38 were identified by comparing the key terms used by different assets. The comparison was incremental, namely we started by comparing key terms of two assets and identifying the overlaps, then we compared the key terms of a third asset with the existing overlaps (i.e., the intersection of assets 1 and 2), but we also compared this third asset with asset 1 and asset 2 individually in order to find eventual new overlaps, and so forth for all the assets. If a term can be found in the middle of Figure 38, it means that at least two of the considered assets used that term. If a term is represented in an individual asset, but not in the middle of Figure 38, this shows a difference in the terminology used by other assets.

Every time an overlapping term was identified, the corresponding font in in the middle of Figure 38 was increased. Therefore, the bigger the terms, the more recurrent these terms are among the assets, for example, *Device*, *Sensor*, *Service* and *State*. Overlapping terms were added in the middle of Figure 38 if there was an almost exact match (at least of the stem). For example, the term *Device* matches exactly the term *Device* in several individual maps (exact match), but it is also used to match the term *Device object* in the ECHONET map and the term *Device Category type* in the SEP2 map (almost exact match). As another example of matching, the term *Measure* matches the stem of term *Measurement* of the SensorML map (stem match).

[63] If there are less than 10 terms, then the information about that asset was not sufficient to reach the lower bound of 10 terms.

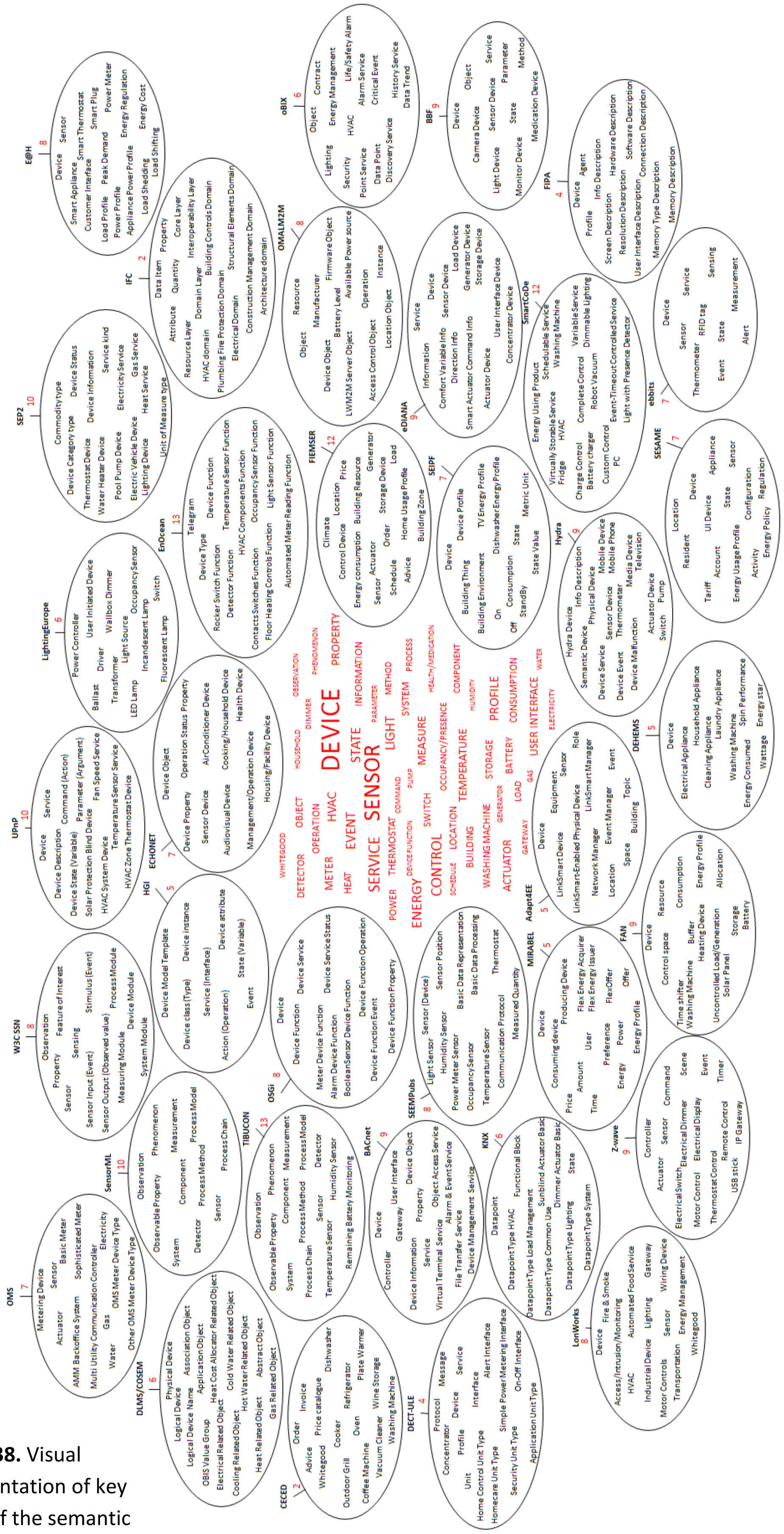

Figure 38. Visual representation of key terms of the semantic assets considered in the stocktaking task.

Each of the assets representations in Figure 38 shows a number (in red) next to the name of the corresponding asset. For example, the UPnP map has a number *10* and the EnOcean map has a number *13*. This number indicates how many key terms used by that specific asset recur in the overlaps in the middle of Figure 38. In other words, the UPnP map has 10 terms overlapping with other maps, namely includes 10 of the most recurring terms among all assets.

5. Conclusions

Based on the stocktaking and assessment work that has been performed we derive four main conclusions:

- We have identified 43 semantic assets that need to be included in our study given the scope as set out by the European Commission. That is 16 more than initially identified in the Invitation to Tender for this study. Of these 43 assets we were able to short-list 20 which provide a good basis for further common ontology development. The short list is composed solely based on how well the asset is covering the scope of the project and if the asset provides concrete semantic specifications, preferably in the form of XML or OWL files.
- The considered assets form a heterogeneous set when considering their semantic coverage. However, we could identify three main trends with a focus on:
    - Devices, sensors and their specification in terms of services, functions and states (e.g., Echonet, eDIANA, EnOcean, OMALightweightM2M, OSGi DAL, SEP2, UPnP);
    - Energy consumption information and profiles to optimize energy efficiency (e.g., FAN, FIEMSER, Mirabel, SESAME);
    - Buildings related semantic models (e.g., DEHEMS, SEEMPubs, SEIPF).

  Most assets mainly focus on one of these three trends and sometimes they do not show much (linguistic) overlap with assets covering one of the other trends. We do however think that assets covering different trends can be connected starting from the most recurrent terms shown in the visual representation in Chapter 4, namely Device, Sensor, Service, State and Event.
- Some of the considered assets do not provide sufficient information and/or documentation to define their semantic coverage (e.g., AIM*, ENERsip, CoAP, Agora)
- The assessment of the items on the long list lead to a short list of assets that we identified as the most relevant for building the common ontology. These assets are in the core of the trends discovered and furthermore provide complete information in terms of data models and product specifications that we can use to build the common ontology. Several semantic assets in the short list provide detailed documentation about the OWL ontologies they have built, but they do not provide a URL to the corresponding OWL files. These assets are eDiana, FIPA, Hydra, and SEIPF. The OWL files are essential for us to make sure that we base the common ontology on the actual models that were defined in the projects or organizations, and not on our own interpretations of the documentation available for these ontologies. As a consequence, if we do not acquire the OWL files we will not include these assets in the development of the common ontology.

Acknowledgements

This study is commissioned by the European Commission. The Project Officer is Rogelio Segovia from the EC's DGCNECT department, who has been indispensable in creating the support of and attention from the smart appliances ecosystem needed to perform this study successfully and to embed it in the industry. The authors would also like to thank the following members of the study's Advisory Board for their helpful guidance and review comments: Markus Eisenhauer, Jerome Euzenat, Lindsay Frost, Frank van Harmelen, Susan Schwarze and Martin van Sinderen. We would further like to acknowledge the ETSI Smart M2M TC and other representatives of ETSI for their enthusiastic support of this study. Finally we would like to mention that representatives of the following projects and organizations were actively involved in providing us with the information we needed: Agora, Broadband Forum, CECED, DECT ULE, Energy@Home, eu.bac, FAN, HGI, LightingEurope, LonWorks, MIRABEL and OSGi Alliance.

References

[1] "Manual for statistics on energy consumption in households", ISSN 2315 - 0 815, Eurostat (2013).

[2] Frank den Hartog, "Consumer Networking Standardization: trends and research opportunities", IEEE Webcast Tutorial, http://www.comsoc.org/webcasts/view/consumer-networking-standardization-trends-and-research-opportunities , IEEE (2011).

[3] Invitation to 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" – SMART 2013/0077, http://ec.europa.eu/digital-agenda/en/news/invitation-tender-study-available-semantics-assets-interoperability-smart-appliances-mapping, EC (2013).

[4] David S. Watson, Mary Ann Piette, Osman Sezgen, and Naoya Motegi, "Machine to Machine (M2M) Technology in Demand Responsive Commercial Buildings", in Proceedings from the ACEEE 2004 Summer Study on Energy Efficiency in Buildings: Breaking out of the Box (2004).

[5] ETSI TS 102 690 v2.1.1, "Machine-to-Machine communications (M2M); Functional architecture", ETSI (2013).

[6] ETSI TR 101 584 V2.1.1, "Machine-to-Machine Communications (M2M); Study on Semantic support for M2M Data", ETSI (2013).

[7] CWA50560:2010 "IFRS (Interoperability Framework Requirement Specification)", CENELEC (2010).

[8] ETSI TR 102 966 V1.1.1, "Machine-to-Machine communications (M2M); Interworking between the M2M Architecture and M2M Area Network technologies", ETSI (2014).

[9] Chuck Eastman, Paul Teicholz, Rafael Sacks, Kathleen Liston, "BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, 2nd Edition", ISBN: 978-0-470-54137-1, Wiley, 2011.

[10] ETSI EN 300 175 "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI)"; parts 1-8, ETSI (2007).

[11] ETSI TS 102 939-1 "Digital Enhanced Cordless Telecommunications (DECT); Ultra Low Energy (ULE); Machine to Machine Communications; Part 1: Home Automation Network (phase 1)", ETSI (2013).

[12] ISO/IEC 14543-3-10:2012, "Information technology -- Home Electronic Systems (HES) -- Part 3-10: Wireless Short-Packet (WSP) protocol optimized for energy harvesting -- Architecture and lower layer protocols", ISO/IEC (2012).

[13] Vincent Gay, *et al*, "D4 – FIEMSER System Architecture", 15 February 2011, http://www.fiemser.eu/?page_id=40 .

[14] Marc Bourdeau, *et al*, "D9 – Interface modules", 30 September 2011, http://www.fiemser.eu/?page_id=40 .

[15] ISO/IEC 14543-3-x, "Information technology -- Home Electronic Systems (HES) Architecture", ISO/IEC (2006-2007).

[16] EN 50090-x-y, "Home and Building Electronic Systems (HBES)", CENELEC (1994-2011).

[17] SML - Smart Message Language - Version 1.02, VDE (2008), http://www.vde.com/de/fnn/extras/tlz/documents/sml_080119_102.pdf .

[18] EN 13757-x, "Communication System for Meters and Remote Reading of Meters", CENELEC (2003-2013).

[19] IEC 61968, "Common Information Model (CIM) / Distribution Management", IEC (2003-2010).

[20] IEEEE 2030.5-2013 "IEEE Adoption of Smart Energy Profile 2.0 Application Protocol Standard", IEEE (2013).

[21] ISO/IEC 29341-x-y "Information technology -- UPnP Device Architecture", ISO/IEC (2008-2011).

[22] ISO 16484 "Building automation and control systems (BACS)", ISO (2004-2007).

[23] M/490 EN "Smart Grid Mandate, Standardization Mandate to European Standardisation Organisations (ESOs) to support European Smart Grid deployment", http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/2011_03_01_mandate_m490_en.pdf .

[24] ISO/IEC 14908-x "Information technology -- Control network protocol", ISO/IEC (2012), EN 14908-x "Open Data Communication in Building Automation, Controls and Building Management - Control Network Protocol", CEN (2014).

[25] IEC 62056-5-3 ed1.0 "Electricity metering data exchange - The DLMS/COSEM suite - Part 5-3: DLMS/COSEM application layer", IEC (2013).

[26] IEC 61850-x ed1.0 "Communication networks and systems in substations", IEC (2003-2013).

[27] RFC 4944 "Transmission of IPv6 Packets over IEEE 802.15.4 Networks", IETF (2007), http://datatracker.ietf.org/doc/rfc4944/; RFC 6282, "Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks", IETF (2011), http://datatracker.ietf.org/doc/rfc6282/ ; RFC 6775 "Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)", IETF (2012), http://datatracker.ietf.org/doc/rfc6775/ .

[28] IEC 61334-4-41 "Distribution automation using distribution line carrier systems - Part 4: Data communication protocols - Section 41: Application protocol - Distribution line message specification", IEC (1996).

[29] IEC 62056-6-1 ed1.0 “Electricity metering data exchange - The DLMS/COSEM suite - Part 6-1: Object Identification System (OBIS)”, IEC (2013).

[30] IEC 62056-6-2 ed1.0 “Electricity metering data exchange - The DLMS/COSEM suite - Part 6-2: COSEM interface classes”, IEC (2013).

[31] Kuo-Ming Chao, N. Shah, R. Farmer, A. Matei, Ding-Yuan Chen, H. Schuster-James, R. Tedd, “A Profile Based Energy Management System for Domestic Electrical Appliances”, in Proc. of the IEEE 7th International Conference on e-Business Engineering (ICEBE), 2010.

[32] EN 15500 “Control for heating, ventilating and air-conditioning applications - Electronic individual zone control equipment”, CEN (2008).

[33] EN 15232 “Energy performance of buildings - Impact of Building Automation, Controls and Building Management”, CEN (2012).

[34] ISO 16739:2013 “Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries”, ISO (2013).

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