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Contents

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Smart Machine-to-Machine communications (SmartM2M).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document provides a standardized framework for the Smart Applications REFerence ontology based on the results of a European Commission Study Group on Smart Appliances ontologies and of different Specialist Task Forces that have supported the maintenance and evolution of the ontology taking into account all the interest of the relevant stakeholders. This reference ontology contains recurring concepts that are used in several domains and is a basis for extensions in particular domains.

The present document also defines the equivalent mapping between the Smart Applications REFference Ontology and the oneM2M Base Ontology.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference/.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

[1] European Commission and TNO: "Study on Semantic Assets for Smart Appliances Interoperability", final report, April 2015.

NOTE: Available at https://sites.google.com/site/smartappliancesproject/deliverables.

[2] "SAREF: the Smart Applications REFerence ontology".

NOTE: Available at https://saref.etsi.org/saref.

[3] European Commission and TNO D-S4 - SMART 2013-0077: "Smart Appliances - Mapping SAREF to short list assets.xlsx", February 2015.

NOTE: Available at https://sites.google.com/site/smartappliancesproject/documents.

[4] ETSI TS 118 112: "oneM2M; Base Ontology (oneM2M TS-0012)".

[5] ETSI TS 103 267 (V2.1.1): "SmartM2M; Smart Appliances; Communication Framework".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TR 103 411: "SmartM2M Smart Appliances SAREF Extension Investigation".

[i.2] ETSI TS 103 410-1: "SmartM2M; Smart Appliances Extension to SAREF; Part 1: Energy Domain".

[i.3] ETSI TS 103 410-2: "SmartM2M; Smart Appliances Extension to SAREF; Part 2: Environment Domain".

[i.4] ETSI TS 103 410-3: "SmartM2M; Smart Appliances Extension to SAREF; Part 3: Building Domain".

[i.5] ETSI TS 103 410-4: "SmartM2M Extension to SAREF Part 4: Smart Cities Domain".

[i.6] ETSI TS 103 410-5: "SmartM2M; Extension to SAREF Part 5: Industry and Manufacturing Domains".

[i.7] ETSI TS 103 410-6: "SmartM2M; Extension to SAREF; Part 6: Smart Agriculture and Food Chain Domain".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

ontology: formal specification of a conceptualization, used to explicitly capture the semantics of a certain reality

smart application: any application in an IoT system making use of the SAREF ontology as specified in the present document and making use of the SAREF communication framework as specified in ETSI TS 103 267 [5]

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

DUL	DOLCE+DnS Ultralite
HVAC	Heating, Ventilation and Air Conditioning
OM	Ontology of units of Measure
oneM2M	oneM2M Partnership Project
OWL	Web Ontology Language
SAREF	Smart Applications REFerence ontology
SAREF4BLDG	SAREF for the Building domain
SAREF4ENER	SAREF for the Energy domain
SAREF4ENVI	SAREF for the Environment domain
SAREF4CITY	SAREF for the Smart Cities domain
SAREF4INMA	SAREF for the Industry and Manufacturing domain
SAREF4AGRI	SAREF for the Smart Agriculture and Food Chain domain
SEAS	Smart Energy Aware Systems
SEP2	Smart Energy Profile 2.0
SSN	Semantic Sensor Network
STF	Specialist Task Force
SUMO	Suggested Upper Merged Ontology
TNO	Netherlands Organisation for Applied Scientific Research
UPnP®	Universal Plug and Play
W3C®	World Wide Web Consortium
WGS84	World Geodetic System 1984

4 Smart Applications Reference Ontology and Semantics

4.1 Introduction and Overview

The Smart Applications REFerence ontology (SAREF) is intended to enable interoperability between solutions from different providers and among various activity sectors in the Internet of Things (IoT), thus contributing to the development of the global digital market.

SAREF shall use the SAREF Communication framework as defined in ETSI TS 103 267 [5].

The SAREF initiative started with a study on "Available Semantics Assets for the Interoperability of Smart Appliances: Mapping into a Common Ontology as a M2M Application Layer Semantics", which was tendered by the European Commission and was carried out by TNO.

Such study acknowledged that the energy utilization of Smart Appliances can be reduced if they are managed and controlled on a system level. The system needs standardized interfaces to ensure interoperability. Many of the required standards already exist, but a common architecture does not, resulting in a market which is too fragmented and powerless. Therefore, a reference ontology of consensus was designed to cover the needs of all appliances relevant for energy efficiency.

The study consisted of three tasks:

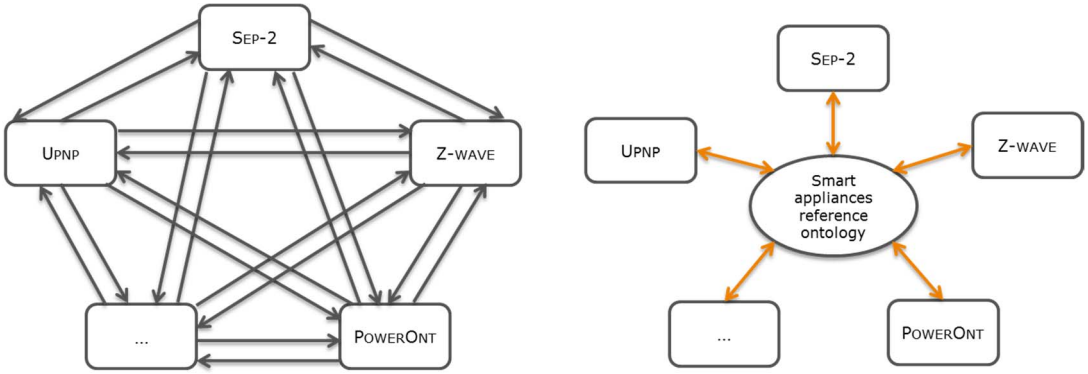
- **Task 1:** Take stock of existing semantic assets and use case assets.
- **Task 2:** Perform a translation exercise of each model (or use case) to a common ontology language and a mapping or matching exercise between all the models.
- **Task 3:** Propose a reference ontology and document the ontology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

NOTE: The ETSI M2M architecture has evolved into the oneM2M architecture, therefore the latter one is the one to be considered.

About 50 different semantic assets (i.e. standards, protocols, data models, ontologies) had been identified that describe various properties of Smart Appliances in residential environments. After translating half of these semantic assets into Web Ontology Language (OWL) (https://sites.google.com/site/smartappliancesproject/ontologies), 20 recurring concepts were used as initial building blocks for creating the Smart Applications REFerence ontology (SAREF). For SAREF in OWL, see [2]. The concepts were mapped from the semantic assets to SAREF to allow for translations between different semantic assets.

SAREF explicitly specifies the recurring core concepts in the Smart Applications domain, the main relationships between these concepts, and axioms to constrain the usage of these concepts and relationships. SAREF is based on the fundamental principles of **reuse and alignment** of concepts and relationships that are defined in existing assets, **modularity** to allow separation and recombination of different parts of the ontology depending on specific needs, **extensibility** to allow further growth of the ontology, and **maintainability** to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) SAREF.

Mappings to other concepts used by different semantic assets allow translation from the reference ontology to specific assets, reducing the effort of translating from one asset to another, since the reference ontology requires one set of mappings to each asset, instead of a dedicated set of mappings for each pair of assets. Figure 1 shows the role of the reference ontology in the mapping by means of sample assets. The mappings of SAREF to various assets are available in [3].



NOTE: UPnP® and Z-Wave® are examples of suitable products available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of these products.

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

SAREF is based on the following main concepts (in alphabetical order):

- Command (e.g. OnCommand, OffCommand, PauseCommand, GetCommand, NotifyCommand, SetLevelCommand).
- Commodity (e.g. Electricity, Gas, Water).
- Device (e.g. Switch, Meter, Sensor).
- FeatureOfInterest.
- Function (i.e. Actuating Function, Event Function, Metering Function, Sensing Function).
- Measurement.
- Profile.
- Property (e.g. Energy, Humidity, Light, Motion, Occupancy, Power, Pressure, Price, Smoke, Temperature, Time).
- Service (e.g. Switch On Service).
- State (e.g. On Off State, Open Close State, Start Stop State, Multi Level State).
- Task (e.g. Cleaning, Comfort, Lighting, Safety, Entertainment, Energy Efficiency).
- UnitOfMeasure (e.g. Currency, Energy Unit, Power Unit, Temperature Unit).

4.2 Principles

The Smart Applications REFerence ontology (SAREF) is conceived as a shared model of consensus that facilitates the matching of existing semantic assets for building smart applications, reducing the effort of translating from one asset to another, since SAREF requires one set of mappings to each asset, instead of a dedicated set of mappings for each pair of assets.

Different semantic assets share some recurring, core concepts, but they often use different terminologies and adopt different data models to represent these concepts. Using SAREF, different assets can keep using their own terminology and data models, but still can relate to each other through their common semantics. In other words, SAREF enables semantic interoperability in smart applications through its shared, core concepts.

SAREF explicitly specifies recurring core concepts in smart applications, the main relationships between these concepts, and axioms to constrain the usage of these concepts and relationships. SAREF has been created based on the following fundamental principles:

- **Reuse and alignment** of concepts and relationships that are defined in existing assets. Since a large amount of work was already being done in the smart appliances and in the Internet of Things domains, nothing has been re-invented, but harmonized and aligned what was already there. SAREF is based on the core concepts that were identified as especially relevant to describe the existing semantic assets for smart applications and is aligned to the main classes and properties of the oneM2M base ontology [4] and of the W3C® Semantic Sensor Network (SSN) ontology.

  SAREF reuses the following resources:

  - based on 20 domain-specific ontologies, e.g. W3C® SSN ontology, Echonet, EnOcean®, SEP2, UPnP® (https://sites.google.com/site/smartappliancesproject/ontologies);
  - reuse of W3C® Time ontology;
  - reuse W3C® WGS84 geo positioning vocabulary (through the SAREF4BLDG extension in ETSI TS 103 410-3 [i.4]);
  - reuse of Ontology of units of Measure (OM) individuals.

- **Modularity** to allow separation and recombination of different parts of the ontology depending on specific needs. SAREF provides building blocks that can be combined to accommodate different needs and points of view. The starting point is the concept of **device**, which is actually common to all the semantic assets considered in the study, although some assets may refer to it with different names, such as **resource** or **product,** but mappings for that are provided in [3]. For example, a "switch" is a device. A device is always designed to perform one or more **functions**, therefore, SAREF offers a list of basic functions that can be eventually combined in order to have more complex functions in a single device. For example, the switch mentioned above offers an actuating function of type "on/off function". Each function has some associated **commands**, which can also be selected as building blocks from a list. For example, the "on/off function" is associated with the commands "on", "off" and "toggle". Depending on the function(s) it performs, a device can be found in some corresponding **states** that are also listed as building blocks, so that it is easy and intuitive to combine devices, functions and states. The switch considered in our example can be found in one of the two states "on" or "off". SAREF also provides a list of **properties** that can be used to further specialize the functioning of a device. For example, a "light switch" specializes the more general "switch" described above for the purpose of controlling the "light" property. An extensive explanation of SAREF, describing its classes and relationships, is presented in the next clause.

- **Extensibility** to allow further growth of the ontology. Different stakeholders can specialize the SAREF concepts according to their needs and points of view, add more specific relationships and axioms to refine the general (common) semantics expressed in the reference ontology, and create new concepts, as long as they explicitly link these extensions to at least one existing concept and/or relationship in SAREF. The minimum requirement is that any extension/specialization shall comply with SAREF. Examples of extensions of SAREF in different domains are SAREF4ENER (energy domain) [i.2], SAREF4ENVI (environment domain) [i.3] and SAREF4BLDG (building domain) [i.4].

- **Maintainability** to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) SAREF. According to the extensibility criterion mentioned above, a new module/ontology can be created to further extend/specialize concepts of SAREF. The party that creates the extension should also be responsible for the maintenance of this extension and its evolution over time. For the strategy proposed in ETSI to extend, maintain and evolve SAREF (and its extensions), see ETSI TR 103 411 [i.1].

The prefixes and namespaces used in SAREF and in the present document are listed in Table 1.

Table 1: Prefixes and namespaces used within the SAREF ontology

Prefix	Namespace
saref	https://saref.etsi.org/core/
dcterms	http://purl.org/dc/terms/
foaf	http://xmlns.com/foaf/0.1/
owl	http://www.w3.org/2002/07/owl#
rdf	http://www.w3.org/1999/02/22-rdf-syntax-ns#
rdfs	http://www.w3.org/2000/01/rdf-schema#
vann	http://purl.org/vocab/vann/
xsd	http://www.w3.org/2001/XMLSchema#

4.3 SAREF

4.3.1 General Overview

Figure 2 shows an overview of the main classes of SAREF and their relationships. A detailed explanation of each class is presented in clause 4.3.2 to clause 4.3.8.

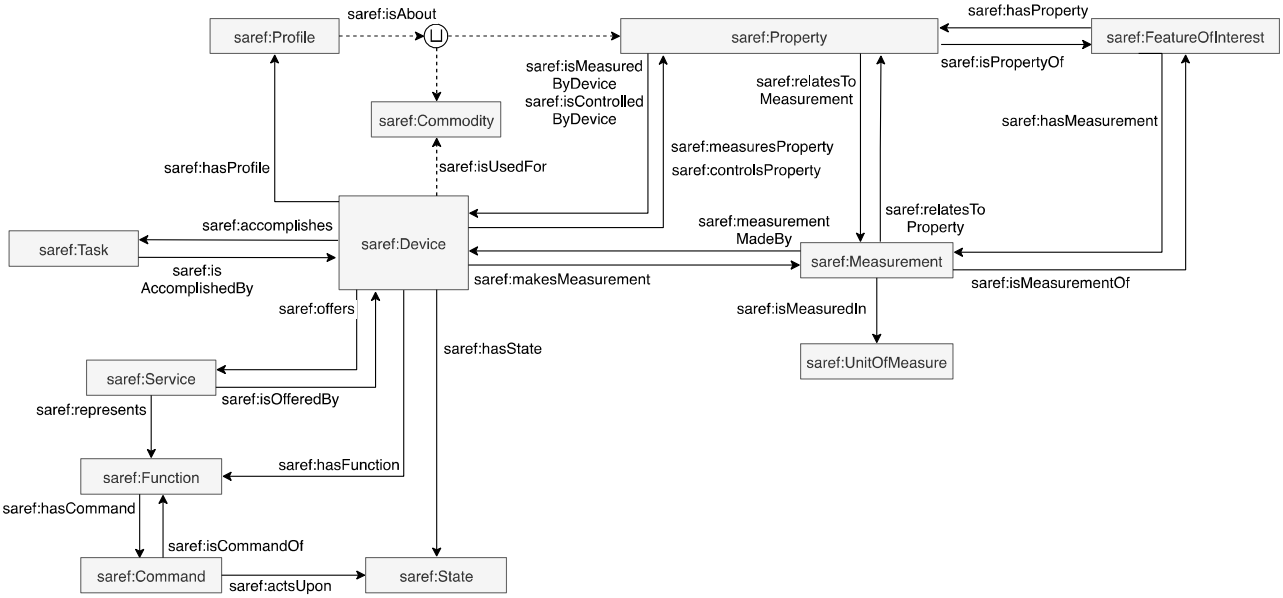


Figure 2: Overview of the SAREF ontology

Table 2 provides a summary of definitions for the main classes of SAREF.

Table 2: Summary of main SAREF definitions

Concept	Definition
Command	A directive that a device shall support to perform a certain function. A command may act upon a state, but does not necessarily act upon a state. For example, the ON command acts upon the ON/OFF state, but the GET command does not act upon any state, it simply gives a directive to retrieve a certain value. A list of commands that are relevant for the purpose of SAREF is proposed, but this list can be extended.
Commodity	A marketable item for which there is demand, but which is supplied without qualitative differentiation across a market. SAREF refers to energy commodities such as electricity, gas, coal and oil.
Device	A tangible object designed to accomplish a particular task in households, common public buildings or offices. In order to accomplish this task, the device performs one or more functions. For example, a washing machine is designed to wash (task) and to accomplish this task it performs a start and stop function.
Feature of interest	A feature of interest represents any real world entity from which a property is measured. It is linked to the different properties it has and to its measurements.

Concept	Definition
Function	The functionality necessary to accomplish the task for which a device is designed. A device can be designed to perform more than one function. Functions can be structured in categories (subclasses) that reflect different points of view, for example, considering the specific application area for which a function can be used (e.g. light, temperature, motion, heat, power, etc.), or the capability that a function can support (e.g. receive, reply, notify, etc.) and so forth.
Measurement	The measured value made over a property. It is also linked to the unit of measure in which the value is expressed and to the timestamp of the measurement.
Profile	A specification associated to a device to collect information about a certain property or commodity (e.g. Energy or Water) for optimizing its usage in the home/building in which the device is located. The profile is linked a certain property or commodity (saref:isAbout), can be calculated over a time span (saref:hasTime) and can be associated to some costs (saref:hasPrice). An example of a profile is the Power Profile defined in the SAREF4ENER extension (this power profile can be associated to a device for optimizing the energy efficiency in the home/building in which the device is located).
Property	Anything that can be sensed, measured or controlled in households, common public buildings or offices. A list of properties that are relevant for the purpose of SAREF is proposed, but this list can be extended.
Service	A representation of a function to a network that makes the function discoverable, registerable, remotely controllable by other devices in the network. A service can represent one or more functions. A service is offered by a device that wants (a certain set of) its function(s) to be discoverable, registerable, remotely controllable by other devices in the network. A service shall specify the device that is offering the service and the function(s) to be represented.
State	The state in which a device can be found, e.g. ON/OFF/STANDBY, or ONLINE/OFFLINE. A list of states that are relevant for the purpose of SAREF is proposed, but this list can be extended.
Task	The goal for which a device is designed (from a user perspective). For example, a washing machine is designed for the task of washing. A list of tasks that are relevant for the purpose of SAREF is proposed, but this list can be extended.
Unit of Measure	The unit of measure is a standard for measurement of a quantity, such as a saref:Property. For example, Power is a property and Watt is a unit of power that represents a definite predetermined power: when it is said 10 Watt, it is actually meant 10 times the definite predetermined power called "watt". The definition of unit of measure in SAREF refers to the definition of unit of measure in the Ontology of units of Measure (OM). A list of some units of measure that are relevant for the purpose of SAREF is proposed, but this list can be extended, also using some other ontologies rather than the Ontology of units of Measure (OM).

4.3.2 Device

SAREF focuses on the concept of device, which is defined as "*a tangible object designed to accomplish a particular task in households, common public buildings or offices. In order to accomplish this task, the device performs one or more functions*". Examples of devices are a light switch, a temperature sensor, an energy meter and a washing machine. A washing machine is designed to wash (task) and to accomplish this task it performs a start and stop function. The `saref:Device` class and its properties are shown in Figure 3.

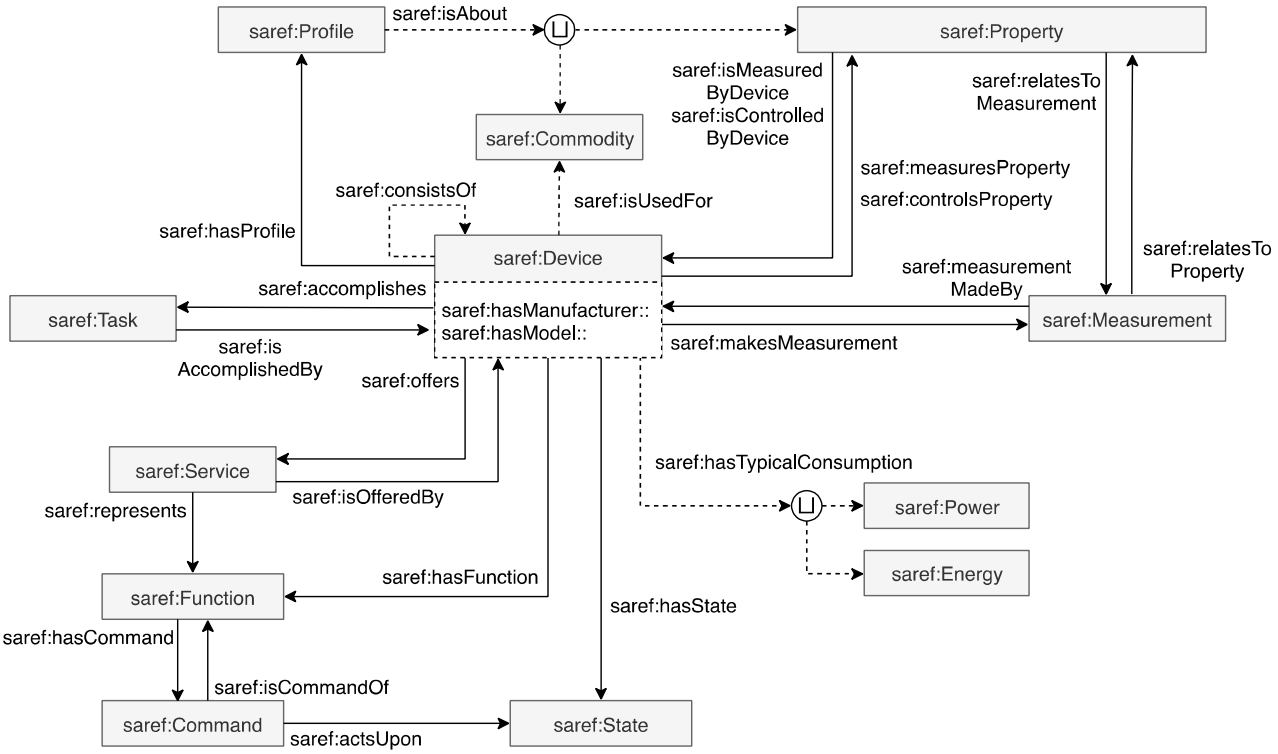


Figure 3: Device class

A `saref:Device` can have some properties that uniquely characterize it, namely its model and manufacturer (`saref:hasModel` and `saref:hasManufacturer` properties, respectively).

SAREF is conceived in a modular way in order to allow the definition of any device from pre-defined building blocks, based on the function(s) that the device performs. Therefore, a `saref:Device` has at least one function (`saref:hasFunction min 1 saref:Function`). Moreover, a `saref:Device` can be used for (`saref:isUsedFor` property) the purpose of offering a commodity, such as `saref:Water` or `saref:Gas`. It can also measure a property, such as `saref:Temperature`, `saref:Energy` and `saref:Smoke`. Moreover, a device may consist of other devices (`saref:consistsOf` property).

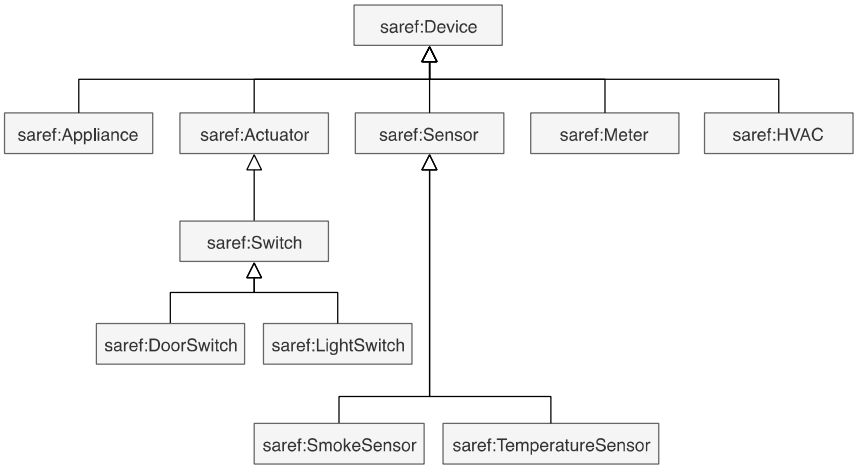


Figure 4: Types of devices

As shown in Figure 4, types of devices that can be represented are actuators (e.g. a `saref:Switch` that can be further specialized in `saref:LightSwitch` and `saref:DoorSwitch`), sensors (e.g. a `saref:SmokeSensor` and `saref:TemperatureSensor`), meters, and appliances. Note that more types of devices, sensors and actuators exist which can be defined to extend SAREF (the device types in Figure 4 represent only some examples that aim at explaining the rationale behind SAREF). A description of these types of devices is presented in the next clause, in combination with the function that they perform. Examples of devices for specific domains are defined in the SAREF extensions ([i.2] to [i.7]).

4.3.3 Function

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

In particular:

- The `saref:ActuatingFunction` allows to "*transmit data to actuators, such as level settings (e.g. temperature) or binary switching (e.g. open/close, on/off)*" and can be divided into different types, such as for example:
  - The actuating function of type `saref:OnOffFunction` allows to "*switch on and off an actuator"*. This function allows the commands `saref:OnCommand`, `saref:OffCommand` and `saref:ToggleCommand`.
  - The actuating function of type `saref:LevelControlFunction` allows to *"do level adjustments of an actuator in a certain range (e.g. 0%-100%), such as dimming a light or set the speed of an electric motor"*. This function allows the commands `saref:SetLevelCommand` (which can be of type `saref:SetAbsoluteLevel` or `saref:SetRelativeLevel`), `saref:StepUpCommand` and `saref:StepDownCommand`.
- The `saref:SensingFunction` allows to "*transmit data from sensors, such as measurement values (e.g. temperature) or sensing data (e.g. occupancy)"*. This function allows the command `saref:GetCommand`.
- The `saref:MeteringFunction` allows to "*get data from a meter, such as current meter reading or instantaneous demand*". This function allows the commands `saref:GetCurrentMeterValueCommand`, `saref:GetMeterDataCommand`, and `saref:GetMeterHistoryCommand`.
- The `saref:EventFunction` allows to "*notify another device that a certain threshold value has been exceeded"*. This function allows the command `saref:NotifyCommand`.

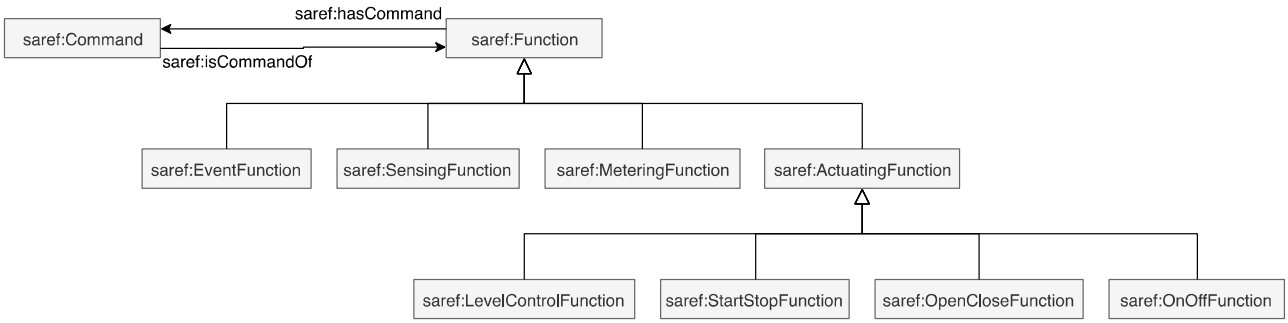


Figure 5: Function class

In order to show how these functions shall be used, some examples of devices and their functions are defined as follows:

- a washing machine is a device of type `saref:Appliance`, accomplishes the task `saref:Washing` and performs an actuating function of type `saref:StartStopFunction`;

- a sensor is a device of type `saref:Sensor` and performs a `saref:SensingFunction`;
- a temperature sensor is a device that consists of a sensor, is of type `saref:Sensor`, performs the `saref:SensingFunction` and measures a property of type `saref:Temperature`;
- a smoke sensor is a device that consists of a sensor, is of type `saref:Sensor`, performs the `saref:SensingFunction` (to measure a property of type `saref:Smoke`) and `saref:EventFunction` (to notify that a certain threshold has been exceeded);
- a switch is a device that is of type `saref:Actuator` and performs an actuating function of type `saref:OnOffFunction` or `saref:OpenCloseFunction`;
- a door switch is a device that consists of a switch, is of type of `saref:Actuator`, performs the `saref:OpenCloseFunction` and is used for the purpose of controlling a building object such as a door;
- a dimmer lamp is a device that is of type `saref:Actuator`, performs an actuating function of type `saref:LevelControlFunction` and measures a property of type `saref:Light`;
- a meter is a device that is of type `saref:Meter` and performs a `saref:MeteringFunction`;
- an energy meter is a device that consists of a meter, is of type `saref:Meter`, performs the `saref:MeteringFunction` and measures the `saref:Energy` property.

4.3.4 Command

A `saref:Function` shall have at least one command associated to it (`saref:hasCommand min 1 saref:Command`). Figure 6 shows the list of commands currently available in SAREF. This list is used here for illustration purposes and can be extended with new commands.

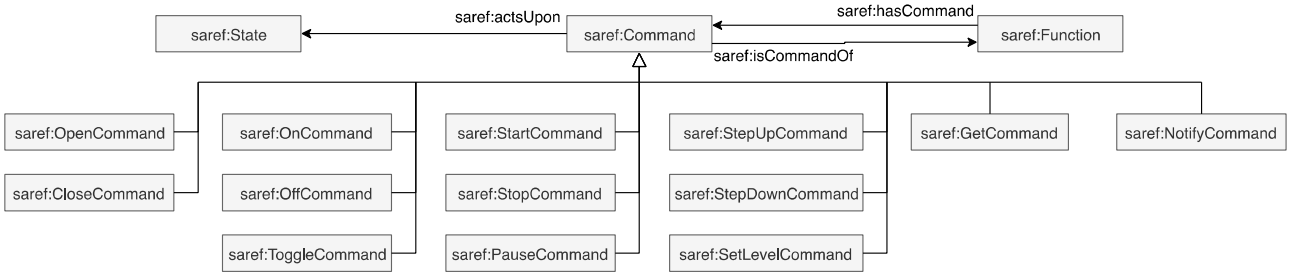


Figure 6: Command class

For example:

- The commands `saref:OnCommand`, `saref:OffCommand` and `saref:ToggleCommand` are associated to the function `saref:OnOffFunction`.
- The commands `saref:SetLevelCommand` (which can be of type `saref:SetAbsoluteLevel` or `saref:SetRelativeLevel`), `saref:StepUpCommand` and `saref:StepDownCommand` are associated to the function `saref:LevelControlFunction`.
- The command `saref:GetCommand` is associated to the function `saref:SensingFunction`.
- The commands `saref:GetCurrentMeterValueCommand`, `saref:GetMeterDataCommand`, `saref:GetMeterHistoryCommand` are associated to the function `saref:MeteringFunction`.
- The command `saref:NotifyCommand` is associated to the function `saref:EventFunction`.

Figure 6 further shows that a command can act upon a state (`saref:actsUpon` relation) to represent that the consequence of a command can be a change of state of a device. Note that a command may act upon a state, but does not necessarily act upon a state. For example, the `saref:OnCommand` acts upon the `saref:OnOffState`, but the `saref:GetCommand` does not act upon any state, since it only gives a directive to retrieve a certain value.

4.3.5 State

Depending on the function(s) it performs, a device can be found in a corresponding `saref:State`, as shown in Figure 7. For example, a switch can be found in the `saref:OnOffState`, which is further specialized in `saref:OnState` and `saref:OffState`. A light switch can be found in the `saref:OnOffState` upon which the `saref:OnCommand` and `saref:OffCommand` shall act. Note that SAREF is not restricted to binary states such as the `saref:OnOffState`, but allows to define also n-ary states (see, for example, the `saref:MultiLevelState` class).

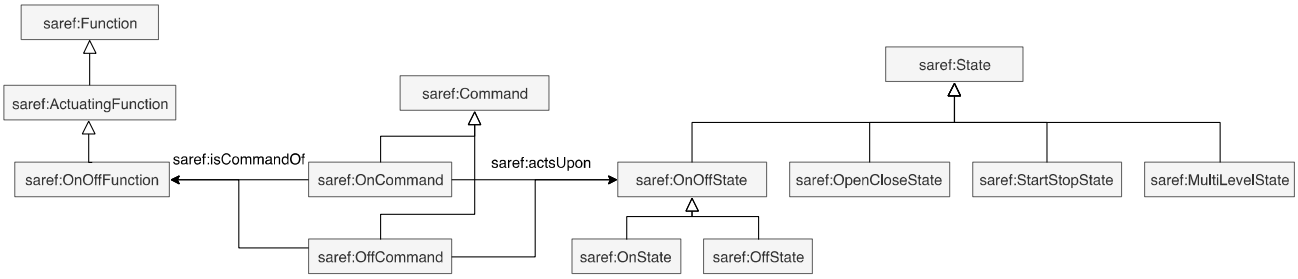


Figure 7: State class

4.3.6 Service

Figure 8 shows that a device offers a service (the `saref:Service` class), which is a representation of a function to a network that makes this function discoverable, registerable and remotely controllable by other devices in the network. A service shall represent at least one function (`saref:represents min 1 saref:Function`) and is offered by at least one device that wants (a certain set of) its function(s) to be discoverable, registerable and remotely controllable by other devices in the network (`saref:isOfferedBy min 1 saref:Device`). Multiple devices can offer the same service. A service shall specify the device that is offering the service and the function(s) to be represented.

For example, a light switch can offer the service of remotely switching the lights in a home through mobile phone devices that are connected to the local network (`saref:SwitchOnService` class). This "remote switching" service represents the `saref:OnOffFunction` previously described.

Note that the concept of service is further elaborated in the oneM2M Base Ontology [4], to which the reader is referred in order to model the details of a service that are out of the scope of SAREF.

Figure 8: Service class

4.3.7 Profile

A device in SAREF can be further characterized by a profile. Figure 9 shows the `saref:Profile` class and its properties. A profile is a specification associated to a device to collect information about a certain property or commodity (e.g. energy or water) for optimizing its usage in the home/building in which the device is located. Therefore, a profile is linked to a certain property or commodity (using the `saref:isAbout` property), can be calculated over a time span (using the `saref:hasTime` property) and can be associated to some costs (using the `saref:hasPrice` property). A specialization of a profile is the Power Profile defined in the SAREF4ENER extension in ETSI TS 103 410-1 [i.2] (this power profile can be associated to a device for optimizing the energy efficiency in the home/building in which the device is located).

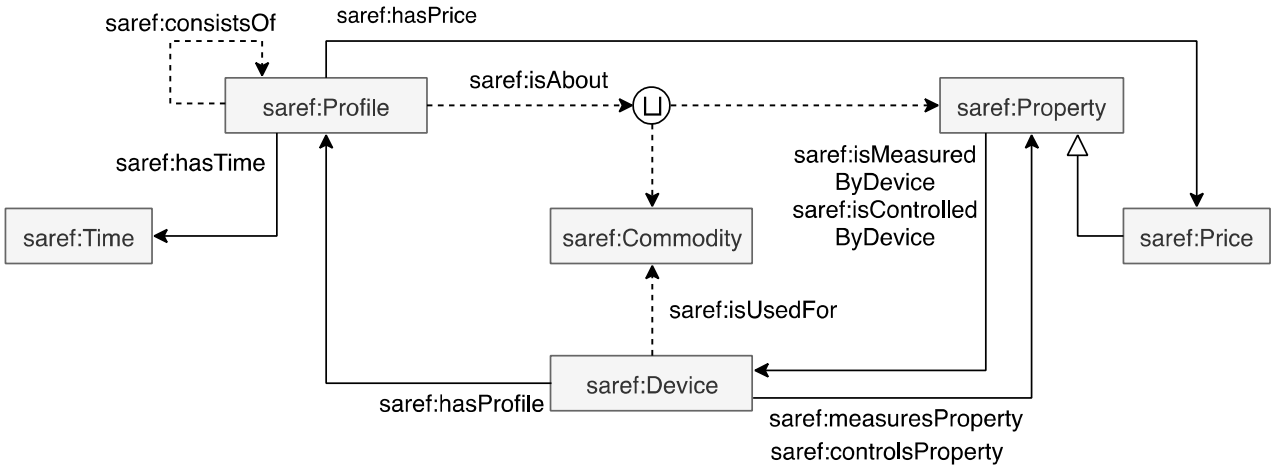


Figure 9: Profile class

4.3.8 Measurement, Property and Unit of Measure

The classes `saref:Measurement`, `saref:Property` and `saref:UnitOfMeasure` allow to relate different measurements from a given device for different properties measured in different units, i.e. the `saref:Measurement` class describes a measurement of a physical quantity (using the `saref:hasValue` property) for a given `saref:Property` and according to a given `saref:UnitOfMeasure`. In this way, it is possible to differentiate between properties and the measurements made for such properties, and to store measurements for a concrete property in different units of measurement. Furthermore, a timestamp can be added (using the `saref:hasTimestamp` property) to identify when the measurement applies to the property, which can be used either for single measurements or for series of measurements (e.g. measurement streams). Figure 10 shows that a `saref:Device` can measure or control a `saref:Property` (which may be from a `saref:FeatureOfInterest`), which in turn relates to a `saref:Measurement`, which in turn is measured in a given `saref:UnitOfMeasure`. Note that it is possible to follow also the inverse direction in which a `saref:Device` makes a measurement in a certain unit of measure (using the `saref:makesMeasurement` property), and this measurement can be related to a `saref:Property` (using the `saref:relatesToProperty` property). A `saref:FeatureOfInterest` represents any real world entity from which a `saref:Property` is measured.

As an example, the `saref:Power` and `saref:Energy` classes can be related to a certain measurement value (using the `saref:hasValue` property), which is measured in a certain unit of measure i.e. `Kilowatt` for power (`saref:PowerUnit`) and `Kilowatt_Hour` for energy (`saref:EnergyUnit`). Analogously, the `saref:Price` class can be related to a certain measurement value that is measured using a certain `saref:Currency`, which is a subclass of the `saref:UnitOfMeasure` class. Further examples on how to define units of measure can be found in the different SAREF extensions ([i.2] to [i.7]).

The `saref:Time` class allows to specify the "time" concept in terms of temporal entities (i.e. instants or intervals) according to the existing W3C® Time ontology to avoid defining this concept from scratch.

NOTE: W3C® and EnOcean® are examples of suitable products available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of these products.

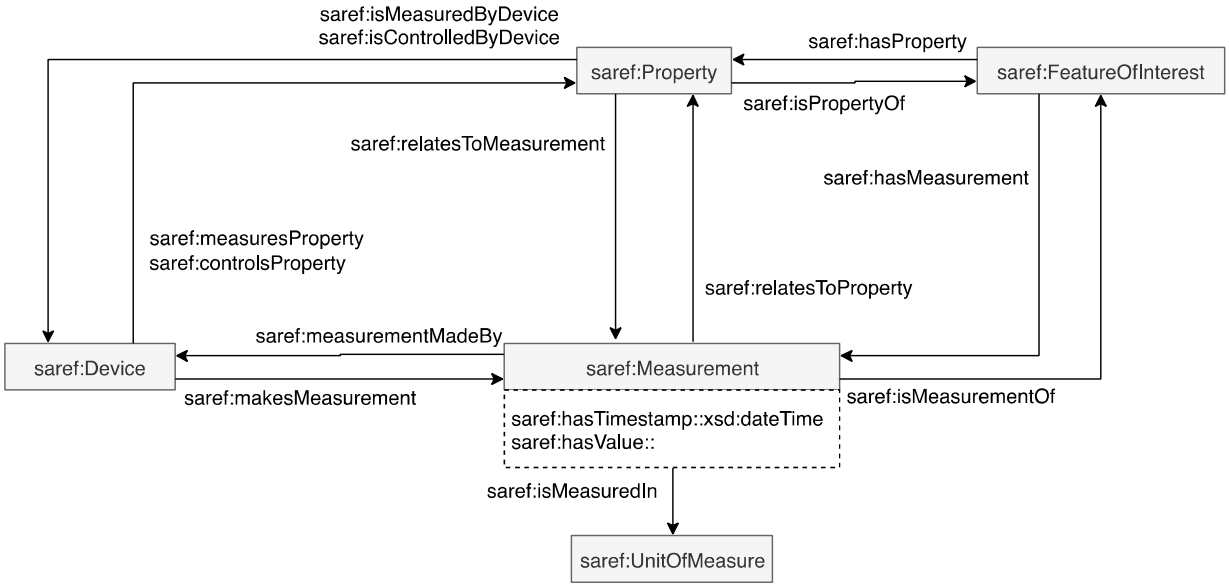


Figure 10: Measurement class

4.4 Observations about SAREF

The present document does not include the examples of devices built using SAREF. Some examples can be found in ETSI TR 103 411 [i.1] and in the different SAREF extensions ([i.2] to [i.7]).

SAREF was created in 2014/2015 by TNO in a study requested by the European Commission. After finishing the study, SAREF was transformed into a Technical Specification by ETSI SmartM2M and published in November 2015. In 2016, ETSI SmartM2M requested a Specialist Task Force (STF) to identify and create possible extensions of SAREF, and provide input to update SAREF according to the requirements collected from the stakeholders that have used SAREF since its first release in April 2015. This led to a new release of SAREF (SAREF 2.0), which incorporated the feedback both from the STF that created the first SAREF extensions, and from the stakeholders that provided their input for improving SAREF. This feedback can be found in ETSI TR 103 411 [i.1] and was used to create the new release of SAREF. In June 2018, another STF started in SmartM2M with the goal (among others) of consolidating SAREF with new reference ontology patterns, based on the experience from the EUREKA ITEA SEAS project. As a result of this STF, 37 different issues were identified and discussed, proposing and agreeing on resolutions for most of them. Furthermore, it was identified the need for moving some transversal terms used in several extensions of SAREF to the core SAREF ontology, because of the broad applicability of such terms. Tis led to the release of the third version of SAREF (SAREF 3.0). A summary of the most relevant changes made in SAREF 2.0 and in SAREF 3.0 is provided in annex B.

SAREF currently does not contain explicit references to upper ontologies such as DUL or SUMO. The use of upper ontologies is a best practice in ontology engineering, but the industrial world - main user of SAREF - is very pragmatic and is not acquainted with high-level upper ontologies. Introducing DUL would have unnecessarily complicated the understanding and, consequently, the adoption of SAREF by the industry. Anyway, SAREF has been built on a solid ontological foundation and can be related to DUL, but this was not explicitly done in order not to confuse industry users. Furthermore, SAREF currently has mappings to the W3C® SSN ontology, which is in turn related to DUL. Therefore, SAREF currently includes an indirect reference to DUL through the W3C® SSN ontology.

The scope of the first release of SAREF created in 2014/2015 by TNO in the study requested by the European Commission was limited to an indoor managed domain, such as a building managed by a building manager or an apartment managed by a user. This scope also included the outdoor premises that belong to the considered indoor managed domain, in other words, a pergola that is part of the building is also within the scope, as well as a sensor located under that pergola. Note that the smart city domain was not originally considered, i.e. if the same sensor that is under the pergola is also in a street, then the sensor in the street was out of the scope of SAREF. After extending SAREF to six different domains, it was clear the need for broadening the scope of SAREF from home appliances and buildings to any device that can be found in smart applications; this motivated the change of name of the ontology from "Smart Appliances REFerence ontology" to "Smart Applications REFerence ontology".

4.5 Extensions of SAREF

SAREF is the reference ontology for smart applications and contains recurring concepts that are used in several domains. SAREF has a close relation with the oneM2M Base Ontology, for which a mapping is defined in clause 5. As smart applications are not restricted to only one domain, it is possible that specific concepts for a certain domain are not part of SAREF. To be able to handle these additional concepts and provide different domains with a proper ontology that reflects the specific needs of that domain, extensions to SAREF should be created. Figure 11 shows SAREF as the upper model to be used as basis for creating extensions in different domains, which are represented as triangles generating from the upper model and specializing core concepts from SAREF. Each domain can have one or more extensions, depending on the complexity of the domain and the different needs. Extensions of SAREF have been created for the Energy, Environment and Building domains and are highlighted in Figure 11. For more details about these extensions and for examples, see SAREF4ENER in ETSI TS 103 410-1 [i.2], SAREF4ENVI in ETSI TS 103 410-2 [i.3], SAREF4BLDG in ETSI TS 103 410-3 [i.4], SAREF4CITY in ETSI TS 103 410-4 [i.5], SAREF4INMA in ETSI TS 103 410-5 [i.6], SAREF4AGRI in ETSI TS 103 410-6 [i.7]. Other extensions can be created for new domains and, if needed, also for the same domains for which extensions already exist. Figure 11 further depicts the equivalence of some concepts between SAREF and the oneM2M Base Ontology.

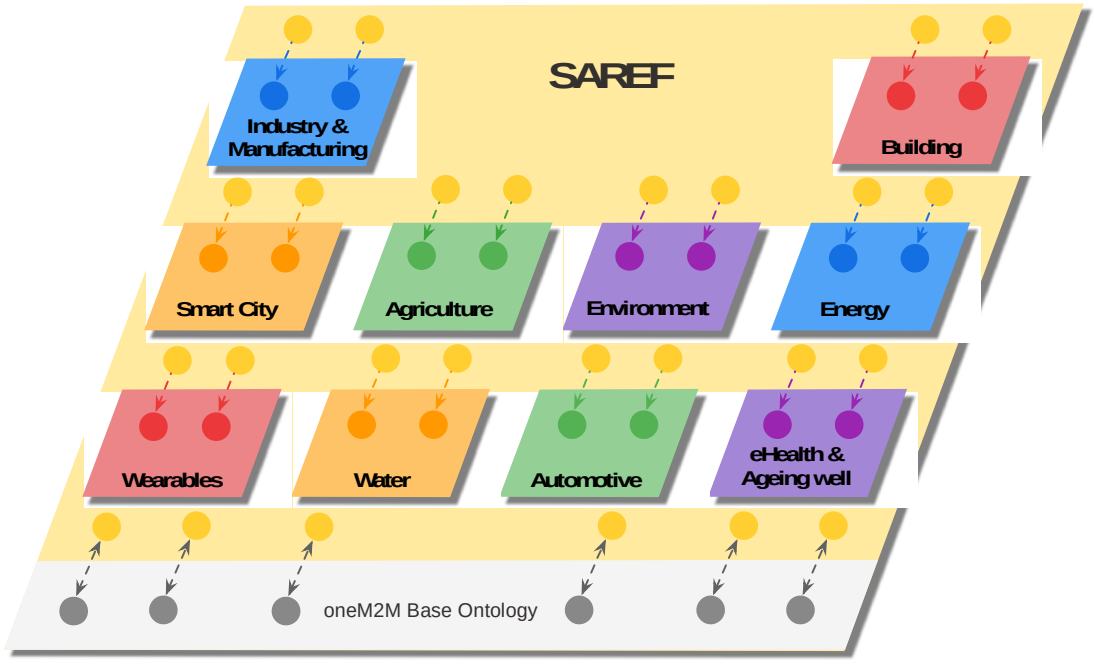


Figure 11: SAREF and its extensions

5 Mapping between SAREF and oneM2M Base Ontology

5.1 Introduction

In ETSI TS 118 112 [4], oneM2M has created a base ontology that describes key classes, relations and properties that are relevant for enabling semantic functionalities within oneM2M systems, as well as enabling interoperability between applications and interworking with existing non-oneM2M technologies. The approach is that given a semantic description of instances according to the oneM2M Base Ontology, a oneM2M resource structure can be automatically created.

General oneM2M resources are created for those ontology instances that are related to functions, e.g. creating an Application Entity resource for a device like a washing machine and creating containers, e.g. for storing the status of the washing machine. They will enable application interactions and thus concern dynamic aspects. Other, more static aspects like the manufacturer of a device will be stored in special semantic descriptor resources that are attached to general oneM2M resources, e.g. there is oneM2M resource representing a device which has a semantic descriptor resource attached that contains semantic information related to the device, e.g. the manufacturer. Such a semantic descriptor resource also contains information concerning the relation to other resources, e.g. operations that can be executed.

A two-step approach for the mapping of SAREF instances to oneM2M resources is used. In the first step, key SAREF classes are mapped to oneM2M Base Ontology classes by defining relations between the SAREF and the oneM2M classes. In the second step, instances modelled according to those SAREF classes for which such a definition exists, are also automatically modelled according to the corresponding oneM2M Base Ontology classes. In the second step, the oneM2M instantiation rules are applied to those instances of SAREF classes that are derived from oneM2M classes. Not all SAREF classes can be mapped to base ontology classes as SAREF models certain aspects that are closely related to the smart applications domain and the base ontology is meant to be agnostic to specific application domains. If no equivalent oneM2M Base Ontology classes exist, e.g. for `saref:Commodity`, the respective SAREF instances are stored together with SAREF instances with which they are connected through an object property and which are mapped to the oneM2M Base Ontology.

5.2 Mapping between SAREF and oneM2M Base Ontology

Figure 12 shows the mapping between SAREF and the oneM2M Base Ontology. Relationships based on `owl:equivalentClass` and `owl:equivalentProperty` are considered to link the key classes and object properties of SAREF and the oneM2M Base Ontology. These are needed to be able to apply the oneM2M instantiation rules to the semantic description of entities that are described according to SAREF.

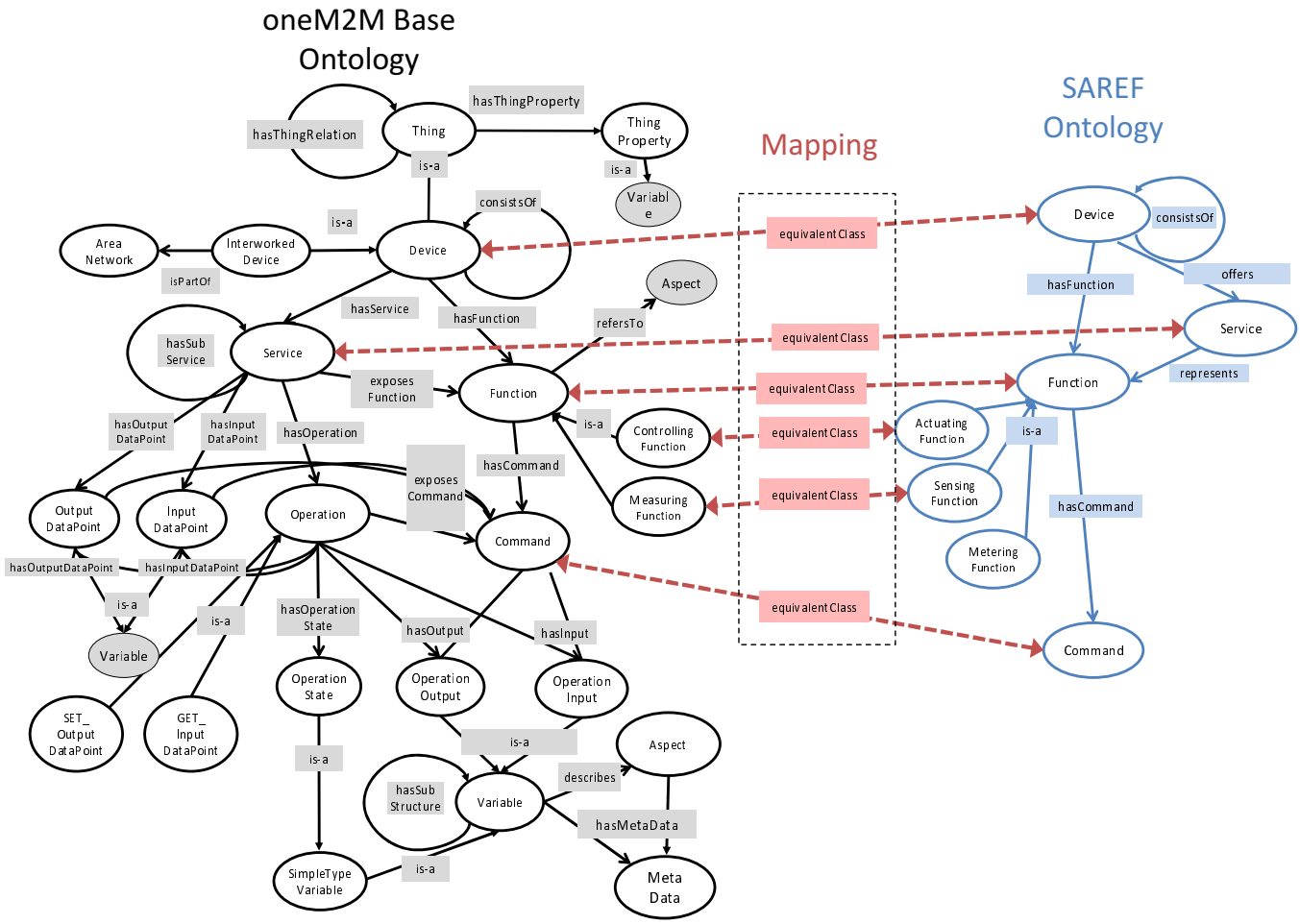


Figure 12: Mapping between SAREF and the oneM2M Base Ontology

Table 3 shows which SAREF class is mapped to which oneM2M class (and vice-versa). As a result, all oneM2M instantiation rules defined for the oneM2M class can also be applied to the instance of the respective SAREF class, and oneM2M instances can be discovered from SAREF when querying for devices, functions, commands and services.

Table 3: Mapping of SAREF classes and oneM2M Base Ontology classes

SAREF	Mapping	oneM2M
saref:Device	owl:equivalentClass	oneM2M:Device
saref:Service	owl:equivalentClass	oneM2M:Service
saref:Function	owl:equivalentClass	oneM2M:Function
saref:SensingFunction	owl:equivalentClass	oneM2M:MeasuringFunction
saref:ActuatingFunction	owl:equivalentClass	oneM2M:ControllingFunction
saref:Command	owl:equivalentClass	oneM2M:Command

Table 4 shows which SAREF object property is mapped to which oneM2M object property.

Table 4: Mapping of SAREF object properties and oneM2M Base Ontology object properties

SAREF	Mapping	oneM2M
saref:offers	owl:equivalentProperty	oneM2M:hasService
saref:hasFunction	owl:equivalentProperty	oneM2M:hasFunction
saref:represents	owl:equivalentProperty	oneM2M:exposesFunction
saref:hasCommand	owl:equivalentProperty	oneM2M:hasCommand
saref:consistsOf	owl:equivalentProperty	oneM2M:consistsOf

5.3 Instantiation Rules for Creating the oneM2M Resource Structure

The Smart Applications oneM2M Mapping shall follow the instantiation rules defined in clause 7 of ETSI TS 118 112 [4].

Annex A (informative): Bibliography

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

Annex B (informative): Change History

Date	Version	Information about changes (see note)
March 2017	V2.1.1	• The classes and properties related to how to represent devices in building spaces (such as the `saref:BuildingSpace` class, `saref:BuildingObject` class and `saref:isLocatedIn` property) have been removed from SAREF and incorporated into the SAREF4BLDG extension related to buildings [i.4], including the reuse of the W3C® WGS84 geo positioning vocabulary. • The `saref:DeviceCategory` and `saref:FunctionCategory` classes have been removed. Instead, the hierarchy of device categories has been implemented directly as subclasses of the `saref:Device` class. • The information specific for energy efficiency has been moved to the SAREF4ENER extension. For example, the `saref:Profile` class has been redefined to accommodate only the properties that are general enough for any type of profile, not only for energy and power. Details on how to specifically model a power profile can be found in the SAREF4ENER extension [i.2]. • The subclasses of the `saref:Energy` class have been removed (i.e. Average Energy, Maximum Energy, Minimum Energy, Total Energy, HVAC Energy, Hot Water Energy and Lighting Energy). • The `saref:Property` class has been split into two classes (`saref:Property` and `saref:Measurement`), as it is done in the SAREF4ENVI extension in [i.3], in order to properly accommodate the distinction between the concept of property (an observable quality of something) and the concept of measurement (a concrete value observed for a property). • Too restrictive cardinality restrictions have been revised, sometimes making them optional rather than mandatory (better to make properties mandatory in the extensions that specialize SAREF for a specific purpose, rather than restricting SAREF, whose purpose is more general). For example, definitions of units of measurement using an enumeration (`owl:oneOf`) were too restrictive because they did not allow using other units than those enumerated. Therefore, the individuals of each class are still there, but the `owl:oneOf` enumeration has been removed. • The `saref:UnitOfMeasure` subclasses use individuals from the OM ontology for unit of measures (http://www.wurvoc.org/vocabularies/om-1.6/), but this is not the only solution. It has been clarified in the comments that the OM ontology is an example, but other ontologies can be used. • The global restrictions (`rdfs:domain` and `rdfs:range`) in object properties have been completely removed not to hinder interoperability. Object properties are now only restricted locally in the classes. • The subclasses of `saref:Task` have been transformed in individuals. • The saref:hasTask property has been removed from the saref:Profile class to resolve an ambiguity with the saref:Task class.
January 2020	V3.1.1	• Added the `saref:FeatureOfInterest` class and the properties used to relate it to `saref:Measurement` (`saref:hasMeasurement` and `saref:isMeasurementOf`) and to `saref:Property` (`saref:hasProperty` and `saref:isPropertyOf`) (#40). • Added the `saref:measurementMadeBy` property as inverse of `saref:makesMeasurement` (#40). • The `saref:relatesToProperty` and `saref:relatesToMeasurement` properties are now inverse of each other (#21). • The range of `saref:hasValue`, which was defined as `xsd:float`, has been removed to support other datatypes for measurements (#24).

Date	Version	Information about changes (see note)
		• The range of datatype properties, which was defined as `xsd:string`, has been removed in order to support strings with language tags (`rdf:langString`). This affects `saref:hasDescription`, `saref:hasManufacturer`, `saref:hasModel` and `saref:hasName`, which now have implicitly a range of `rdfs:Literal` (#1). • The `saref:hasName` property has been removed and the use of `rdfs:label` is recommended (#3). • The `saref:hasDescription` property has been deprecated and the use of `rdfs:comment` is recommended (#6). • Too restrictive restrictions have been removed and in some cases the ontology documentation has been updated to reflect this: a `saref:Command` having at most one `saref:hasDescription` (#2); a `saref:Task` being accomplished by at least one `saref:Device` (#14); a `saref:Device` having a typical consumption of only energy or power (#19); a `saref:Commodity` being measured in units of measure (#20); restrictions on the values of `saref:accomplishes` that only covered specific use cases (#13); universal restrictions on the `saref:actsUpon` property have been changed to existential ones (#31); restrictions on the commands that a `saref:Function` may have, since there could be others not included in the defined enumerations (#28); restrictive documentation of `saref:EventFunction` and `saref:SmokeSensor` (#18). • Bugs have been fixed: some devices (`saref:DoorSwitch`, `saref:EnergyMeter`, `saref:LigthSwitch`, `saref:SmokeSensor`, and `saref:TemperatureSensor`) were defined as subclass of a device and at the same time as consisting of such device (#11); a `saref:LightSwitch` controls light and does not measure light, since it is an actuator (#12); incorrect documentation of `saref:OnState` and `saref:OffState` (#39). • The `saref:BuildingRelated`, `saref:EnergyRelated` and `saref:FunctionRelated` classes have been removed, since the different extensions already classify the device types (#3). • The instances of the subclasses of `saref:Command` have been removed, since they represent examples (#32). • The instances of `saref:UnitOfMeasure` have been moved to examples (#22). • The classes related to the SAREF4ENER extension have been removed: `saref:Generator`, `saref:Storage`, `saref:Load` and `saref:EnergyMeter` (#3). • Some instances of `saref:Device` have been moved to examples: `saref:WashingMachine`, `saref:LightingDevice`, `saref:MicroRenewable`, `saref:Multimedia`, and `saref:Network` (#23). • Added domain and range axioms wherever the definition of a property unambiguously identifies the domain or the range of the property (#15). • The OWL Time ontology is not imported anymore (#36). • The documentation of some ontology terms has been updated for clarification (#5). • Language tags have been added to all labels and comments (#7).
NOTE: In some cases, references have been added to indicate the issue in the ETSI Forge (https://forge.etsi.org/rep/SAREF/saref-core/issues) where the change was discussed and implemented.		

History

Document history		
V1.1.1	November 2015	Publication
V2.1.1	March 2017	Publication
V3.1.1	February 2020	Publication