SAREF4SYST: a SAREF Reference Ontology Pattern for Representing Systems and their Interconnections

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Abstract

This paper introduces the SAREF reference ontology pattern SAREF4SYST, which defines systems, connections between systems, and connection points to which systems can be connected. These basic concepts can be used generically to define the topology of entities of interest and can be specialised for multiple domains. SAREF4SYST has already been reused or aligned to in different domains related to cyber-physical systems, including electrical power systems, smart buildings and smart lifts, communication networks, and multiphysics simulations.

Keywords

Ontology Design Pattern, SAREF, Topology, Systems, Connections

1. Introduction

The Smart Applications REFerence ontology (SAREF) [1, 2] is a reference ontology for the Internet of Things (IoT) developed by the European Telecommunication Standards Institute (ETSI) SmartM2M Technical Committee (TC) in close interaction with the industry. SAREF contains core concepts that are common to several IoT domains and, to be able to handle specific data elements for a certain domain, dedicated extensions of SAREF have been created for the domains of energy, building, environment, smart city, industry and manufacturing, agrifood, automotive, eHealth / ageing well, wearables, water, smart lifts [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13]. SAREF serves as the means to connect the extensions in different domains.

SAREF and its different extensions were developed quite independently by different teams of experts, sometimes in parallel. Sometimes different modelling decisions were made, with the result that SAREF extensions having important discrepancies. TC SmartM2M started to identify ontology patterns that may be used to homogenise the structure of SAREF extensions. Specialist Task Force (STF) 653 "SAREF Patterns" aims at homogenising and facilitating the use of SAREF and existing 11 SAREF extensions by grounding them using a set of SAREF reference ontology patterns, which consist of combination of an ontological definition, and specification of how to apply it to different domains. The ultimate goal is to help ensuring a homogeneous structure of the overall SAREF ontology, speed up the development of extensions, and improve

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semantic interoperability.

In this paper we introduce the first such SAREF reference ontology pattern SAREF4SYST, which defines systems, connections between systems, and connection points to which systems can be connected. SAREF4SYST has been published as ETSI Technical Specification (TS) 103 548 in 2019 as part of previous STF 556 "Consolidation of SAREF and its community of users, based on the experience of the EUREKA ITEA - 12004 SEAS" [14], but it has not yet been presented to the community of researchers on pattern-based ontology engineering.

The rest of this paper is organised as follows. Section 2 provides general application scenarios for the pattern. Then Section 3 overviews the ontological description of the pattern and how it may be used in different domains. Finally Section 4 discusses some of its influences and uptake.

2. Motivating Scenarios for SAREF4SYST

SAREF4SYST defines Systems, Connections between systems, and Connection Points at which systems may be connected. These core concepts can be used generically to define the topology of features of interest, which is knowledge relevant for use cases in various application domains of Cyber-Physical Systems.

SAREF4SYST can be used for example to describe zones inside a building (systems), that share frontiers of different types (connections). Properties of systems are typically state variables (e.g. temperature, volume, energy, mass), while those of connection points are typically interaction capacities and flows (e.g. thermal transmittance, energy flow, matter flow, impedance).

The following paragraphs illustrate the applicability of SAREF4SYST in three different domains. Note that modeling properties of features of interest is not part of SAREF4SYST.

Power Energy. In the Smart Energy domain, electric power systems can exchange electricity with other electric power systems. The electric energy can flow both ways in some cases (from the Public Grid to a Prosumer), or in only one way (from the Public Grid to a Load). Electric power systems can be made up of different sub-systems. Generic sub-types of electric power systems include producers, consumers, storage systems, transmission systems.

Electric power systems may be connected one to another at electrical connection points. An Electric power system may have multiple connection points (Multiple Winding Transformer generally have one single primary winding with two or more secondary windings). Generic sub-types of electrical connection points include plugs, sockets, direct-current, single-phase, three-phase, connection points.

An Electrical connection may exist between two Electric power systems through two of their respective connection points. Generic sub-types of electrical connections include Single-phase Buses, Three-phase Buses. A single-phase electric power system can be connected using different configurations at a three-phase bus (phase 1-to-neutral, phase 2-to-neutral, phase 3-to-neutral).

Smart Building. Buildings, Storeys, Spaces, are different sub-types of Zones. Zones can contain sub-zones. Zones can be adjacent or intersect with other zones. Two zones may share one or more connections. For example some fresh air may be created inside a storey if it has two controllable openings to the exterior at different cardinal points. Lifts have one or more

openings, and evolve in a shaft. Storeys may have openings to the shaft. Both the lift openings and the storey openings may have doors that may be in an open or closed state.

Communication networks. Smart devices contain microcontrollers with Input/Output ports and RadioFrequency (RF) communication modules of different kinds. Wired communication may be established between two devices directly, and between two or more devices through some bus. RF communication from a sender to receivers may be established at a certain radiofrequency, with each party powering its RF module at a certain level, and receivers having a relative measure of the Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR).

3. Ontological Description and Application Guidelines

SAREF4SYST consists both of a core ontology, and guidelines to create ontologies applying the SAREF4SYST ontology pattern. The core ontology is a lightweight OWL-DL ontology that defines 3 classes and 9 object properties. It uses namespace https://saref.etsi.org/saref4syst/ prefixed as s4syst: and is available as open source at https://saref.etsi.org/sources/saref4syst/ under the ETSI BSD-3 license, and is submitted as Architectural ODP on the ontologydesignpatterns.org website as http://ontologydesignpatterns.org/wiki/Submissions:SAREF4SYST.

Figure 1 provides a general overview of these classes and properties. In this figure, rectangles are used to denote classes. Plain arrows are used to represent Object Properties between classes. The origin of the arrow is the domain of the property, and the target of the arrow is the range of the property. Dashed arrows with identifiers between stereotype signs (i.e. "« »") refer to OWL axioms that are applied to some property. Four pairs of properties are inverse one of the other; the property s4syst:connectedTo is symmetric, and properties s4syst:hasSubSystem and s4syst:subSystemOf are transitive. A symbol =1 near the target of an arrow denotes a cardinality of 1. A symbol ∃ denotes a local existential restriction.
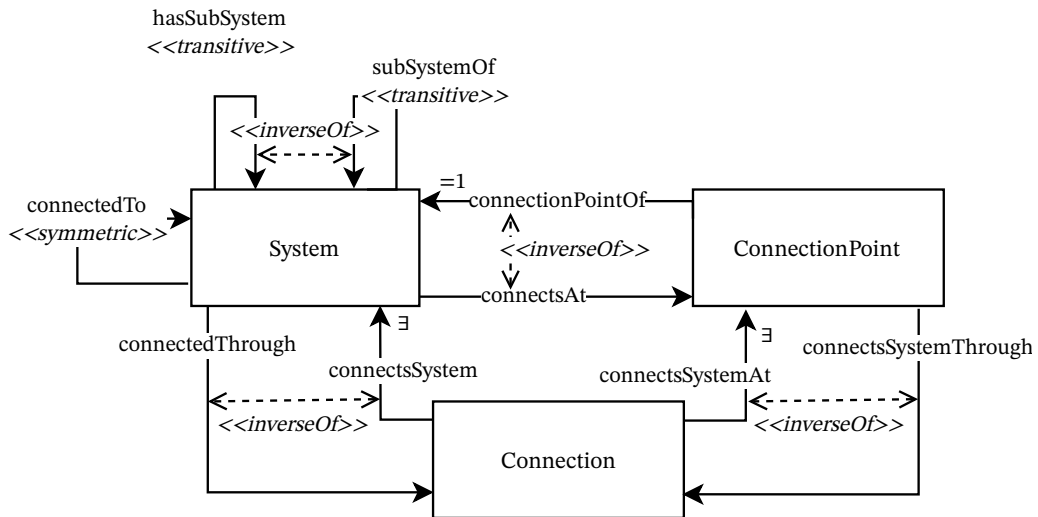

Figure 1: Overview of the SAREF4SYST ontology pattern (adapted from [14])

3.1. Systems and sub-systems

A s4syst:System is defined as a part of the universe that is virtually isolated from the environment. The system properties are typically state variables (e.g. consumed or stored energy, agent population, temperature, volume, humidity). Figure 2 illustrates classes and properties that can be used to define connected systems and their sub-systems.
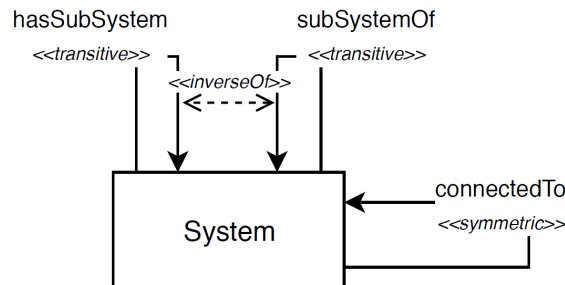

Figure 2: Systems, sub-systems

This module reuses the PARTOF ODP. A connection between two s4syst:Systems, modelled by s4syst:connectedTo, describes the *potential* interactions between connected s4syst:Systems. For example s4lift:canConnectToNetwork, from the SAREF extension for Smart Lifts (SAREF4LIFT [13]) describes a relationship between a system and a network it *can* connect to.

s4syst:connectedTo is symmetric. Sub-properties, however, are not necessarily symmetric, and can be defined for example to model that some matter only flows from one system to the other. For example property s4lift:connectedToEmergencyBattery links a s4lift:ElectricPowerSystem system to another that is its emergency battery.

These core entities are defined as follows:

s4syst:System. The class of systems, i.e., systems virtually isolated from the environment, whose behaviour and interactions with the environment are modeled. Systems can be connected to other systems. Connected systems interact in some ways. Systems can also have subsystems. Properties of subsystems somehow contribute to the properties of the supersystem.

s4syst:connectedTo. Links a system to a system it is connected to. Connected systems interact in some way. The exact meaning of "interact" is defined by sub properties of s4syst:connectedTo. Property s4syst:connectedTo is symmetric. This property can be qualified using class s4syst:Connection, which connects the two systems. If there is a connection between several systems, then one may infer these systems are pairwise connected.

s4syst:subSystemOf. Links a system to its super system. Properties of subsystems somehow contribute to the properties of the super system. The exact meaning of "contribute" is defined by sub properties of s4syst:subSystemOf. Property s4syst:subSystemOf is transitive.

3.2. Connections between systems

A *connection* can be qualified using class s4syst:Connection. Figure 3 illustrates classes and properties that can be used to qualify connections between s4syst:Systems.
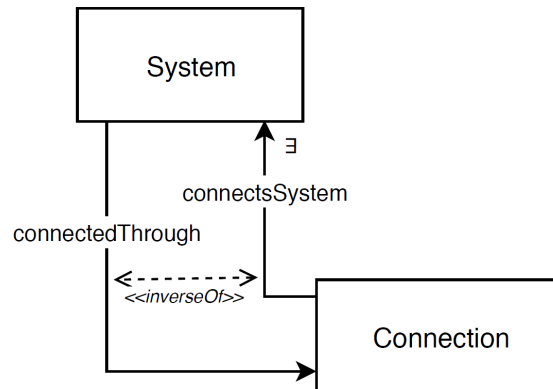

Figure 3: Connections between systems through which systems connect.

These core entities are defined as follows:

s4syst:Connection. The class of connections between systems. This class qualifies property s4syst:connectedTo. A connection describes potential interactions between systems. Any two connected systems are connected through a connection. A connection can connect more than two systems at the same time.

s4syst:connectsSystem. Links a connection to one of the systems it connects.

s4syst:connectedThrough. Links a system to one of its connections to other systems.

3.3. Connections points of systems

A s4syst:System connects to other s4syst:Systems at *connection points*. A connection point belongs to one and only one s4syst:System, and can be described using the class s4syst:ConnectionPoint.

Figure 4 illustrates the classes and the properties that can be used to describe connection points of a s4syst:System. One can then associate a s4syst:ConnectionPoint with properties (saref:Property) that describe it (e.g. position and speed, voltage and intensity, thermal transmittance).

These core entities are defined as follows:

s4syst:ConnectionPoint. The class of connection points of systems, at which they may be connected to other systems. This class qualifies properties s4syst:connectsSystem and s4syst:connectedThrough. A connection point belongs to exactly one system. Any system connected through a connection is connected at one of its connection points to the connection. The system of a connection point that is connected through a connection is itself connected through the connection.
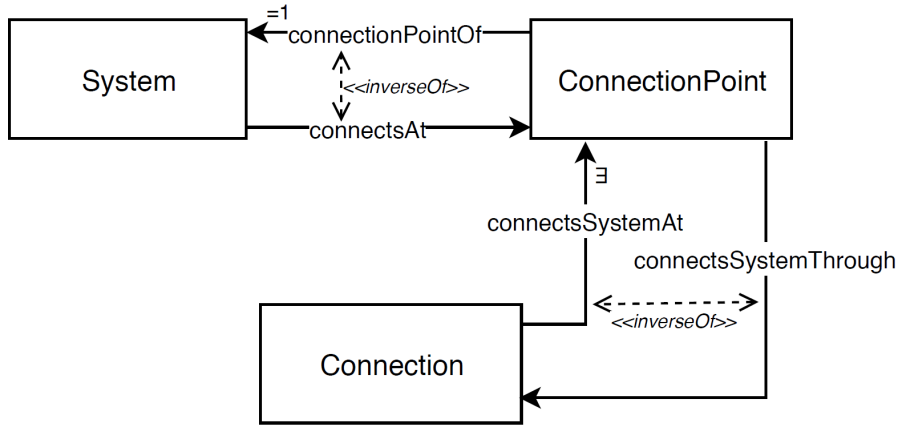
Figure 4: Connection points of systems, where other systems connect

s4syst:connectionPointOf. Links a connection point to the one and only one system it belongs to.

s4syst:connectsAt. Links a system to one of the connection points at which it connects.

s4syst:connectsSystemThrough. Links a connection point to one of the connections through which it connects its system.

s4syst:connectsAt. Links a connection to one of the connection points at which it connects a system.

Furthermore, the following sub-property chain axioms are defined:

$$\text{s4syst:connectsSystem} \sqsubseteq \text{s4syst:connectsSystemAt} \; o \; \text{s4syst:connectionPointOf} \quad (1)$$

$$\text{s4syst:connectedThrough} \sqsubseteq \text{s4syst:connectsAt} \; o \; \text{s4syst:connectsSystemThrough} \quad (2)$$

These allow to infer that a connection at a connection point necessarily connects the system of that connection point (Axiom 1), and that if a connection point connects its system through a connection, then the system is connected through this connection (Axiom 2).

3.4. Applications of the SAREF4SYST Pattern

ETSI TS 103 548 [14] not only describes the terms and the axioms in the SAREF4SYST ontology, but also provides many examples of how the classes and properties may be extended. In addition, it devises guidelines for applying the pattern to verticals. Applications of the SAREF4SYST pattern are subsets of ontologies that define sub-classes and/or sub-properties of the classes and properties of SAREF4SYST. In particular, extensions should preserve the connective words in the name of properties (*Of, At, Through*).

The label of the sub-property should use the same morpho-syntactic structure as its super-property. ([14, Clause 5.3.3.2])

The technical specification also guides the users in choosing the type of axioms that may be appropriate for the pattern application.

A sub-property of the s4syst:connectedThrough property may have an inverse property. If defined, the English-tagged labels and comments of these two properties shall reflect this aspect. ([14, Clause 5.3.3.2])

A sub-class of the s4syst:System class may have an existential restriction on a sub-property of s4syst:connectedThrough to some sub-class of s4syst:Connection ([14, Clause 5.3.3.2])

4. Influences and Uptake

SAREF4SYST is the result of incorporating the seas:SystemOntology ontology into SAREF, which is one of the core modules of the Smart Energy Aware Systems (SEAS) ontology [15]. SAREF4SYST relaxes the SEAS Systems pattern as seas:subSystemOf was defined as a functional, and s4syst:subSystemOf is not.

The SAREF extension for Smart Lifts (SAREF4LIFT [13]) is the first extension that extensively apply the SAREF4SYST pattern. Figure 5 illustrates how the core three classes have been specialized. SAREF4LIFT furthermore uses the SAREF4SYST patterns to define sup-properties:

Examples *Smart Lift Installation*[1] and *Smart Lift General Configuration*[2] illustrate the use of the SAREF4SYST pattern and its different classes and properties.

Sub-properties of s4syst:hasSubSystem: s4lift:hasAlarmSOSSystem

Sub-properties of s4syst:connectedTo: s4lift:canConnectToNetwork, s4lift:connectedToEmergencyBattery

Sub-properties of s4syst:connectsAt: s4lift:hasMainPowerSupply, s4lift:hasStandardPowerSupply

Sub-properties of s4syst:connectedThrough: s4lift:hasCarService

Several works have closely or remotely adopted the patterns behind SAREF4SYST.

The TUBES System Ontology (TSO) and the Flow System Ontology (FSO) align to SAREF4SYST for the description of flow systems in buildings. TSO aims to explicitly define the hierarchical, structural, and functional aspects of interconnected building service systems in the Architecture Engineering, and Construction (AEC) industry and their relationships to spatial entities throughout their whole life cycle. FSO aims to describe the matter and energy flow between systems and components, and the composition of such systems [16, 17].

SAREF4SYST is used by Bjørnskov and Jradi [18] to model interconnected systems in the Digital Twin of a building, and simulate its behaviour.

Roxin et. al. in [19] investigates potential alignment between SAREF ontologies, including SAREF4SYST, and the Modelica system modeling language for modeling of cyber-physical systems supporting acausal connection of components governed by mathematical equations. SAREF4SYST naturally aligns to the system modeling in Modelica.

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[1]https://saref.etsi.org/saref4lift/v1.1.1/example/TS103735_Clause_6_4_SLInstallation.ttl
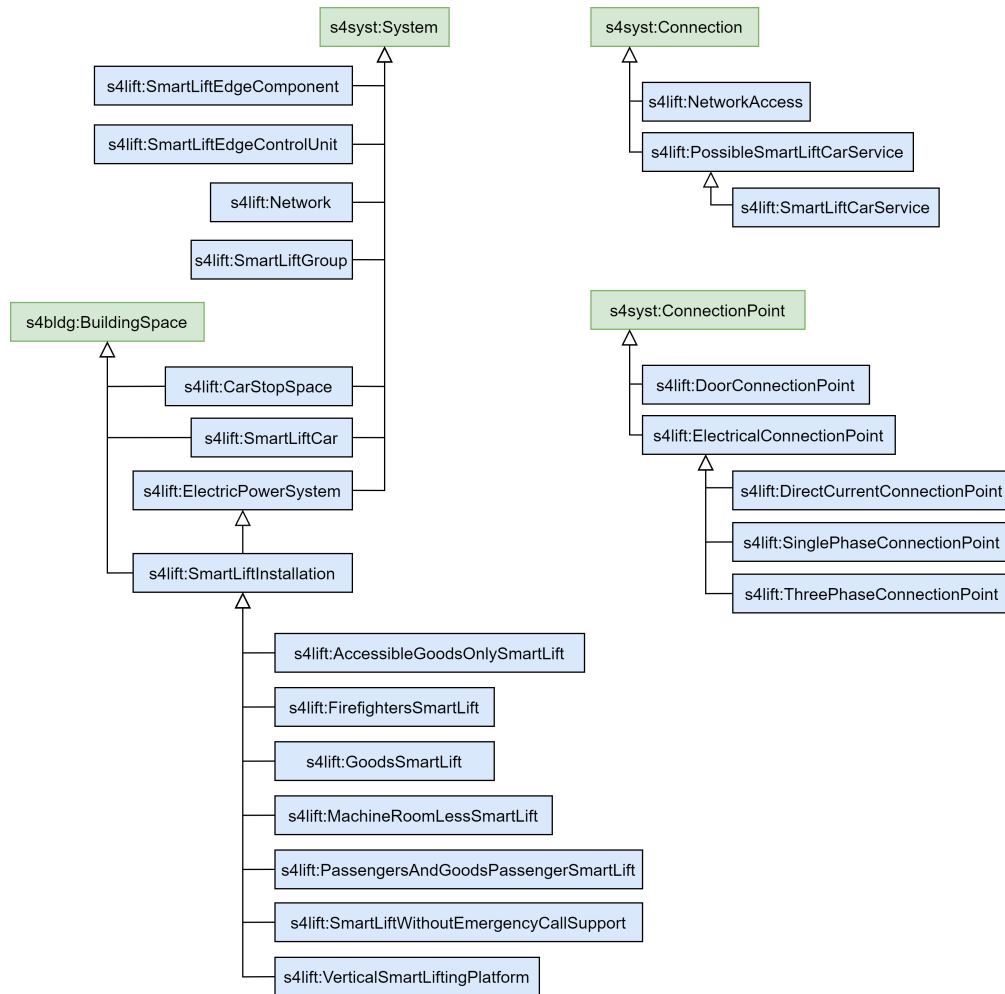[2]https://saref.etsi.org/saref4lift/v1.1.1/example/TS103735_Clause_6_5_SLConfiguration.ttl

Figure 5: Overview of the SAREF4LIFT classes for systems and connections (Source: [13])

5. Conclusion

SAREF4SYST is the first SAREF Reference Ontology pattern. It has proven to be useful to model various types of system, connection through which these systems interact in some way, and the connection point at which these systems connect. More patterns for SAREF are currently being discussed in the context of STF 578 "SAREF Patterns", and should be described beside SAREF4SYST in a new version of ETSI TS 103 548.

Acknowledgments

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