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INTERNATIONAL STANDARD

Internet of Things (IoT) – Interoperability for IoT systems –
Part 3: Semantic interoperability

colour inside

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INTERNET OF THINGS (IoT) – INTEROPERABILITY FOR IoT SYSTEMS –

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FOREWORD

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The text of this International Standard is based on the following documents:

Draft	Report on voting
JTC1-SC41/233/FDIS	JTC1-SC41/244/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1, available at: www.iec.ch/members_experts/refdocs and www.iso.org/directives.

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INTRODUCTION

The use of the Internet of Things (IoT) is increasing every year, in application areas such as manufacturing, healthcare, and new cross-domain applications related to smart cities (e.g. water, energy, transport, or health). Most IoT systems want to share information, which can be done by interoperability. Mechanisms are therefore needed on how to exchange information and use associated data and data description.

IoT interoperability is described as a successful interaction among entities specified in ISO/IEC 30141 [1] [1], for instance between IoT services provided by different IoT service providers. It can be achieved using the interoperability facet model defined in ISO/IEC 21823-1, which defines five facets: transport, syntactic, semantic, behavioural and policy interoperability.

IoT semantic interoperability is the facet which enables the exchange of data between IoT systems using understood data information models (or semantic meanings). According to a recently published white paper [2]:

> "Semantic interoperability is achieved when interacting systems attribute the same meaning to an exchanged piece of data, ensuring consistency of the data across systems regardless of individual data format. This consistency of meaning can be derived from pre-existing standards or agreements on the format and meaning of data or it can be derived in a dynamic way using shared vocabularies either in a schema form and/or in an ontology-driven approach."

As shown in Figure 1,

– semantic interoperability means that information in different data information models can be translated into understandable meaning and exchanged between applications;
– semantic interoperability provides the capability for applications to understand exchanged information;
– semantic interoperability for IoT is achieved by invoking services, and by using specific knowledge and concepts of IoT.

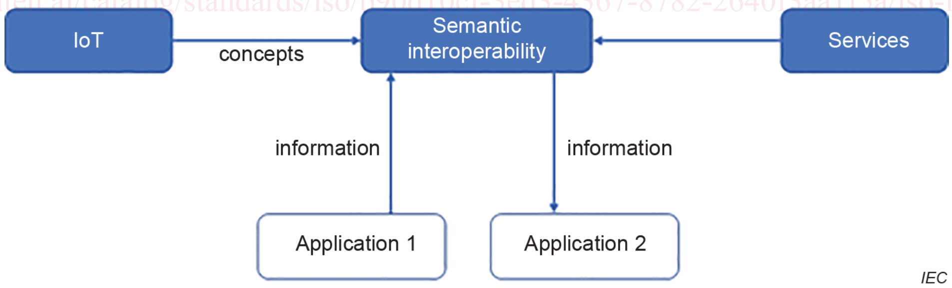

Figure 1 – Semantic interoperability facet for IoT

Semantic interoperability is achieved through the use of metadata, or descriptions of data. The approach of providing data and descriptions has been widely used in IT systems. Two examples are:

a) conceptual schemas have been used to describe database content;
b) record layouts have been used to display the content of a database record.

As shown in Figure 2, many services invoked by semantic interoperability involve metadata, thus enabling their discovery, understanding and (re)usability.

[1] Numbers in square brackets refer to the Bibliography.

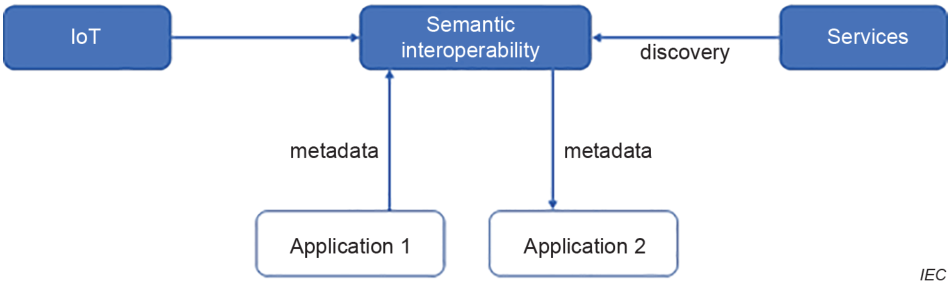

Figure 2 – Using metadata in semantic interoperability

Metadata provides IoT systems with a common understanding of exchanged data. Figure 3 shows how the meaning of data is defined by the metadata to a specific room temperature (left column) and how it is described with metadata (right column).

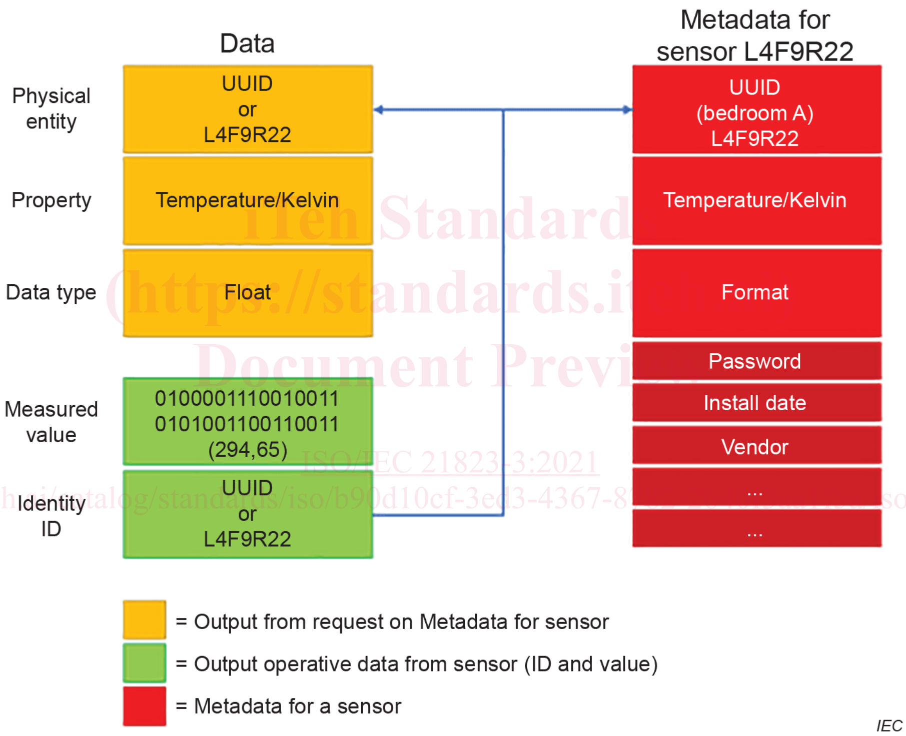

Figure 3 – Meaningfulness of the data, described with metadata

Knowledge that metadata represents can be described using ontologies. In other words, semantic interoperability needs shared, unambiguous, machine-understandable metadata, to be able to perform exchange of information using metadata. The application of semantics in IoT has still been limited because most metadata are developed independently, making it difficult for IoT entities or applications to interoperate semantically. In this document, an ontology-driven approach for semantic interoperability is specified to design and specify metadata, so that the sensors, devices, systems and services can express metadata information and data by applying the ontologies to achieve semantic interoperability. Stakeholders targeted by this document include ontology engineers and IoT system engineers who are building semantic interoperability capabilities for IoT systems.

This document also specifies methods and techniques to build semantic interoperability for IoT systems. Clause 5 focuses on the IoT semantic interoperability process. Clause 6 focuses on the IoT semantic interoperability life cycle management.

Informative annexes provide additional information and guidance. Annex A, Annex B and Annex C provide guidance on how to learn IoT semantic interoperability, develop IoT semantic interoperability, and manage IoT semantic interoperability life cycle, respectively. Annex D provides ontological specification of the IoT Reference Architecture specified in ISO/IEC 30141 [1]. Annex E provides related existing ontologies that are applicable for IoT semantic interoperability.

INTERNET OF THINGS (IoT) – INTEROPERABILITY FOR IoT SYSTEMS –

Part 3: Semantic interoperability

1 Scope

This document provides the basic concepts for IoT systems semantic interoperability, as described in the facet model of ISO/IEC 21823 -1, including:

– requirements of the core ontologies for semantic interoperability;
– best practices and guidance on how to use ontologies and to develop domain-specific applications, including the need to allow for extensibility and connection to external ontologies;
– cross-domain specification and formalization of ontologies to provide harmonized utilization of existing ontologies;
– relevant IoT ontologies along with comparative study of the characteristics and approaches in terms of modularity, extensibility, reusability, scalability, interoperability with upper ontologies, and so on;
– use cases and service scenarios that exhibit necessities and requirements of semantic interoperability.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 20924, *Internet of Things (IoT) – Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 20924 and the following apply. ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
semantic interoperability
interoperability so that the meaning of the data model within the context of a subject area is understood by the participating systems

[SOURCE: ISO/IEC 19941:2017, 3.1.5, modified – In the term, "data" has been deleted.]

3.2
metadata
data that defines and describes other data

[SOURCE: ISO/IEC 11179-3:2013, 3.2.74]

3.3
ontology
specification of concrete or abstract things, and the relationships among them, in a prescribed domain of knowledge

Note 1 to entry: The specification should be computer processable.

[SOURCE: ISO/IEC 19763-3:2020, 3.1.1.1]

4 Abbreviated terms

ICT information and communication technology

IoT Internet of Things

PKI public key infrastructure

5 IoT semantic interoperability process

5.1 Overview

IoT semantic interoperability enables the exchange of data between IoT systems using understood data information models (or semantic meanings). Such models are based on ontologies, which are processable specifications of concepts and relations concerning IoT systems. The benefit of IoT semantic interoperability is to contribute to meet interoperability, reusability, scalability or trustworthiness properties. IoT semantic interoperability has the following stakeholders and concerns:

a) ontology engineers, who focus on ontology development in a concern;

b) IoT system engineers, who focus on IoT system development and integration of semantic interoperability capabilities in a concern.

As shown in Figure 4, this document provides ontology engineers and IoT system engineers with requirements and specification of methods to prepare and build semantic interoperability.

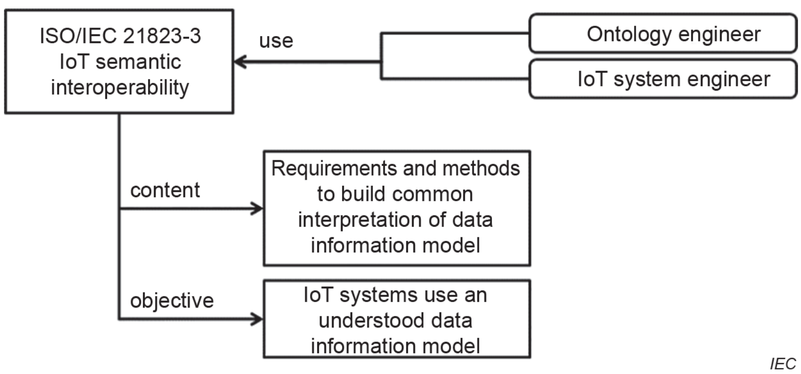

Figure 4 – Objective of semantic interoperability standard

Two types of requirements are identified:

1) IoT semantic interoperability requirements, which focus on how to create data information models, how to develop and integrate interpretation capability in IoT systems;

2) life cycle requirements, which focus on the management of data information model perimeters, of data information model design, and of data information model maintenance.

5.2 IoT semantic interoperability process requirements

The following processes shall be carried out by IoT system engineers and ontology engineers:

– data information model creation;

– semantic interoperability capability integration;

– semantic interoperability engineering support.

Table 1 provides for each process a list of requirements with a rationale and a resulting work product that can be used as evidence for conformance.

Table 1 – IoT semantic interoperability process requirements

Processes	Requirements	Rationale	Resulting work product
Data information model creation	Capture common knowledge using common ontologies	IoT systems rely on common architecture, capabilities and communication means, e.g. IoT sensors, actuators, gateways, devices.	Data information model based on the gathered and documented common knowledge on the IoT system
	Capture domain-specific knowledge using domain ontologies	IoT systems can focus on specific domains such as transport, energy, health.	Domain specific data information model on the IoT system
	Capture cross-domain knowledge using cross-domain ontologies	IoT systems can cover cross-domains. For instance, an electric-mobility IoT system belongs to the transport and the energy domain.	Cross-domain specific data information model on the IoT system
Semantic interoperability capability integration	Develop an IoT system capability to exchange information about IoT device interoperability	IoT systems can use various interoperability parameters including technical parameters (e.g. drivers, protocols) and semantic parameters (e.g. application capabilities). Exchange of such parameters can take place using metadata prior to device nominal operation. Metadata can be exposed in the form of schema or subschema or by OWL/XML or JSON-LD. The exchange can involve a proxy when an IoT device cannot provide the capability directly.	IoT system capability to exchange information on IoT device interoperability
	Develop an IoT system capability to negotiate interoperability profiles	IoT systems can use multiple knowledge representations. Agreement is needed on the representation to be used for information exchange. Negotiation is needed to agree on the level of semantic knowledge that is at stake, e.g. using representations of parameters and agreeing on interoperability profiles. The negotiation can involve a proxy when an IoT device cannot provide the capability directly.	IoT system capability to negotiate interoperability profiles
	Validate and integrate the various capabilities to enable IoT device interoperability	IoT systems integrate multiple technologies to enable interoperability (e.g. drivers, protocols, middleware) corresponding to different interoperability facets. They also integrate multiple operations (e.g. discovery, negotiation) to enable interoperability.	IoT device providing overall interoperability capability
Semantic interoperability engineering support	Provide and apply tools to achieve semantic interoperability	Engineers need supporting tools such as ontology discovery and selection, mapping, alignment, merging and integration.	Selection of tools to achieve semantic interoperability

5.3 IoT semantic interoperability models

IoT semantic interoperability can be described with two models: a process model and a usage model. The process model focuses on how semantic interoperability capability is created. The usage model focuses on how semantic information is used and exchanged.

Figure 5 provides the process model for IoT semantic interoperability. It is based on the assumption that interoperability knowledge is made available in processable forms such as the knowledge graph, constructed through ontologies. The entities in Figure 5 will be further described in 5.4.1.

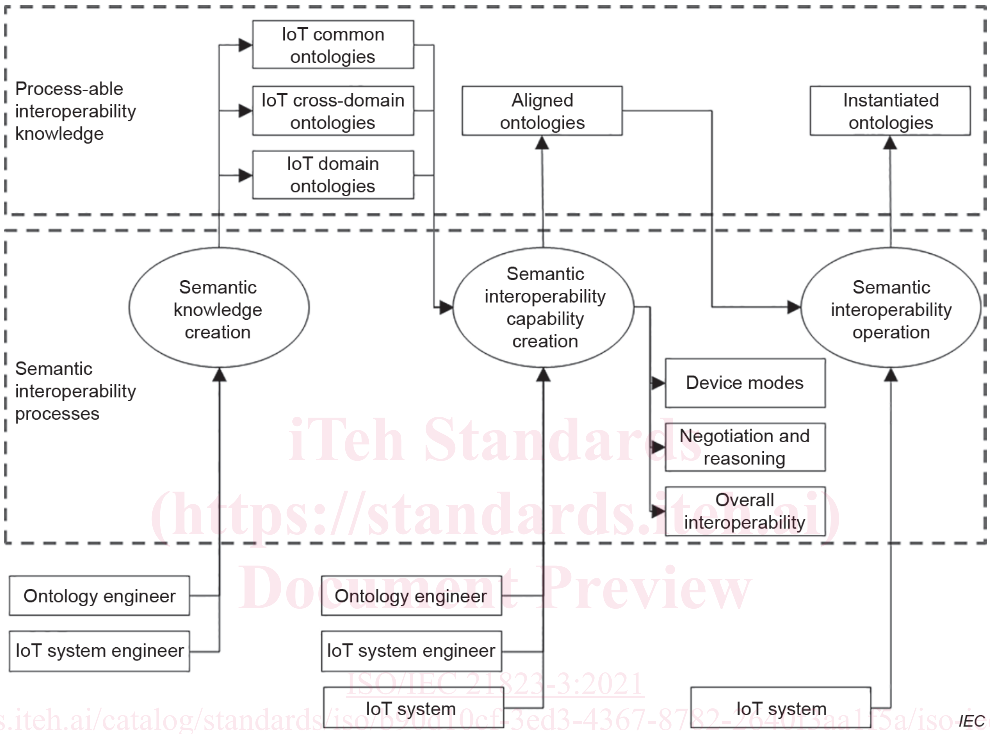

Figure 5 – IoT semantic interoperability process model

IoT semantic interoperability involves the following stakeholders:

– ontology engineers, who focus on ontology development;

– IoT system engineers, who focus on the development of IoT systems and the integration of interoperability capabilities.

IoT semantic interoperability includes the following processes.

a) Semantic knowledge creation: the purpose of this process is to create semantic information for interoperability. This process is carried out by ontology engineers and IoT system engineers. The input to this process is the knowledge of the engineers. The outcome of this process is a consistent digital representation of the semantic information used for interoperability, represented by ontologies, including IoT common ontologies, IoT cross-domain ontologies and IoT domain ontologies.

b) Semantic interoperability capability creation: the purpose of this process is to create semantic interoperability capabilities and to adapt semantic information to a desired semantic information representation. The capabilities are the following:

   1) device mode capability;

   2) negotiation and reasoning capability;

   3) overall interoperability.

This process is carried out by ontology engineers, IoT system engineers as well as the IoT system itself if it has semantic information adaptation processing capabilities. The input to this process is the IoT domain, IoT cross-domain and IoT common ontologies. The outcome of this process is aligned ontologies.

This process is assisted by ontology engineering support tools, as well as reasoning capabilities such as rule-based reasoning, ontology-based reasoning or machine learning.

c) Semantic interoperability use: the purpose of this process is to exchange semantic information with other IoT systems. This process is carried out by the IoT system. The input to this is the aligned ontologies. The outcome of this process is instantiated ontologies.

This process is assisted by ontology engineering support tools, as well as reasoning capabilities such as rule-based reasoning, ontology-based reasoning or machine learning.

The use of semantic information is based on the model shown in Figure 6.

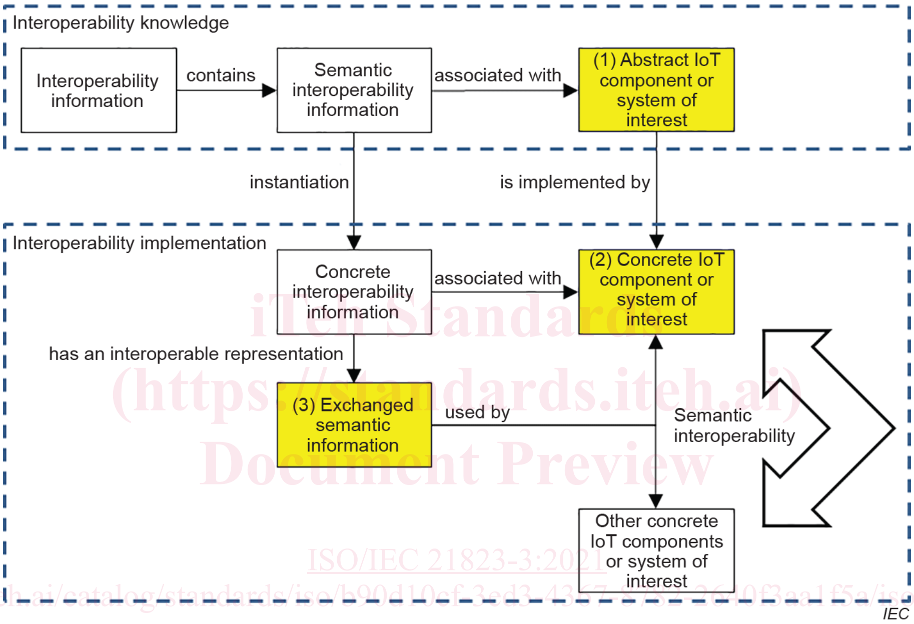

Figure 6 – Semantic information usage model

The semantic information usage model includes the following.

– An abstract model of an IoT component or system-of-interest: interoperability information contains semantic interoperability information which is associated with an abstract IoT component or system-of-interest in a domain. An example is a temperature model associated with an abstract IoT temperature sensor.

– A concrete model of the IoT component of system-of-interest: concrete interoperability information is associated with the concrete IoT component or system-of-interest in operation. An example is the instantiated temperature model associated with a physical temperature sensor.

– Exchanged semantic information: a computer processable representation of semantic information that can be used by other concrete IoT components of systems. An example is the interoperable representation of the temperature information provided by the physical temperature sensor.