On the Classification of Cyberphysical Smart Objects in the Internet of Things

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Abstract. The vision of the Internet of Things (IoT) based on Smart Objects (SOs) promotes an high-level architectural organization of the future IoT designed around the basic concept of SO. An SO is an autonomous, cyberphysical object augmented with sensing/actuation, processing, storing, and networking capabilities. An important issue in supporting future SO-based IoT systems is how to classify SOs. Classification of SOs is an important activity directly influencing the definition of effective SO discovery services and management systems. In particular, the discovery service is a fundamental middleware component of the IoT as it allows SOs and their users to dynamically discover distributed SOs and, specifically, the services, operations, and data that they provide. This paper aims at proposing a reference taxonomy for SOs that is highly functional for an SO discovery service, and, more generally, for an SO management system. The taxonomy is based on a metadata model that is able to describe all the cyberphysical characteristics (geophysical, functional, and non-functional) of an SO.

Keywords: Internet of Things, Smart Objects, Classification, Discovery, Management

1 Introduction

According to the "Thing-oriented" vision, the Internet of Things (IoT) refers to a world-wide network of interconnected heterogeneous objects (sensors, actuators, smart devices, smart objects, RFID, embedded computers, etc.) uniquely addressable, based on standard communication protocols [3]. In such an IoT, all things have their identities, physical attributes, and interfaces. They are seamlessly integrated into the information network such that they become active participants in business, information and social processes wherever and whenever needed and proper.

In this paper, we refer to the IoT as a loosely coupled, decentralized system of smart objects (SOs) [12][6]. In particular, an SO is an autonomous, cyberphysical object augmented with sensing/actuating, processing, storing, and networking capabilities.

The establishment of an SO-oriented IoT raises many technical issues involving low-level communication protocols, programming languages, system architecture, middleware (notably including discovery and matchmaking), management system, and development methodologies for SO-based (large-scale) applications.

Classification of SOs is an important building block enabling both discovery and management of SOs. In fact, SO classification allows to characterize an SO from several perspectives or aspects that are needed to identify and exploit it for different purposes. A few research efforts can be found in the literature about SO classification [17],[12],[11],[13], which is indeed still in its inception phase.

This paper proposes a taxonomy for SOs that is based on a metadata model able to describe all the characteristics (geophysical, functional, and non-functional) of cyberphysical SOs. This model is technology-neutral and can be implemented by using any data modeling language (e.g. XML, JSON, etc) and embedded into SO discovery middleware components or SO management systems.

The remainder of the paper is organized as follows. Section 2 overviews the background concepts related to SO-oriented IoT systems. Section 3 describes the currently available classification models for SOs. In Section 4, we describe our metadata model for SO classification. Finally, Section 5 concludes the paper, discusses on-going work and delineates some future research challenges.

2 Background

The transition from the current "Human-Oriented" Internet to the "Things-Oriented" Internet is already in place, and the dividing line between the real world and the virtual one is bound to weaken. The development of new enabling technologies, increasingly pervasive (like RFID, sensor networks, short range wireless communications, etc.), combined with the use of concepts and methodologies already well-established (inherent to distributed computing and the Artificial Intelligence) make the IoT as the most potentially disruptive technological revolution of the last 50 years [1]. Moreover, the IoT is considered to be the enabling element which will definitely integrate and worldwide connect Smart City, Smart Grid, Building Automation Systems, Body Sensors Networks, currently developed as "poor" intranet of smart things [18]. The long-term results of such a revolution are not entirely predictable, as happened to the Internet in the '60s: in fact, political, social, technological impacts cannot be precisely assessed. However, even in the short-term, forecasts say that in 2020 the number of personal smart devices will be 7 units pro capita and the linked industries are from multiple sources estimated around $1.9 trillion dollars [1,2]. Consequently, a wide range of researchers from industry and academia, as well as businesses and government agencies are proving to be interested in the IoT and hence in the SO technology. In the SO-based IoT (see Figure 1), SOs cooperate to dynamically compose and deliver evolved services to humans or to other objects. Thinking

[1] https://www.gartner.com/newsroom/id/2602817
[2] http://share.cisco.com/internet-of-things.html

about how to make objects smart and applications to exploit them is quite intuitive, while it is much more difficult to design an architecture that supports such a complex ecosystem. First, it is necessary to ensure ubiquitous connectivity to all kinds of devices, even the cheapest ones and those with smaller energy and computational requirements. For that purpose, a new Internet layer, which embodies application, transport, and network protocols for effectively supporting communication among SOs, should be introduced. Then, effective and autonomous management for both SOs and application services need to be defined, so that all IoT system components are uniquely identifiable and easy, but at the same time safely and in privacy, to be composed.

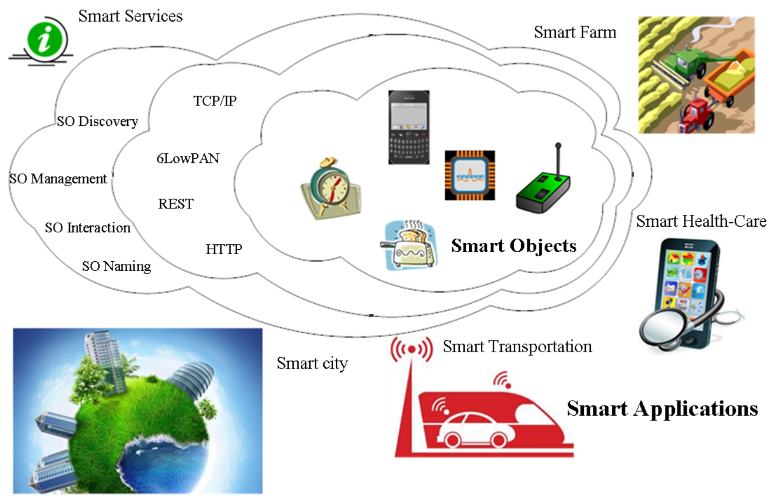

Fig. 1. A view of an SO-based IoT system and related smart applications.

The design of a set of fundamental mechanisms for SO naming, interoperability, discovery, interaction and orchestration, converging in a middleware layer, is probably the most urgent and even more challenging task. In fact, despite the Internet of today, the problem of scale in IoT will have much more stringent and critical dimension [15], and entirely new issues would result from the cyberphysical nature of SO [14]. On this basis, the traditional models of networks, in which the management functionality resides outside the network in dedicated management stations and servers, need to be abandoned, pushing cognitive and autonomic management abilities directly into SOs at design time. It is worth noting that, apart from future IoT management architectures, classification of SOs is another important task that involves the definition of a suitable SO metadata model on the basis of which SOs can be discovered and managed according to their cyberphysical characteristics.

3 Related Work

In [17], an SO classification accoding to the concepts of creator and purpose is defined. In particular, the creator can be either an individual creating SOs for a personal purpose (e.g. personal use) or an industrial company that creates SOs for business. The former SOs are called *self-made* whereas the latter ones are named *ready-made*. The purpose of an SO may be to play a role in a specific application/system or to be reused in a wide range of different applications. The former is defined *specific*, while the latter *open-ended*. However, such a classification only considers two dimensions (creator and purpose) that are not related to the cyberphysical characteristics of the SOs. Thus, such classification cannot be used in an operational way within an IoT system. In [12] authors classify SOs in *activity-aware* objects, *policy-aware* objects, and *process-aware* objects. Each SO type is characterized by the following design dimensions: (i) awareness, which is the ability of SOs to understand (environmental or human) events of the SO surrounding context; (ii) representation, which refers to the programming model of the SO; and (iii) interaction, which defines the communication with users. Such classification is oriented to the design of SOs within an application domain and can be usefully exploited during IoT systems development. However, such contribution is not operational as it can only be used to classify SOs according to design dimensions.

We are indeed interested in operational classifications that are the base to build up SO discovery services and management systems.

[11] presented an operational SO classification based on two documents: *smart object description document* (SODD) and *profile description document* (PDD). SODD contains the meta information of the SO: name, vendor, and list of profiles. PDD specifies a profile which can be either a detector or an actuator. A detector contains information about a specific sensing device according to the Sensor Modeling Language (SML), whereas an actuator is modelled through the Actuator Modeling Language (AML). The proposed classification is specific to the SO implementation and management supported by the FedNet middleware [11]. In [13] and [9], authors proposed a metadata model to represent functional and non functional characteristics of SOs in a structured way. The metadata model is divided into four main categories: *type*, *device*, *services*, and *location*. The type is the SO type (e.g. smart pen, smart table, etc). The device defines the hw/sw characteristics of the SO device. Services contains the list of services provided by the SO; in particular, a service can have one or more operations implementing it. The location represents the position of the SO. This metadata model is more general than the previous one and its implementation is currently available in a discovery framework (named SmartSearch) for SO indexing, discovery and dynamic selection [13],[9].

4 A Metadata Model for Classification of Cyberphysical Smart Objects

The proposed metadata model is an extension of the one proposed in [13],[9] and also borrows some concepts from the other models discussed in Section 3. The metadata model is portrayed in Figure 2 according to the UML class diagram formalism. In particular, the proposed model defines a set of metadata categories that can characterize an SO in any application domain of interest (e.g. Smart Cities, Smart Factories, Smart Home, Smart Grid, Smart Emergency, etc). The metadata represent the SOs static parameters, while the related dynamic parameters can be retrieved through operations associated to the available services.

Our metadata model is organized in the following eight main categories:

- **Identifier**: represents the identifier (or ID) of the SO, which allows its unique identification within the IoT or a IoT subsystem.
- **Creator**: represents the SO creator, which can be either an individual creating the SO for personal use, an industrial company that creates it for business, or an academic research lab implementing it for research purposes.
- **Physical Property**: represents all physical properties of the original object without any augmentation and smartness.
- **Type**: represents the primary type of SO (e.g. a smart pen, a smart chair, a smart office). Moreover, a secondary type can also be given that contains information about the SO design classification as proposed in [12].
- **Device**: defines the hardware and software characteristics of the device that allow to augment and make smart the object. Device can be specialized into one of the following three categories:
  - **Computer**: represents the features of the main processing unit of the SO (e.g. PC, embedded computer, plug computer, smartphone).
  - **Sensor**: models the characteristics of a sensor node belonging to the SO.
  - **Actuator**: models the characteristics of an actuator node of the SO.
- **Service**: represents a service provided by the SO. A service has a name, a description, the type (sensing, actuation, object state), the return (primitive or complex) type. It can also be associated with **QoS indicators**. Each service may contain a list of one or more different operations that implement the service.
  - **Operation**: defines the individual operation that may be invoked on a service. An operation is equipped with a set of parameters necessary for its invocation, and a description.
- **Location**: represents the geophysical position of the SO. It can be set in absolute terms, specifying the coordinates (latitude and longitude), and/or in relative terms through the use of location tags.
- **QoS Param**: defines a QoS parameter associated to the SO. Different QoS parameters may be defined such as trust, reliability, availability, etc.

The generation of a metadata description document for a simple SO can be done by the SO creator/manager who, knowing the SO in details, can describe its characteristics following the required formalism. Moreover, generation could be automatically accomplished by a module installed on the SO, usually called *information provider*, which can dynamically generate the metadata [13].

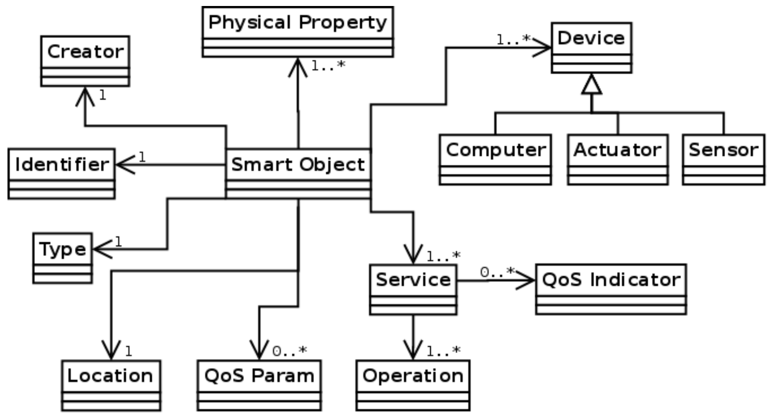

Fig. 2. Smart Object Metadata Model.

4.1 An Example of Metadata Representation

In Figure 3, the description of an SO (Smart Desk), based on the proposed metadata model implemented in the JSON format, is reported. The smart desk is able to detect the presence of its user and is equipped with a display that provides information to its user. The manually-generated JSON document has eight members associated with each of the eight categories of metadata previously described (Identifier, Creator, Physical Property, Type, Device, Service, Location, and QoS Param). In particular, the smart desk provides a sensing service to check whether or not a user is at the desk and an actuation service to send messages, targeting the desk user, onto the desk display. There is only one QoS Param defined which is the level of trust (in the range 0..1) of the smart desk.

5 Conclusions

In this paper we have proposed a novel metadata model for SO classification. The model is operational and can be embedded into discovery services for indexing, searching and selecting SOs and into SO management systems for SO querying. The model extends and enhances different SO classification metadata models currently available in the literature. On-going work is being devoted to implement the model into the ACOSO agent-oriented middleware for SO development [8],[10],[7]. Future research challenges will involve the definition of algorithms/methods for automatic multi-layer classification of SOs [5][2]. In fact, even though the proposed model is currently thought for operational purposes (strongly related to discovery services or management systems), text-based representations of SOs (e.g. JSON or XML-based) could be processed for obtaining higher-level classifications so as to create a cyberphysical digital library. This library could be used not only to access the SOs according to catalogs like it is commonly done with digital documents/objects of digital libraries [16][4], but also to support (i) the development process of SOs, specifically the design phase, and (ii) the analysis of SOs, i.e. all live and historical information produced and/or recorded by SOs, through ad-hoc defined GUIs.

6 Acknowledgements

Authors wish to thank Paolo Trunfio and Marco Lackovic for the definition and implementation of the previous version of the smart objects metadata model. This work has been partially supported by DICET INMOTO Organization of Cultural Heritage for Smart Tourism and REal Time Accessibility (OR.C.HE.S.T.R.A.) project funded by the Italian Government (PON04a2 D).

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```
 {
  "identifier":{ "id": "desk1"},
  "creator":{ "name": "Sensyscal Lab"},
  "physical_properties": [ {"dimension": "120x80x90"} ],
  "type": {
    "primaryType": "desk",
    "secondaryType": "activity-aware"
  },
  "devices": [
    { "computer" :{ "type": "PC"},
    { "sensor" :{ "type": "presence"},
    { "actuator" :{ "type": "monitor"}
  ],
  "services": [{
      "id": "isUserAtDesk",
      "name": "isUserAtDesk",
      "type": "sensing",
      "return-type": "boolean",
      "description": "TRUE: user is at desk; FALSE: user is not at desk",
      "operations": [{
          "id": "isUserAtDesk1",
          "description": "one shot request to retrieve the user's presence at desk"
      }]},
     {
      "id": "setDisplay",
      "name": "setDisplay",
      "type": "actuation",
      "param": "message",
      "return-type": "none",
      "description": "The message param is output on the Display",
      "operations":[ {
          "id": "setDisplay1",
          "param": "information message",
          "description": "visualize information message on the display"
       }]}
  ],
  "location": {
    "latitude":  "3921'47.16''N",
    "longitude":  "1613'32.58''E",
    "place": "University of Calabria",
    "building": "Cube 41C",
    "floor": "3",
    "room": "Sensyscal Lab",
  },
  "QoS_params": [ {"trust": "0.95"}]
}
```

Fig. 3. JSON representation of a smart desk according to the SO metadata model.