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A comprehensive semantic model for smart object description and request resolution in the internet of things

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Abstract

The Internet of Things is a natural continuity of the Ambient Intelligence where smart and ambient environments are built by integrating a large number of interconnected smart objects with heterogeneous capabilities abstracted as software services. The aim is to design cross-domain applications that compose and select most relevant services, which best match user requirements and closely meet the specified quality-of-service level. However, semantic description and representation of such smart devices, including their hosted services and their provided real world data, is still a challenging issue. Semantic Web technologies are seen as a promising tool for this purpose. Indeed, applying these technologies in the Internet of Things enables smart objects to efficiently share their data, exchange their services and cooperate to better satisfy both functional and non-functional user requirements. In this paper, we propose a new semantic model for smart objects description and users request resolution using ontological techniques combined with description logics. Such a model facilitates intelligent functions, including reasoning over service data and semantic interoperability enabling among devices. A case study for smart environment monitoring has been proposed to illustrate the effectiveness and usability of our approach.

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Keywords: *Internet of Things; Ambient Intelligence; Smart Environments; Semantic Model; Service and Device Description; Description Logics; Semantic Web Technologies; Ontology; QoS Evaluation; Request Description, Request Resolution.*

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1. Introduction

The convergence of the Ambient Intelligence (AmI) and the Internet of Things (IoT)[1,2,3] envisions a world where varieties of objects (i.e. things), with sensing and actuation capabilities, are connected to the Internet and can be joined, all the time and everywhere, through small portable devices like Smartphones. These objects can individually provide services or cooperate to provide value-added services that none of them could provide alone. The overall challenge; however, is how to achieve interoperability among such heterogeneous objects and how to represent effectively their provided IoT data. In other words, how to abstract IoT devices' resources as software services, independently from the application domain, considering the interplay between those devices and the physical world. This includes both the state of the devices themselves and their relationships with the main entities of our surroundings (e.g. persons, places and appliances). Semantic Web technologies are a promising initiative to overcome these issues. The Semantic Web community has been working on approaches to make the Web machine-readable[4] and IoT data meanings more comprehensive using reasoning techniques. This facilitates automatic service composition and selection as well as advanced tasks involving smart devices such as device management[5], query processing[6], and application-level services[7].

Various research works have been proposed in recent years to improve interoperability between heterogeneous IoT devices using semantic web technologies[8-18]. In reference[9], a novel framework for the Semantic Web of Things based on a backward-compatible extension of the Constrained Application Protocol (CoAP) is proposed. In reference[10], instead of using a predefined vocabulary to tag devices in the Haystack framework, an ontology design pattern is proposed. In reference[11], a semantic description of IoT devices, based on the RESTdesc format[12], is proposed to deal with automatic and self-configurable service composition in highly dynamic and resource-constrained environments using CoAP. The proposed approach extends the work presented in reference[13] to manage the physical states of IoT devices and their provided services. In reference[14], Sensor Markup Language (SenML)[15] and Resource Description Framework (RDF) are adopted to represent devices' parameters. In reference[16], a semantic approach is proposed for robots interaction with humans, agents and systems using natural language. In reference[17], an ontology-based framework is proposed to discover, search, use and share information and services of residential environment devices. In reference[18], a description ontology is proposed for the IoT domain by integrating and extending existing work with some concepts such as: IoT service modeling, Quality of Services (QoS), Quality of Information (QoI), and IoT service test.

The works discussed above show that some semantic models have been proposed and used to represent, reason and manipulate IoT devices. Nevertheless, current solutions only allow simplistic data-oriented representation of IoT devices without representing the whole smart environment. It is not clearly explained how the proposed models can link between the different entities of the physical world and the virtual services provided by IoT devices. In other words, it is not clearly answered to which entities IoT devices are attached; which entities they might control; in which space are they located; and which services (context, event and/or action) they might provide? Full semantic device/service representation models should answer such questions. Moreover, user requirements should be involved in such models and a similarity degree between user requests and the available devices/services should also be provided.

To overcome the aforementioned shortcomings of existing work, we propose in this paper, a new semantic model that supports both IoT devices and user request descriptions. The present work is in the continuity of previous works conducted in our laboratory [19,20,21]. It focuses on interoperability at the data and knowledge level of IoT devices. On the one hand, IoT devices description comprises a description of the physical device itself along with its hosted services. On the other hand, user request description includes functional and non-functional requirements. By combining several domain ontologies with description logics, compatible with widely used semantic models, the proposed approach promotes reuse and support more efficient inference in the IoT. The rest of this paper is organized as follows. Section II presents the proposed semantic model describing IoT devices. This is followed by an explanation of the user request description and resolution approach in Section III. Section IV describes the Living Lab and the use-case scenario for user assistance in an Ambient-Assisted Living (AAL) environment. Finally, Section V gives conclusions and ideas for future work.