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A Semantic-aware Framework for Service Definition and Discovery in the Internet of Things Using CoAP

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Abstract

The future of machine-to-machine (M2M) communications relies on reusability, scalability, and interoperability of services. Internet of Things (IoT) aims to provide an environment where smart devices can easily expose their services, while providing accurate service discovery functionality for clients to consume them. Semantic-first approaches and service annotation techniques have already been studied in the service definition context and most of them leverage WSDL or RESTFul services. However, IoT environments, due to their heterogeneous nature and often constrained resources, demand a more flexible and scalable approach. In this paper, semantic annotation of services is supported through ontologies defined for API definition languages such as Swagger and RAML. We leverage the CoAP protocol and linked-data serialization format (JSON-LD) to represent services, entities, and properties in a semantic-aware framework. This enables intelligent discovery of services. A case study on reducing energy consumption in data centers is used to demonstrate the effectiveness of our proposed framework.

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Keywords: Internet of things; service discovery; linked data; semantics; CoAP protocol

1. Introduction

The term Internet of Things (IoT), first introduced by Ashton in 1999[1], envisions the idea of interconnecting smart devices and physical objects, referred to as Things, to the worldwide Internet network, while exposing their features and services to authorized entities in a secure manner. This context-awareness can make our surrounding objects smart and allow them to share their status or react to external stimuli. Being context-aware and able to understand and exchange domain-specific information are fundamental requirements of successful cross-domain applications[2,3,4].

The surge in data generated by devices, humans, autonomous software systems, and many other resources has introduced serious challenges in terms of data acquisition, storage, and knowledge extraction. This is exacerbated

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when dealing with inter-disciplinary domains. The IoT which promises to enhance interoperability and connectivity among the vast network of smart devices and their controlling authorities can add to the aforementioned data deluge problem due to their proliferation. Since heterogeneity is one of the core characteristics of IoT, services need to be decoupled and self-informative.

Service-oriented architectures (SOA) and methodologies have been widely adopted and studied in distributed systems, well before the emergence of IoT. However, due to huge number of entities and large diverse service pool in IoT, the trend has shifted towards using more lightweight services. Traditional SOAP-based services have been gradually replaced by RESTful services and APIs are now the new players in this field. APIs are easier to define, invoke, share, and monitor compared to other service definition methods. Enterprises can commercialize their APIs more effectively, since more tools and documentation is available for end-user consumers. Generally, IoT environments span across multiple domains and to make interoperability between different domains functional, one beneficial approach is using semantic technologies. To achieve this goal, we need to combine the power of semantic-aware service discovery with modern and standard service definition methods that take into account the special requirements of IoT such as limited and scattered resources. In this paper, we propose a system that facilitates service definition by leveraging API definition languages and implements an efficient discovery component by semantically tagging services. The approach utilises both CoAP and HTTP requests for service discovery and semantics storage.

Sharing service domain knowledge by leveraging semantic technologies is a common approach for implementing semantic interoperability across various domains. Accordingly, an integrated service infrastructure and discovery framework that includes the required components for storing, indexing, and querying shared semantic data can be a good candid solution. However, current solutions merely support minimal representation of resources and provide basic discovery of resources and properties based on text matching. In many cases, considerable human effort is required to design, deploy, and link modern IoT and Semantic Web of Things (SWoT) applications. The framework developed in this paper overcomes many of these issues.

The rest of the paper is organized as follows: Section II provides a literature review of relevant works and terminologies. Discussions of Web of Things and how it can be implemented using RESTFul services, Linked Data and the CoAP protocol are present in Section III. Section IV contains our proposed system architecture along with details of its major components. Section V presents the case study and is followed by the conclusion and future works section.

2. Related Work

Software typically consists of different components and each component consumes and exposes a small number of well-defined services. When services are well documented and defined, system integration can be much easier and consequently, application and user interactions with the system become smoother and more transparent. The effect and importance of services has been the causing factor behind emergence and evolution of Service Oriented Architectures (SoA) alongside service definition languages such as WSDL for SOAP and recently, Web APIs for documenting RESTful services.

IoT is based on communication of sensors and machines, hence a vast body of literature can be found on approaches that aim to make the sensory layer smart and context-aware and benefit from the Semantic Web. SSN-XG developed by World Wide Web Consortium (W3C) and OntoSensor[5] are two prominent reference ontologies for data annotation in Semantic Sensor Networks (SSN). In [6], the authors propose an application that is capable of extracting and measuring functional, non-functional, and other properties of sensors. They show how the OWL-defined ontologies for these properties and other available services can form a composition system to meet diverse user demands. Linked Open Data (LOD) is another solution considered in various researches [7,8]. LoD provides guidelines for merging and linking newly created semantic data with existing ontologies. Gramegna et al.[9] propose a SSN-based framework that implements a backwards compatible CoAP extension to discover and match not only semantic-enriched sensors, but also annotated events.

Generally, there are two approaches for semantically annotating and representing services. The first approach—known as semantic first—emphasizes the separation of semantic service representation from the underlying technical description (for example WSDL for SOAP or API description documents for REST). OWL-S[10] and WSMO[11] follow this methodology and include a grounding procedure that links semantic and technical discriptions. On the other hand, WSDL-S[12] and other similar approaches embed semantic annotations into technical descriptions directly. In