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ABSTRACT

Recently, IoT adoption has increased in several domains. IoT devices are multi-modal and heterogeneous due to their varied properties, standards, and manufactures. This leads to interoperability issues, which can be solved using semantic technologies. Likewise, these devices participate in numerous cross-organizational business processes (BPs). Being resource-constrained, they must be managed in an energy-aware manner to avoid BP failures. However, due to lack of a common ontology and formalization of energy-related concepts impedes their optimal management in BPs. To bridge this gap, the authors capitalize on existing semantic models such as FIESTA-IoT and IoT-BPO. They propose the following: (i) formalization of IoT concepts in BPs related to energy, their properties and constraints, and (ii) resolving resource conflicts based on strategies. The feasibility of this framework is illustrated by evaluating the semantic model for its coverage of concepts from IoT-A reference model, along with proof of concept tools that allows ontology-based support for process modeling.

KEYWORDS


INTRODUCTION

The Internet of Things (IoT) revolution was kick started with the use of radio-frequency identification (RFID) Tags, Sensors and Sensor network in supply chain management (SCM) to track physical objects (Ashton, 2009). However, the recent improvement in hardware technology has contributed to the real momentum for the adoption of IoT. This is because these devices have become better and more affordable for mass production and usage (Ruppen, 2013). In general, an IoT device interacts with the physical world and provides information about it via a standard service. In fact, IoT is considered as one of the key technology enablers for fostering the vision of a “smart ecosystem” such as smart cities, smart logistics, and smart factories, i.e., Industry 4.0 (Suri, Cuccuru, et al., 2017). However, these IoT devices are multi-modal and heterogeneous in nature due to their specific properties and characteristics such as energy capacity, sensitivity or computation power (Atzori, 2010). This leads to interoperability issues, increased complexity, and creates a bottleneck for their application in various domains. These concerns can be tackled by using semantic technologies (Thoma, 2014). Moreover,
several research initiatives have been aiming towards fostering the IoT domain, such as the EU FP7 project, The Internet of Things Architecture (IoT-A) (Bauer, 2013). In IoT-A, researchers defined the IoT domain model, identified its main concepts, and the inter-relationships between them (De, 2017). Likewise, the EU H2020 project, Federated Interoperable Semantic IoT Testbeds and Applications (FIESTA-IoT2), contributed towards solving interoperability issues in IoT domain (Agarwal, 2016). In addition, these heterogeneous IoT devices must be orchestrated in a specific sequence to create a defined value for an end user (or system). Thus, it is natural to see the IoT devices participating in several cross-organizational business processes (BPs), which orchestrates them along with other resources, i.e., human and non-human (e.g., enterprise services) to achieve a specific business goal.

Business Process Management (BPM) is a classic example of a Process-Aware Information System (PAIS) (Dumas, 2005), which manages and executes operational processes involving resources based on some pre-defined process model. These BP models comprise of activities, their execution order along with certain perspectives (behavioral or organizational). With the growing significance for efficient resource management, PAIS are evolving into Process-and Resource-Aware Information System (PRAIS) (Cabanillas, 2016). From a BP viewpoint, these IoT devices act as non-human resources with specific complexity (based on features and behavior), participating in cross-organizational environment. For instance, a process monitoring a perishable item (such as a Chinese Orchid), measures a “physical quantity” (such as temperature) via a specific activity (or task) that is associated with a temperature sensor. This sensor interacts with the physical world and provides the information via a software (native service) on the sensor device to the activity executing in the process (Meyer, 2011). Nevertheless, a single process may involve multiple sensors measuring different physical quantities and having different characteristics such as energy capacity or sensitivity levels, thus increasing the overall complexity for optimal resource management. In order to leverage these IoT devices, a PAIS must become an IoT-aware PRAIS by including IoT-related concepts in the process models (at design-time). This is because the concepts such as energy cost are highly significant for managing battery-operated devices. Nonetheless, even with a growing interest towards integration of IoT concepts in BPM, there is lack for tackling the complexity of IoT domain by taking into account the energy related concepts.

In this paper, we address this research gap by proposing a semantic framework that defines the concepts and relationships between IoT and BPM domain by including essential features such as “Access Costs” (AC) (energy related) and “Quality of Information” (QoI) (Martinho, 2014). Our work capitalizes on the IoT-BPO3 semantic model (Suri, Gaaloul, et al., 2017), which is an initial work to integrate the IoT concepts with BPM domain. However, being quite simple, IoT-BPO did not consider any energy related concepts, and lacked various features making it inadequate to be used for modeling and/or accessing information from distinct heterogeneous devices. Thus, we propose a novel comprehensive cross-domain ontology called “Internet of Things in Business Processes Ontology” (ThingsPrO) following the best practices4 for ontology development. The details about this ontology can be found online at our university webpage5.

Following the best practices, ThingsPrO re-uses existing concepts and relation from IoT-BPO and the FIESTA-IoT ontology. Being a comprehensive cross-domain ontology, FIESTA-IoT includes various concepts related to energy properties, which are needed to formalize the access cost (AC) estimations (i.e., energy and other costs) along with QoI. Concretely, our framework fosters optimal IoT resource management in BPs by: (1) formalizing energy related concepts in IoT along with their relation with BPs (objective-1), (2) providing strategies for resolving resource-based conflicts (objective-2), and (3) populating an ontology-based knowledge base containing information about the processes and the heterogeneous IoT resources. This knowledge base helps to unify the representation of both, the IoT resources and process models. Being machine-readable, it supports inferring and discovering new relationships and possible inconsistencies (objective-3). In addition, ThingsPrO also supports inclusion of information specific to Service Level Agreement (SLA) and Quality of Service (QoS) of the processes and its relationship with energy-related concepts in IoT. Furthermore, with
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