



Introduction to the Special Issue on Multiagent Systems and Services in the Internet of Things

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Over the past two decades, the **Internet of Things (IoT)** has evolved from silos built around custom protocol stacks into a system of systems built around standards—and the recent standardization of the **Web of Things (WoT)** at the IETF and the W3C further facilitates application-layer interoperability in the IoT. Constrained Web servers now target devices with as little as 10 KiB of RAM and 100 KiB of ROM, which means sensors and actuators can be abstracted behind embedded Web services. Going further, the WoT aims to provide uniform access to IoT devices through the Web—by hiding the protocols and interfaces used to access the devices behind abstract interaction patterns and hypermedia controls. From the edge of the network to the cloud, the Web is now emerging as a uniform hypermedia fabric that interconnects IoT devices and digital services.

Still, many research questions remain open. IoT systems are not only inherently complex and heterogeneous, but also highly dynamic as the availability of devices (and their services) changes continually. Moreover, the IoT is inherently decentralized because it is not under the control of a single entity. In such settings, traditional engineering paradigms become impractical. Researchers and practitioners in the IoT community therefore require means to build sophisticated software agents that can achieve their design objectives through flexible interaction with other entities in their system. Many of the underlying research questions the IoT community is now confronted with—such as how to balance goal-directed and reactive behavior in software agents, or how to design and govern interactions in a decentralized IoT—have been investigated in the scientific literature on multiagent systems. At the same time, the IoT unlocks new practical use cases for multiagent systems.

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This special issue presents research focused on the engineering of IoT systems that draws from several areas, including multiagent systems, Web services, and the Semantic Web. The contributions of selected articles range from conceptual work to applied research. We provide a brief overview of the articles in this issue in what follows.

In “[Resilient Distributed Constraint Reasoning to Autonomously Configure and Adapt IoT Environments](#)”, Pierre Rust, Gauthier Picard, and Fano Ramparany address the problem of configuring environments populated with IoT devices: In such environments, multiple devices might act on the same parameters (e.g., light, heating, or humidity levels) and thus a coordination mechanism is needed. The authors formulate this problem as a **Distributed Constraint Optimization Problem (DCOP)**, a topic in research on multiagent systems, and introduce an integrated stack of DCOP mechanisms for creating self-configuring, adaptive, and resilient IoT environments. The paper supports the approach with experimental results in simulated smart home environments and presents a prototypical deployment over a network of Raspberry Pi devices.

In “[Web of Digital Twins](#)”, Alessandro Ricci, Angelo Croatti, Stefano Mariani, Sara Montagna, and Marco Picone introduce an abstract model and architecture for an open, distributed, and dynamic ecosystem of digital twins. Digital twins are counterparts of physical assets meant to represent their state, functionality, history, to predict their evolution, or to augment them with new features. Here digital twins are represented through knowledge graphs that can be interconnected into one world-wide, distributed knowledge graph in order to create a Web of Digital Twins. The paper focuses on modeling complex realities of interrelated physical assets that may belong to different domains and different organizations. The use of knowledge graphs aims to provide intelligent agents with a proper knowledge-level abstraction for perceiving and reasoning about complex physical realities. The paper presents two case studies in healthcare (major trauma management) and smart mobility.

In “[Towards Semantic Management of On-Device Applications in Industrial IoT](#)”, Haoyu Ren, Darko Anicic, and Thomas Runkler present an approach for managing software artifacts across IoT devices by extending the W3C WoT Thing Description¹ with semantic models of software artifacts. The aim is to facilitate the discovery of devices and software artifacts, the matching of software requirements to hardware capabilities, and the orchestration of software artifacts across devices. The paper focuses on two specific types of software artifacts, neural network models and complex event processing rules, both of which can be flashed to devices. To demonstrate the feasibility of the approach, the paper reports on a prototype implementation for an industrial workstation consisting of a conveyor belt and several IoT devices.

In “[A Reputation-based Framework for Honest Provenance Reporting](#)”, Lina Barakat, Philip Taylor, Nathan Griffiths, and Simon Miles propose to use reputation models to incentivize service providers to reveal truthful information about the circumstances underlying their services. Circumstance information is particularly useful for assessing IoT services. The proposed framework extends existing reputation models to incorporate the availability and reliability of circumstances data into the reputation assessment process. Assessor agents can then act on behalf of clients to rank and select service providers according to their circumstance-influenced reputation. Provider agents act on behalf of service providers to maximize their perceived reputation by adjusting their policies for circumstances provisioning. The paper reports on experimental results that support the effectiveness of the framework in an attack-free environment and its robustness against several attack types being considered.

¹Sebastien Kaebisch et al. (eds.), Web of Things (WoT) Thing Description, W3C Recommendation 9 April 2020: <https://www.w3.org/TR/wot-thing-description/>.

In “[Governance of Autonomous Agents on the Web: Challenges and Opportunities](#)”, Timotheus Kampik, Adnane Mansour, Olivier Boissier, Sabrina Kirrane, Julian Padget, Terry Payne, Munindar P. Singh, Valentina Tamma, and Antoine Zimmermann introduce a conceptual framework for the governance of socio-technical multiagent systems on the Web. The conceptual framework is contextualized to the W3C Web of Things Architecture² and is supported by a synthesis of related research on norms, policies, and preferences across the multiagent systems and Semantic Web communities. The paper motivates the need for joint research across these communities through a structured set of challenges and discusses the practical maturity of these challenges.

We hope the selected articles will help transfer ideas, knowledge, and results across the research communities targeted by this special issue. We wish you a pleasant reading!

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²Matthias Kovatsch et al. (eds.), Web of Things (WoT) Architecture, W3C Recommendation 9 April 2020: <https://www.w3.org/TR/wot-architecture/>.