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Editorial

Engineering future interoperable and open IoT systems

The term Internet of Things (IoT) refers to a loosely-coupled, decentralized and dynamic system in which billions (even trillions) of everyday objects are endowed with smartness, in order to increase their own capabilities, seamlessly communicate and cooperate despite their physical/functional heterogeneities, becoming so active participants in business, logistics, information and social processes. IoT, however, cannot be completely enclosed by a single definition, because there are at least two different visions referring to the same scenario but putting the emphasis on, respectively, the concept of "smart objects as building block" for the IoT (Kortuem et al., 2010; Fortino and Trunfio, 2014) and the aspects of "anywhere, anytime and anything connection" (Atzori et al., 2010).

In recent years, due to a great interest of both Industry and Academy in researching and developing IoT technology, many solutions at different levels have been implemented (from the IoT device-level to full-fledged IoT platforms such as OpenIoT, FIWare, Butler, iCore). Not having yet a unique architectural reference standard for IoT systems (different proposals indeed exist, such as IoT-A, AIOTI, IEEE P2430, ETSI M2M) and not foreseeing to have one in the near future, future IoT scenarios will be characterized by a high-degree of heterogeneity at any level (device, networking, middleware, application service, data and semantics), preventing IoT solutions to interoperate. Lack of interoperability causes major technological and business-oriented issues such as impossibility to plug non-interoperable IoT devices into heterogeneous IoT platforms, impossibility to develop IoT applications exploiting multiple platforms in homogeneous and/or cross domains, slowness of IoT technology introduction at large-scale, discouragement in adopting IoT technology, increase of costs, scarce reusability of technical solutions, user dissatisfaction. However, apart from interoperability and openness (e.g. the H2020 INTER-IoT project http://www.inter-iot.eu specifically aims to address such issues (Fortino et al., 2014)), other major issues exist in the IoT engineering area (Kubler et al., 2016) from several points of view: techniques and frameworks for the management of IoT networks, middleware specifically defined for programming and managing IoT systems and applications, methods for semantically defining IoT systems in terms of specific ontologies and models, and software engineering methodologies and tools for supporting IoT systems development.

This special issue has been conceived to address some of the aforementioned issues. After a thorough review phase, we selected five articles (out of 18 submitted) that address several research challenges related to engineering (open) IoT systems and related applications. These include: framework for the management of IoT networks, mobile gateways for interoperability of heterogeneous IoT devices, open middlewares for programming IoT systems, and semantics methods for IoT systems and applications.

The paper "*plexi: Adaptive Re-scheduling Web Service of Time Synchronized Low-power Wireless Networks*" (Exarchakos et al., 2017) authored by G. Exarchakos, I. Oztelcan, D. Sarakiotis, and A. Liotta, focuses on a network management framework for managing IoT networks. At low-power industrial IoT (IIoT) where dependability is the key requirement, pinpointing communication bottlenecks and reconfiguring the complete network entails costs that explode with scale. While IEEE802.15.4e-2012 TSCH networks are gradually making their way to real world use cases as the solution to reliable connectivity in low-power lossy networks, their monitoring and (re)configuration according to the needs of the industrial application and environment remain a challenge. *plexi* is the first network management entity (NME) that monitors and reschedules time slotted channel hopping networks. An interface between the nodes and NME is defined and implemented for both sides. Through experimentation on a special purpose scheduler, plexi proves to closely follow network topology changes and to reconfigure the network as needed.

In the paper entitled "*Enabling IoT Interoperability Through Opportunistic Smartphone-based Mobile Gateways*" (Aloi et al., 2017) by G. Aloi, G. Caliciuri, G. Fortino, R. Gravina, P. Pace, W. Russo, and C. Savaglio, authors discuss about interoperability issues in the IoT arena that increasingly represent significant challenges to be addressed in the near future. The presented solution explores the potentials of off-the-shelf smartphones to work as mobile gateways, also providing a flexible and transparent interface between different IoT devices and the Internet. Moreover, the implemented software architecture is able to support novel and attractive functionalities, such as the opportunistic IoT devices discovery, management and control coupled with data collection, processing and diffusion. The work is also supported by a detailed testbed, based on different smartphones, to validate the feasibility of the proposed solution. The validation considered reference parameters, such as memory and CPU usage, and also the limitations of the solution in terms of energy consumption due to simultaneously active radio interfaces that reduce the smartphone lifetime.

The paper on "*Making System of Systems Interoperable – the Core Components of the Arrowhead Framework*" (Varga et al., 2017) by P. Varga, F. Blomstedt, L. Lino Ferreira, J. Eliasson, M. Johansson, J. Delsing, I. Martinez de Soria, proposes the Arrowhead Framework for systems of systems (SoS) programming in the IoT context. In particular, interconnected, cooperative SoS start to evolve nowadays, although there is still a lack of efficient support on how

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to design, develop, deploy and operate them. The Arrowhead Framework, based on a Service-Oriented Architecture, actually aims to provide such a kind of a support, while presenting not only guideline principles, but practical tools, as well. The Arrowhead architectural setup is split into three levels: SoS, Systems and Services. The definition and descriptive documentation of these elements actually support proper understanding between various development groups. This way it helps to ensure the interoperability among different systems. Furthermore, the proposed framework defines a basic set of core systems (Service Registry, Authorization and Orchestration) that are mandatory for all Arrowhead-compliant installations. Finally, the compliance of a system to the Arrowhead Framework must also be proven in order to ensure its full compatibility, which is supported by specific test tools. In order to prove its suitability at various ranges of applications, the Arrowhead Framework is currently being used in over 20 different installations, covering the domains of home and industrial automation, production, virtual markets of energy and electrical vehicles infrastructures.

The paper entitled "*Enabling Synergy in IoT: Platform to Service and Beyond*" (Andersen et al., 2017) by M. P. Andersen, G. Fierro, D. E. Culler, presents techniques for IoT systems engineering at micro (device-level) and macro (composition of devices to provide services) scales. While IoT is a hot topic at the moment, with new technologies appearing on mainstream media weekly, very little attention is paid to the architecture of the supporting infrastructure that must exist for IoT devices to function *en-masse* in society. This paper begins with hardware considerations for long-term IoT engineering such as mixed-mode communication for both device-to-device and device-to-human communication. In the firmware space, it proposes an abstraction of asynchronous complexity to decrease power consumption and common failure modes. Beyond the device, issues at two different scales (local and wide-area) are considered. Here the dominant problem is sustainable assembly of individual devices into composite services that remain adaptable but secure, even as devices and their environments change over time.

In the paper "*Semantic Interoperability in the Internet of Things: An Overview From the Inter-IoT Perspective*" (Ganzha et al., 2017) by M. Ganzha, M. Paprzycki, W. Pawłowski, P. Szmeja, and K. Wasielewska, authors systematically analyse semantic interoperability in the IoT domain. Lack of interoperability is one of the key issues that slow down the uptake of the IoT. Here, big companies try to outmanoeuvre each other to become the "number one" to whom everyone else will have to adjust. At the same time, SME's are focused on selling their products and do not have time/resources to make their products interoperable with others. Solutions that can bring cooperation to IoT ecosystems can be built on different layers of the software stack. Content of this paper deals with data and semantics interoperability. However, the first step in any research is to establish the state-of-the-art in any discipline. In this sense, the authors investigate what ontologies can be used as a foundation for semantic interoperability solutions. Specifically, the article summarizes the state-of-the-art in (i) IoT ontologies, and ontologies of (ii) (e/m)Health and (iii) transportation and logistics. Furthermore, it outlines initial ideas concerning potential approaches to semantic interoperability.

We hope that the five papers included in this special issue will provide valuable knowledge for those researchers and practitioners working in the area of IoT systems engineering and related application domains.

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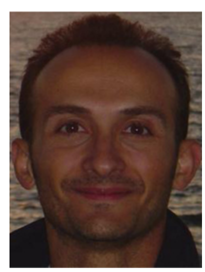

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