The Internet of Things: connecting the world

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1 Internet of Things

In the last few years, we have seen an increased interest in The Internet of Things (IoT). IoT is a network of Internet-enabled objects in a world where physical objects are seamlessly integrated into the information network and where the physical objects can become active participants in business processes. The Internet of Things [1] brings together two key concepts: Internet-connected devices everywhere in any time and any place and ubiquitous computing, where “*the most profound technologies are those that disappear*” [2] in such a way that these devices made themselves indistinguishable from explicit technology that the humans use in their lives. IoT aims at increasing the ubiquity of the Internet by integrating every object for interaction via embedded systems and leads to the highly distributed network of devices communicating with human beings as well as other devices. These objects can communicate with humans and enable people to monitor and control them through intelligent services in anytime and anywhere, taking into account security and privacy issues.

Benefits from IoT will allow improving the services as perceived by the users, for example saving energy, enhancing comfort, getting better healthcare, and increased independence. On the other hand, IoT raises new technical and ethical challenges. The European Research Cluster on the Internet of Things has identified the trendiest

application areas in the Internet of Things (IoT), in the document “The Internet of Things 2012—New Horizons” and grouped them in different domains [3]: applications development facilities; autonomic and self-aware IoT; IoT infrastructure as a service; IoT-aware open networks and location; large-scale IoT process deployment; data management and security; device-level energy issues; standardization; and societal, economic, and legal issues.

2 Special issue contents

This special issue of Personal and Ubiquitous Computing journal contains papers selected from a set of invited papers extracted from the papers presented at The 10th IEEE International Symposium on Parallel and Distributed Processing with Applications (ISPA 2012) [4], held in Madrid, Spain, July 10–13, 2012. ISPA 2012 accepted 32 papers out of 98 full paper submissions covering both foundational and practical issues in parallel and distributed programming and systems. Eight selected papers were invited to submit extended versions to this special issue, but only 3 were selected for publication after going through the PUC peer review process.

The objective of ISPA 2012 is to provide a forum for scientists and engineers in academia and industry to exchange and discuss their experiences, new ideas, research results, and applications about all aspects of parallel and distributed computing and networking. It featured session presentations, workshops, tutorials and keynote speeches. ISPA-12 is sponsored by IEEE Technical Committee on Scalable Computing (TCSC) and IEEE Computer Society. Past ISPA symposiums were successfully held in the following countries: ISPA-03 (Aizu, Japan), ISPA-04 (Hong Kong), ISPA-05 (Nanjing, China), ISPA-

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06 (Sorrento, Italy), ISPA-07 (Niagara Falls, Canada), ISPA-08 (Sydney, Australia), ISPA-09 (Chengdu, China), ISPA-10 (Taipei, Taiwan), and ISPA-11 (Busan, Korea).

In this issue, international researches address three of those challenges: energy efficiency and autonomy, open networks and location independent human-readable identification, and device-independent application development facilities.

Escolar and her colleagues study a major problem in wireless sensor networks: energy management. They propose techniques to manage energy in solar cells-powered wireless sensor networks, in order to provide quality of service. Sensor nodes equipped with solar cells and rechargeable batteries are useful in many outdoor, long-lasting applications. In these sensors nodes, the cycles of energy harvesting and battery recharge need to be managed appropriately in order to avoid sensor node unavailability due to energy shortages. In order to achieve this goal, they suggest sensor nodes to be programmed with alternate scheduling plans, each corresponding to a given energy requirement and meeting a given quality level. Thus, sensor nodes can select the scheduling plan that best suits the expected energy production and the residual battery charge, in order to avoid sensor nodes unavailability. They also propose an algorithm for the selection of the scheduling plan aiming to keep the overall energy consumption neutral, so that sensor nodes' activities can be sustained uninterruptedly.

Mongay and Krawiec propose a novel architecture of the ID (Identifier) layer for Internet of Things, which is embedded in the network level instead of traditional overlay solutions. Their contribution characterizes development of human-readable, hierarchical ID-based unified addressing for both objects and services, corresponding to their locations. In this way, users gain easier access to the IoT resources and native support for multi-cast. Furthermore, they take advantage of the Networking Named Content approach to specify rules for ID-based data transfer. The network nodes have capabilities to cache forwarded data for handling future requests, which may decrease network overload and facilitate cooperation between applications and sensors which periodically move into sleep mode for saving energy. ID-based routing offers decoupling of identification of objects/services from their location. Awareness of forwarded IoT data together with hierarchical distribution of the network makes feasible the local management of users and objects, that is, the essential IoT processes such as object/service registration, publication, searching, and resolution, can be managed locally in the network node. This offers high flexibility and manageability and improves response of the system when the number of handled things scales. The paper presents the architecture of the proposed solution for ID layer focusing

on modules and mechanisms of the ID network node, as well as detailed description of registration, resolution, and forwarding processes. Furthermore, the implementation of the system, performed on Linux-based routers, was tested to confirm the correctness of ID layer processes. The tests show that the performance of ID network node is not worse than the performance of a classical IP Linux router running on an identical physical device.

Finally, Chmielewski's paper presents the concept of *Device-Independent Architecture* which provides separation of applications from devices and facilitates development of device-independent applications. Additionally, the separation introduced by the Device-Independent Architecture enables implementation of multi-device scenarios where a single application employs multiple devices at the same time. The final goal of this work is to cope with the part of the Internet of Things composed of devices that directly interact with users, who have grown considerably in the past years. With new smartphones, tablets, and other Internet-enabled devices that appear on the market, this trend is still increasing. However, existing application development processes and tools, designed for single device applications, do not allow developers to fully and efficiently address this opportunity. Applications are developed for a particular type of devices or a particular programming platform. This limits the number of potential users and makes it difficult to seamlessly use an application on multiple devices owned by users. To take full advantage of the Internet of Things, applications should be able to run on any device—they should be ubiquitous. The experiment described in the paper proves that such device-independent applications indeed may be used on any suitable device—they have a chance to become ubiquitous.

The former studies propose solutions for challenges identified in the IoT world and will contribute toward a multi-level, multi-platform, and more energy-aware IoT architecture. However, the research field is widely open, and future research is needed to provide answers to other remaining challenges such as data processing and storage, self-adaptation, resilience, cloud computing and IoT convergence, and many other topics.

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