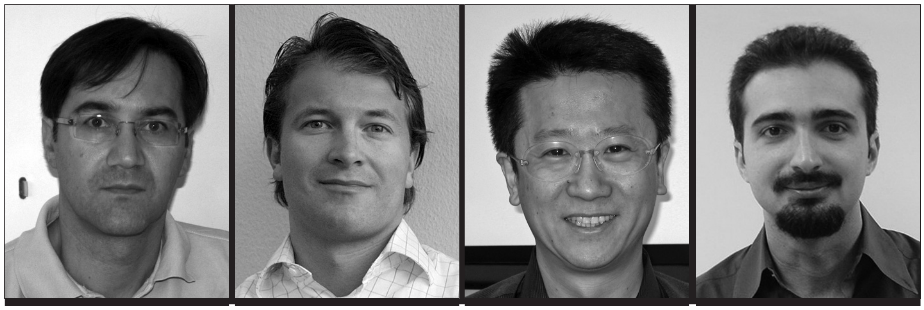
GUEST EDITORIAL

THE INTERNET OF THINGS



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In the last few years, a stimulating idea is fast emerging in the wireless scenario: the pervasive presence around us of a variety of "things" or "objects" such as devices, sensors, actuators, and mobile phones, which, through unique addressing schemes, are able to interact with each other and cooperate with their neighboring "smart" components to reach common goals. This novel paradigm, named the "Internet of Things" (IoT), continues on the path set by the concept of the smart environment and paves the way to the deployment of numerous applications with a significant impact on many fields of future everyday life.

Its importance has been recognized worldwide: the U.S. National Intelligence Council lists the IoT among the six technologies that may impact U.S. national power by 2025; the European Commission is financing several research projects on the subject within the VII Framework Programme; and in Asia increasing research efforts are being devoted to the definition of technologies for the IoT. China announced in January 2010 that they are promoting the Internet of Things by naming Wuxi City the National Innovation Demonstration Zone of IoT.

The IoT paradigm's feasibility stems from the maturity level reached by several key technologies. From a wireless communication perspective, the IoT paradigm is strongly related to the effective integration of wireless sensor networks (WSNs) and radio frequency identification (RFID) systems.

WSN technologies are now at the stage that there is a standard (IEEE 802.15.4), which is universally recognized, and RFID-based systems have proven their value in logistic applications. What is currently being developed are solutions, such as 6LoWPAN, ROLL, and the EPCglobal network, to fully integrate these technologies into the overall Internet.

While RFID systems are (mostly) passive nodes that react to solicitations by an RFID reader, enablement of the IoT also requires WSN nodes to be self-reliant for energy. Nowadays, this is possible thanks to the energy harvesting technologies that are becoming ever more efficient in obtaining energy from the surrounding environment.

Finally, cooperation between elements of the IoT to provide added value services is possible thanks to application layer solutions derived from web technologies such as SOAP, XML, and REST, all leveraging HTTP, being modified to fit into low-capability IoT nodes. Needless to say, IPv6 is an important transport infrastructure to connect myriad things.

From what we have said so far, it is evident that the IoT's future is bright, although its full deployment must overcome several compelling constraints. The IoT will be composed of a tremendously huge number of nodes; this poses serious scalability requirements on any solution proposed for the IoT. Furthermore, nodes may profoundly differ from one another; therefore, any proposed approach must effectively deal with heterogeneity. Regardless of such heterogeneity, it looks obvious that one characteristic will be common to most elements of the IoT: they will have scarce or very scarce energy capabilities. This makes energy efficiency the main constraint in the design process. Moreover, given that all such nodes will collect information about the environment surrounding individuals and, directly or indirectly, about individuals themselves, security and privacy issues must definitely be taken into account. Finally, proposed solutions must be open and enable interactions with systems based on different technical solutions.

Manifold challenging research issues derive from the cited constraints. Maybe the definition of a universally recognized reference architecture is the most relevant. This will enable the necessary transition from already existing "intranets" of Things to the novel "Internet" of Things. Effective candidate solutions should be as loose as possible to easily integrate existing solutions, while providing simple interfaces enabling the development of services and applications that involve elements of different systems.

Mobility management is a further research issue that deserves in-depth investigation. In fact, things will move, and the system should be able to locate them whenever needed. Here the major difficulties are related to the number of mobile nodes in the IoT, which has an impact on scalability.

Another research area to be addressed regards the characterization of the traffic that will traverse the IoT. In fact, such traffic will have completely different features from the traffic traversing the Internet today. This is because most of it will be generated and directed to machines that communicate in a different way from humans. Also, their expectations are different, which poses new problems related to quality of service (QoS) support, which thus should be revisited in its fundamentals.

Differences in traffic characteristics, along with the energy constraints and the specific features of the IoT communication environment, will be the stimulus for research activities on the study, modeling, and design of protocols at both the network and transport layers of the protocol stack.

Finally, great research effort is required to address the problem of supporting security and privacy in the IoT. This is a difficult task given that most nodes in the IoT will have scarce capacities in terms of both energy and processing capabilities. We observe that as long as there are no trustworthy and well recognized solutions to security and privacy support, people will resist the deployment on a large scale of such a pervasive technology as the IoT is supposed to become.

In this Special Issue we collect contributions that investigate viable approaches to the solution of some of the highlighted research problems.

The first article, "Pervasive Electromagnetics: Sensing Paradigms by Passive RFID Technology" by G. Marrocco, investigates the current trend in integrating sensing and passive RFID technologies into the same node. Approaches are described to enable passive communications and sensing of several environmental parameters. This research issue is in line with successful research projects such as the Wireless Identification and Sensing Platform (WISP).

Passive RFID reacts to queries by a tag reader that powers tags. This approach does not allow nodes to communicate with each other and independently start a communication. To solve this problem while maintaining energy self-reliance, energy harvesting can be applied. The possibilities offered by current energy harvesting solutions and the resulting communication constraints are presented in the second article, "Energy-Harvesting Active Networked Tags (EnHANTs) for Ubiquitous Object Networking" by M. Gorlatova, P. Kinget, I. Kymissis, D. Rubenstein, X. Wang, and G. Zussaman.

In order to run IoT applications, nodes need to be aware of their neighbors. This requires appropriate energy efficient yet rapid solutions. In "Toward Proximity-Aware Internetworking" M. Scott Corson, R. Laroia, J. Li, V. Park, T. Richardson, and G. Tsirtsis present Aura-net, a mobile communication system realizing proximity-aware networking. The system is based on a wireless technology called FlashLinkQ that allows energy-efficient discovery of neighbor nodes.

A complete solution for the integration of WSNs in the IoT is presented in "SNAIL: An IP-Based Wireless Sensor Network Approach to the Internet of Things" by S. Hong, D. Kim, M. Ha, S. Bae, S. J. Park, W. Jung, and J.-E. Kim. In this article the focus is mostly on mobility support, web enablement, time synchronization, and security. SNAIL has been implemented and deployed in both IPv4 and IPv6 testbeds running over the Korea Advanced Research Network.

A more architectural view is provided in "From Today's INTRAnet of Things to a Future INTERnet of Things: A Wireless- and Mobile-Related view" by M. Zorzi, A. Gluhak, S. Lange, and A. Bassi. Here the most compelling research issues to be addressed in order to enable the above passage are presented and then a solution is proposed putting emphasis on the architectural choices and node mobility support.

The subsequent article, "Embedded Web Services" by Z. Shelby, focuses on the application layer. More specifically, it describes the key technologies and then analyzes how such technologies should be modified to fit the features characterizing the IoT communication scenario. Indeed, it is clear that web service technologies, which will be most likely considered for IoT applications, were not designed to work in extremely resource constrained environments such as the IoT.

Our special issue concludes with a jump into the future. Miniaturizing technology will soon enable the commercial production of nano-scale machines that will be embedded in most objects and even implanted in human body. Such machines will need to communicate, which takes us to the concept of "The Internet of Nano-Things." This is the title of the last article of our special issue in which I. F. Akyildiz and J. M. Jornet present a survey on the enabling technologies, possible solutions, and numerous research challenges related to the integration of nano-machines in a worldwide network of interconnected nano-devices.

BIOGRAPHIES

ANTONIO IERA [SM'07] (antonio.iera@unirc.it) graduated in computer engineering from the University of Calabria, Italy, in 1991, and received a Master diploma in information technology from CEFRIEL/Politecnico di Milano, Italy, in 1992 and a Ph.D. degree from the University of Calabria in 1996. From 1994 to 1995 he was with the Mobile Network Division Research Center, Siemens AG, Germany, and since 1997 he has been with the University Mediterranea of Reggio Calabria, Italy, where currently he is a full professor of telecommunications and director of the Laboratory for Advanced Research into Telecommunication Systems (www.arts.unirc.it). His research interests include broadband and heterogeneous wireless networks, personal communication systems, RFID, and the Internet of Things.

CHRISTIAN FLOERKEMEIER received his Bachelor's and M.Eng. degrees in electrical and information science from Cambridge University, United Kingdom, in 1999 and his Ph.D. from ETH Zurich, Switzerland, in computer science in 2006. He has been involved in the RFID standardization effort of the Auto-ID Center and EPCglobal since he joined the Auto-ID Center in 2001. He is currently associate director of the Auto-ID Laboratory at the Massachusetts Institute of Technology, Cambridge. Before joining the Auto-ID Lab at MIT, he was associate director of the Swiss Auto-ID Lab at ETH Zurich. From 1999 until 2001 he worked as head of software development for Ubiworks, an Amsterdam-based software company. He is the co-founder of the open source RFID project Fosstrak, maintains the LLRP Toolkit Java library, and has published numerous papers on radio frequency identification and pervasive computing.

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