Towards the Internet of Relevant Things

The IEEE 802.15.4 Standard

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1. Duration

Half-day Tutorial (3 hours)

2. Abstract (max 300 words)

The Internet of Things (IoT) will completely change the way we live and work. In near future, billions of smart objects will be connected to the Internet, paving the way for a large number of innovative services in different application domains including smart cities, smart buildings, factory automation, e-health, etc. In many of such domains, applications have stringent requirements in terms of communication reliability, timeliness, scalability, and energy efficiency. To address the needs of such critical applications, the IEEE has recently released the 802.15.4e amendment that extends the original 802.15.4-2006 standard. By combining time slotted access with multi-channel communication and frequency hopping, the new 802.15.4e MAC protocols can provide highly-reliable, time-bounded, and low-power communication. Also, they can easily support multi-hop mesh networks.

This tutorial will present the opportunities offered by the new standard in the perspective of the Internet of Things. Specifically, it will start with a description of the IEEE 802.15.4 standard to highlight the main reasons that limit its adoption in critical application scenarios. Then, the improvements introduced by 802.15.4e will be discussed, with focus on the main 802.15.4e MAC protocols (i.e., TSCH, DSME). For each considered MAC protocol, a description of its specific features will be provided and potential application domains will be identified. The tutorial will also include a survey of the main research activities on 802.15.4e networks. Special attention will be devoted to issues arising from the integration of 802.15.4e MAC protocols within the IoT framework.

3. Target Audience and Motivation

This tutorial is intended for researcher and practitioners willing to receive an introduction to the new IEEE 802.15.4e standard and/or a state-of-the-art analysis about the research activities on IEEE 802.15.4e networks.

The tutorial will emphasize the opportunities offered by the new standard for critical applications, in the perspective of the Internet of Things. The integration of the new standard within the IoT framework poses a number of challenges and is still an open issue. Recently, the IETF (Internet Engineering Task Force) has started the 6TiSCH initiative to investigate possible solutions.

The topic is very timely and there are a number of open research issues that could stimulate the interests of the participants. The tutorial will emphasize possible future research directions in this field.

4. Tutorial Description

In the future *Internet of Things* (IoT) a very large number of real-life objects will be connected to the Internet generating and consuming information. IoT elements (also called smart objects) will no longer be only computers and personal communication devices but all kinds of devices (e.g., cars, robots, machine tools), living beings (e.g., persons, animals, and plants) and things (e.g., garments, food, drugs, etc.). The Internet of Things paves the way for a tremendous number of innovative services in different domains including smart cities, smart buildings, factory automation, e-health, etc.

Energy efficiency is typically the main concern in many application domains since smart objects are typically powered by batteries with a limited energy budget and their replacement can be very expensive or, even, impossible. However, *reliability* and *timeliness* are very critical issues in a number of application domains (e.g., for industrial and healthcare applications). Finally, *scalability* is extremely important when the application involves a very large number of smart objects (e.g., in smart cities, smart buildings, etc).

The IEEE 802.15.4 standard is currently the reference communication technology for low-power wireless sensor/actuator networks and is expected to be a major enabling technology for the Internet of Things. However, many studies have highlighted that the 802.15.4 MAC protocol suffers from a number of limitations (such as unbounded delay, no protection against interference and fading, limited communication reliability, need for powered relay nodes) that prevent its adoption in many IoT domains. In order to overcome these limitations, in 2008 the IEEE set up a Working Group (named 802.15.4e WG) to enhance and add functionalities to the 802.15.4 MAC, so as to address the emerging needs of critical applications. The final result was the release of the 802.15.4e MAC amendment in 2012.

The main goal of this tutorial is to present the opportunities offered by the new standard in the perspective of the Internet of Things for critical applications. Open research issues, related with this technology, will be emphasized and possible future research directions will be presented.

The tutorial will first discuss the main limitations of the 802.15.4 standard. Then, it will present the most relevant improvements introduced by the new 802.15.4e standard to address the requirements of critical applications. The focus will be on 802.15.4e MAC protocols, namely, *Time Slotted Channel Hopping* (TSCH), *Deterministic and Synchronous Multi-channel Extension* (DSME) and *Low Latency Deterministic Networks* (LLDN).

For each considered MAC protocol, a description of its specific features will be provided and potential application domains will be identified. The tutorial will also include a survey of the main research activities on the above-mentioned MAC protocols. Special attention will be devoted to issues arising from the integration of 802.15.4e MAC protocols in the IoT framework. Combining a dynamic and flexible routing mechanism (e.g., RPL) with the 802.15.4e time-slotted access method introduces a number of problems that need to be solved. Recently, the IETF (Internet Engineering Task Force) has started the 6TiSCH initiative to investigate possible solutions.

A tentative time-schedule of the tutorial is as follows:

- Introduction (10 minutes)
- IEEE 802.15.4 MAC protocol and its main limitations (30 minutes)
- IEEE 802.15.4e: motivation and general description (10 minutes)
- LLDN MAC, literature review and open issues (10 minutes)
- DSME MAC, literature review and open issues (40 minutes)
- TSCH MAC, literature review and open issues (60 minutes)
- Integration of TSCH (and DSME) with IoT protocols (15 minutes)
- Summary of open issues and future research directions (5 minutes)

5. Expected Background of the Audience

Knowledge of basic computer networking concepts is assumed, whereas knowledge of 802.15.4 standard is considered a plus.

6. Instructor's Biography

Giuseppe Anastasi is Full Professor and Associate Head at the Department of Information Engineering (DII) of the University of Pisa, Italy. He is also the director of the *Smart Cities National Lab*, supported by CINI (Italian University Consortium for Informatics). Finally, he directs the executive Master in *Smart Cities*, a post-graduate specialization program organized by the University of Pisa in cooperation with the Institute for Informatics and Telematics (IIT) of the Italian National Research Council (CNR).

His scientific interests include *Distributed and P2P Systems*, *Internet of Things*, *Pervasive Computing*, *Sustainable Computing*, and *ICT for Smart Cities*. He is the founding co-director of the *Pervasive Computing & Networking Laboratory* (PerLab) at the University of Pisa, and has contributed to many research programs funded by both national and international institutions. He is a co-editor of two books: *Advanced Lectures in Networking* (LNCS 2497, Springer, 2002) and *Methodologies and Technologies for Networked Enterprises* (LNCS 7200, Springer, 2012). He has published about 130 research papers in the area of computer networking and pervasive computing, gathering more than 4500 citations according to Google Scholar (H-index=30).

Dr. Anastasi is Associate Editor of *Sustainable Computing (SUSCOM)* and Area Editor of *Pervasive and Mobile Computing* (*PMC*). He is currently serving as Program Co-chair of the *IEEE Mobile Ad Hoc and Senso Networks (MSN 2015)* and of the *IEEE International Conference on Smart Computing (SMARTCOMP 2016*). Previously, he has served as Area Editor of *Computer Communications* (ComCom, 2008-10), General Co-chair of *IEEE WoWMoM 2005*, Program Chair of *IFIP/IEEE SustainIT 2012*, IEEE PerCom 2010 and IEEE WoWMoM 2008, Vice Program Chair of IEEE MASS 2007. He has been the co-founder of a number of successful international workshops and conferences. Currently, he is a member of the Board of Directors of the Italian National University Consortium for Informatics (CINI). He has been a member of the IEEE Computer Society since 1994.

Dr. Anastasi received the M.Sc. degree in Electronics Engineering, and the Ph.D. degree in Computer Engineering, both from the University of Pisa, in 1990 and 1995, respectively. Additional Information available at: http://www.iet.unipi.it/~anastasi/.

7. Teaching Material

- A previous, shorter, version of this tutorial was given as invited talk at the Sun Yat-sen University, Guangzhou, China, May 16, 2014 (http://info.iet.unipi.it/~anastasi/talks/2014-Guangzhou.pdf)
- D. De Guglielmo, G. Anastasi, A Seghetti, "From IEEE 802.15.4 to IEEE 802.15.4e: a Step towards the Internet of Things**"**, Chapter 10 in *Advances onto the Internet of Things (*S. Gaglio, G. Lo Re, Editors), Series on Advances in Intelligent Systems and Computing, N. 260, January 2014. Springer (http://info.iet.unipi.it/~anastasi/papers/book-lo-re-10.pdf)