Supporting Real-Time Communication in Large-Scale Wireless Sensor Networks

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INTRODUCTION

Automation activities are essential for the competitiveness increase in all industrial sectors. According to Chen, German, & Dressler (2010), an increasing number of industrial applications are focusing on wireless networks as a core technology. Wireless technologies have also been identified as a very attractive option for industrial and factory automation, distributed control systems, automotive systems and other kinds of networked embedded systems (Willig, 2008).

Within this context, wireless sensor systems can revolutionize industrial processing and help industry meet the demands of increased competitiveness. Wireless sensor technology offers reliable, autonomous process control to improve product quality, increase yield and reduce costs. Thus, the use of Wireless Sensor Networks (WSN) in the industry is an attractive topic of research. Multiple research works have been addressing routing and energy-efficiency problems. However, little attention has been given to the support of real-time communication in large-scale WSNs.

The WSN literature proposes two work contexts: standards and routing protocols. In the standard context, one of the more frequently used wireless Sensor Network technologies is the IEEE 802.15.4 standard. The IEEE 802.15.4-2011 (IEEE Std 802.15.4-2011, 2011) is a standard designed for Low-Rate Wireless Personal Area Networks (LR-WPANs), which focus on short-range operation, low-data rate, energy-efficiency, and low-cost implementations. However, the standard has a number of limitations that hinder the construction of large-scale wireless sensor networks with temporal constraints. Thus, the IEEE 802.15.4e and 802.15.5 standards were released to enhance the real-time properties of the 802.15.4 MAC protocol (e.g. lower latency and higher robustness and determinism), and to increase the network scalability through the support of mesh topologies. The IEEE 802.15.4e standard (IEEE Std 802.15.4e-2012, 2012) introduces additional medium access control (MAC) mechanism and frame formats that allow devices to support a wide range of industrial and commercial applications. However, this standard also has a limitation set, as the lack of performance evaluation works in large-scale networks (Rodenas-Herraiz, Garcia-Sanchez, Garcia-Sanchez, & Garcia-Haro, 2013). The IEEE 802.15.5 standard (IEEE Std 802.15.5-2009, 2009) proposes a mesh topology through to implementation of a logical tree and mesh links, increasing the network scalability.

In the routing protocol context, the literature proposes several challenges and special considerations in the design of routing protocols for wireless sensor networks (Li, Zhang, Hao, & Li, 2011; Akkaya, & Younis, 2005; Liu, 2012; Radi, Dezfouli, Bakar, & Chung, 2012). Multiple research works have been addressing routing and energy-efficiency problems. However, little attention has been given to the support of real-time communication in large-scale WSNs.

This article discusses the state-of-the-art of standards and routing protocols for WSN, focusing on their adaptation to large-scale WSNs and on the impact that WSN topologies have upon their real-time properties. It first includes a background and discussion about the standards for WSN and their main features, involving the real-time and large-scale aspects. Then, within this

DOI: 10.4018/978-1-4666-5888-2.ch725

context, it is presents several research works about routing protocol in WSN. Finally, the article presents the conclusions and final considerations.

BACKGROUND

Wireless sensor networks are special *ad hoc* networks that can be used in several application areas, such as: home, health, and environmental monitoring, robotic, vehicle systems, and military applications. With the advent of new technologies in the context of wireless communication, digital microelectronics, it is possible to build wireless sensor devices increasingly robustness, with more storage, processing, and energy capabilities. Within this context, with these capabilities and reduction of device size and costs, it becomes possible the design of large-scale wireless sensor networks.

Over the years, several standards have been defined for wireless sensor networks. The IEEE 802.15.4 standard is one of the more commonly used wireless Sensor Network technologies. The IEEE 802.15.4-2011 standard defines the PHYsical layer (PHY) and Medium Access Control (MAC) sublayers specifications for Low-Rate Wireless Personal Area Network (LR-WPAN). A Low-Rate Wireless Personal Area Network (LR-WPAN) is a simple, low-cost communication network that allows wireless connectivity in applications with limited power and relaxed throughput requirements (IEEE Std 802.15.4-2011, 2011).

However, the IEEE 802.15.4 standard has a number of limitations that hinder the construction of large-scale wireless sensor networks with temporal constraints, such as: short-range communications with a small bandwidth, not adequately address critical requirements and determinism, only seven guaranteed time slots (GTS), single channel, and lack of multi-hop communications and mesh capability. Therefore, the IEEE 802.15.4e and IEEE 802.15.5 standards were released, in order to minimize the limitations of the IEEE 802.15.4 standard. On the one hand, the IEEE 802.15.4e standard implements a number of improvements, in order to support the industrial market requirements, such as: a new multi superframe structure, extension of the GTS slots and frequency channels (channel diversity). However, the standard also has a limitation set, for example, in large-scale deployments, topology changes can generate additional overhead due to re-scheduling of the beacon, which increases the energy consumption. Moreover, whether information cannot be dispatched in a unique superframe, it is necessary to wait the next multi superframe, which can generate delays. In addition, lack of performance evaluation works in large-scale networks (Rodenas-Herraiz et al., 2013).

On the other hand, the IEEE 802.15.5 standard proposes a mesh topology through to implementation of a logical tree and mesh links, increasing the network scalability. However, the main problems of the IEEE 802.15.5 standard are the lack of a complete performance evaluation (Rodenas-Herraiz et al., 2013), besides not provide end-to-end reliability and security (IEEE Std 802.15.5-2009, 2009).

Several relevant works were proposed in the literature, with different approaches. Different works have been address performance evaluation, solutions and reviews of the IEEE 802.15.4 standard (Koubaa, Cunha, & Alves, 2007; Hanzalek, & Jurcík, 2010; Ayoub, Ouni, & Kamoun, 2012; Chen, Talanis, German, & Dressler, 2009). Chen et al. (2010), Jeong, & Lee (2012), and Stanislowski, Vilajosana, Wang, Watteyne, & Pister (2013) have been presented solutions and performance evaluation of the IEEE 802.15.4e. Moreover, Lee et al. (2010), and Cho, Lee, o, Kwon, & Choi (2009) have been presented solutions and reviews of the IEEE 802.15.5 standard.

CHALLENGES OF REAL-TIME COMMUNICATION IN IEEE 802.15.X

Due to the inherent characteristics of sensor networks, which consists of a large number of sensor nodes deployed in a specific environment with the purpose of sensing different physical variables, it is very diversified the number of WSN-based applications. Thus, WSN becomes a research question very popular and attractive for scientific community, especially in industrial automation. In fact, there are several works in the literature for IEEE 802.15.4-based wireless sensor networks, addressing different issues. However, the most of these works focus on energy consumption and efficiency.

According to Chen et al. (2009), the real-time aspects are not a primary concern. Also, Teng, & Kim (2010) point out the energy problem as the main focus of the most work efforts in WSN and they highlight the