Chapter 7
Evaluating the Performance of the IEEE 802.15.4 Standard in Supporting Time-Critical Wireless Sensor Networks

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ABSTRACT

The performance of wireless sensor networks (WSNs) at monitoring time-critical events is an important research topic, mainly due to the need to ensure that the actions to be taken upon these events are timely. To determine the effectiveness of the IEEE 802.15.4 standard at monitoring time-critical events in WSNs, we introduce a routing scheme based on drain announcements that seeks minimum routing overhead. We carried out a novel performance evaluation of the IEEE 802.15.4 technology under different conditions, to determine whether or not near-real-time event monitoring is feasible. By analyzing different simulation metrics such as packet loss rate, average end-to-end delay, and routing overhead, we determine the degree of effectiveness of the IEEE 802.15.4 standard at supporting time-critical tasks in multi-hop WSNs, evidencing its limitations upon the size and the amount of traffic flowing through the network.

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INTRODUCTION

The IEEE 802.15.4 standard (IEEE 802 part 15.4, 2006) has gained great popularity in recent years in applications characterized by low-rate data transfers and strict power consumption requirements.

The ZigBee specification (ZigBee Alliance, 2008) builds upon the IEEE 802.15.4 standard, to provide the appropriate support for building monitoring applications in wireless sensor networks. In particular, it makes use of the physical (PHY) and medium access control (MAC) layers defined by the IEEE 802.15.4 standard, and defines the upper levels of the protocol stack - network and above - that the 802.15.4 standard does not cover, thus offering seamless communication with sensors, actuators and other small devices for measuring and controlling tasks that do not require high bandwidth, but require low power consumption and latency.

The MAC layer plays an important role in determining the efficiency of the bandwidth sharing in wireless channels and the energy cost of the communication (Gutiérrez, Callaway & Barrett, 2003). The IEEE 802.15.4 is a standard that defines the level of physical and medium access control for wireless personal area networks with low data rate transmissions (LR-WPAN). The 802.15.4 standard is intended for applications that require secure communication with low data transmission rate, while maximizing the battery lifetime. The current version was adopted in 2006.

Among the potential applications of the IEEE 802.15.4 technology we have time-critical event monitoring, in which the delivery time of recorded information is of utmost importance (e.g. fire, gas escape, and intruder detection). The main requirement imposed on WSNs when supporting time-critical event monitoring is that data must travel throughout the network within a short-time interval. Therefore, the worst-case delay becomes a critical issue, and it is determined by the environment and the configuration of the WSN in terms of network topology, number of nodes, and node density.

WSNs supporting time-critical event monitoring applications are characterized by stricter requirements compared to other applications. In the former, the sensor nodes must react immediately upon the detection of an event, sending the sensed data to the drain in the shortest possible time. Notice that the relevance of the data is directly related to the response time of the WSNs (e.g., when tracking an intruder). Thus, for an effective support of time-critical event monitoring, the time needed to transfer the data packets from the sensor nodes to the drain is of utmost importance. Since end-to-end delay depends on factors such as a) the technology used, b) the routing protocol, c) the mean and worst-case number of hops, and d) the load over the network; the combined effect of these factors must be analyzed to determine the viability of a solution at supporting different critical-event monitoring applications.

In this chapter, we provide a detailed performance analysis of the IEEE 802.15.4 standard when supporting time-critical applications over wireless sensor networks.

BACKGROUND ON PERFORMANCE OF WSN APPLICATIONS

In the literature, we can find a lot of work that addresses the behaviour and performance of WSN applications. Nevertheless, only a few researchers have addressed the evaluation of the performance of IEEE 802.15.4 standard in supporting time-critical event monitoring. Zheng and Lee (Zheng & Lee, 2006) conducted a study to obtain the performance of various features, such as beacon and non-beacon modes, network autoconfiguration, tree formation and association, coordinator relocation, and orphans nodes for WSNs based on the IEEE 802.15.4 standard. They had previously described some application scenarios to show the potential of 802.15.4, including an overview of