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Scheduling the Real-Time Transmission of Periodic Measurements in 802.15.4 Wireless Sensor Network

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Abstract

Wireless sensor networks (WSN) are a major technological innovation developed in recent years with many important applications, for example in Cyber-Physical Systems and Internet of Things environments. Although there are many proposals for handling real-time traffic in WSNs, most of them fall into best-effort mechanisms that do not provide real-time guarantees. At the MAC level, the IEEE 802.15.4 standard defines a reservation mechanism called Guaranteed Time Slots (GTS) that uses a first-come first-served service policy, which is not enough to ensure the real-time delivery of packets. In this work, we present a formal definition of the scheduling problem for a sensor network using a reservation mechanism (such as GTS) that provides guarantees for the real-time delivery of packets. We also present a heuristic approach for finding feasible schedules when possible or determining if the requirements of a set of sensors are not feasible.

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Keywords: *Wireless Sensor Network; Real-Time; GTS; IEEE 802.15.4; Scheduling algorithm.*

1. Introduction

Wireless sensor networks are becoming a widely-spread technology with applications in areas such as cyber-physical systems, internet of things, smart environments, smart grids, etc. Some of these applications are demanding the WSN the capacity of real-time delivery of packets, but current standards fall short of providing strict real-time guarantees and in many cases even establishing its feasibility for a given set of sensor requirements. In this paper, we present a novel scheduling technique for ensuring the transmission of packets with real-time requirements at the MAC layer of a WSN. We explore the applicability of our technique under the IEEE 802.15.4 standard, which is commonly

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used in WSN, but noting that our technique is applicable in other environments based in time-slots with reservations.

The paper has been structured as follows: section two talks about the basic concepts of a WSN and related works; section three defines the problem of scheduling the real-time transmission in a WSN. Section four presents the solution heuristic we developed and section five considers its application under some practical examples. Finally, we present our conclusions and future works.

2. Review of WSN concepts:

A Wireless Sensor Network (WSN) is composed of many small wireless nodes, called sensors, which are interconnected with each other for transmitting small packets [1]. Typically, the sensors communicate wirelessly and currently the most widely known standard for low data rates and short ranges is the IEEE 802.15.4 standard [2].

The IEEE 802.15.4 standard defines several medium access mechanisms [3]. The first one is the well-known Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). This mode has no time slots and no beacon transmissions for synchronizing the nodes. In this mode, nodes content for access to the channel and there are no performance guarantees. Common problems in this mode are packet losses due to congestion and interference of hidden nodes, which have a negative impact on various performance metrics such as the throughput, latency and delivery ratio of the network. A second medium access mechanism introduces the notion of time-slots within a *superframe* structure. In this mode, all the nodes are synchronized with respect of a network coordinator which periodically transmits a *beacon*. In the beacon-enabled mode, the coordinator sends a periodic beacon to identify the beginning of the superframe and to synchronize all the nodes associated to the coordinator [3]. The Beacon Interval (BI) defines the time between two consecutive beacons. The beacon interval includes an active period and optionally, an inactive period. The active period, called the superframe, is divided into 16 equally-sized time slots, during which frame transmissions are allowed. During the inactive period (if it exists), all nodes may enter in a sleep mode, thus saving energy. The lengths of the Beacon Interval (BI) and the Superframe Duration (SD) are determined by two parameters, the Beacon Order (BO) and the Superframe Order (SO). The IEEE 802.15.4 protocol also offers the possibility of having a Contention-Free Period (CFP) within the superframe. The CFP is optional and it is activated upon request from a node to the coordinator for allocating time slots. Upon receiving this request, the coordinator checks whether there are sufficient resources and, if possible, allocates the requested time slots. These time slots are called Guaranteed Time Slots (GTS). If the available resources are not sufficient, the GTS request fails. When a node has reserved time-slots, it transmits data frames during these slots. In summary, the superframe is divided in time-slots and there are two transmission modes for the accessing a time-slots: The contention based mode, in which access to the time-slot is resolved using CSMA/CA; and the Guaranteed Time Slot (GTS) mode, where nodes reserve several time-slots with the network coordinator. Given that contention may occur even in time-slotted CSMA/CA mode, we adopt the model of reserved time-slots for our work, particularly the GTS mode when using the 802.15.4 standard.

2.1. Related Works:

We found many related works, here we present a summary of the most relevant ones taking into consideration variables such as the number of nodes in the WSN, the limited number of time-slots available for reservations, and the compliance with the periodic delivery of packets in the WSN.

Information about these types of problems can be found in: [1] and [3-5], among others. Some authors present solutions that promote profound changes to the IEEE 802.15.4 standard, among which are: [1], [3-4], [6] and [13]. Other authors have developed scheduling procedures in which the resources of the MAC layer are exploited to the maximum, thus eliminating sleep periods. These schemes exploit the resources to a level that may be an overkill in many practical situations. They also imply a significant sacrifice in terms of a higher energy consumption [7-10]. Although there are proposals for the problems presented, to the best of our knowledge there is no solution that conforms to the characteristics of WSN such as those build on top of the IEEE 802.15.4 standard. In this work, we present an alternative to efficiently allocate MAC layer resources of a WSN, subject to real-time constraints of data transmissions.