Slot Allocation Algorithms for Minimizing Delay in Alarm-Driven WSNs Applications

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ABSTRACT

Energy-efficiency and latency requirements in alarm-driven Wireless Sensor Networks often demand the use of TDMA protocols with special features such as cascading of timeslots, in a way that the sensor-to-sink delay bound can stay below the duration of a single frame. However, this single TDMA frame should be as small as possible. The results presented in this paper point to the conclusion that a largest-distances-first strategy can achieve the smallest single frame sizes, and also the lowest frame size variations. A quite simple distributed version of this algorithm is presented, which obtains the same results of its centralized version. Simulations also show that this discipline presents the best results in terms of sensor-to-sink slot distance, even if they require a few more slots than breadth-first in multi-frame scenarios. [Article copies are available for purchase from InfoSci-on-Demand.com]

Keywords: Alarm-Driven Applications; Cascading Minimum Single Frame Size Problem; Slot Allocation Algorithms; Slot Distance; TDMA; WSNs

INTRODUCTION

Wireless sensor Networks (WSNs) are geographically distributed, self-organized and robustly networked micro-sensing systems that can be readily deployed and operated in environments in which more conventional infrastructure-based systems and networks are impractical, or cost-ineffective. WSN nodes are interconnected by means of a wireless communications technology, collaborating to forward the sensorial data hop-by-hop from the source node to the sink nodes.

In this paper, we mainly address critical alarm-driven WSN applications, such as
surveillance of sensitive areas (e.g., intrusion detection and tracking). In this kind of WSN applications, traffic generation can be characterized as very sporadic, but the generation of an alarm report demands an immediate response to the event, which makes this kind of traffic very delay-sensitive. However, as WSNs devices have limited energy resources, low duty-cycles are also required. These two goals are usually contradictory, but TDMA protocols can provide low latency in the convergecast of data from the nodes to the sink, while still providing low duty-cycles. The quick convergecast is usually achieved by building a routing tree routed on the sink node, and by ordering the timeslots in the path from a node to the sink, in such a way that the receiving slot(s) number(s) of a given node is lower than its transmitting slot number, while the slot distance is kept as low as possible (a procedure that is called “cascading of timeslots”). On the other hand, low duty-cycle can be achieved by TDMA protocols, since each node only needs to be active during its reception and transmission slots, while staying asleep for the rest of the TDMA frame.

With the objective of guarantying the same sensor-to-sink packet delay bound for all the nodes in the network, communication of alarms to the sink can be made in just one frame. However the size of the single frame is desirably the lowest possible. In this paper, several TDMA scheduling algorithms are simulated with the objectives of achieving low single frame sizes and low latencies.

This paper presents the related work in Section 2. In Section 3, the Cascading Minimum Single Frame Size Problem is defined. Section 4 presents the simulation model, the set of slot allocation algorithms, and their results in terms of achieving low single frame sizes, and low node-to-sink slot distances. Section 5 presents the simulations results obtained for a pre-determined frame size, in terms of node-to-sink slot distances. And finally, Section 6 presents simulation results, in terms of the actually required non-single frame sizes, and the respective worst-case delays of the communication of alarms to the sink.

**RELATED WORK**

While not being a pure TDMA protocol, the Data-gathering MAC (D-MAC) protocol, presented in Lu et al. (2004), uses staggered synchronization so that a data packet received by a node at one level of the tree, is transmitted to the next level in the following time period (i.e., cascading the transmissions in the overall transmission period). The node is then allowed to sleep until the reception period for its level occurs again. D-MAC is still a CSMA/CA-based protocol as nodes at the same level of the tree have to compete for timeslot access and may also interfere with nodes located in the same area. Support of several sinks in D-MAC is troublesome.

The use of TDMA for fast broadcast (the converse problem of convergecast) is a well-known subject, which has been studied in the context of multi-hop radio networks. Chlamtac & Kutten (1987) show that the problem of determining optimal channel allocation for fast broadcasting is NP-hard. Two algorithms for tree construction and slot assignment are presented, namely a centralized version, and its distributed version. The distributed algorithm begins at the source node, for which the first slot is granted, and builds a spanning tree, such that each node has a slot number higher than its parent slot, but with the smallest possible value, in order to cascade the broadcast. Tree construction and slot assignment are performed depth-first, by means of passing a token to one node at a time, and by exchanging appropriate protocol messages with the neighbor nodes, in order to obtain a TDMA schedule that meets some slot allocation rules, and that achieves conflict-free schedules. These protocols are also designed to achieve spatial reuse of the slots, with relatively small TDMA frame sizes.

Another protocol that was designed to achieve TDMA conflict-free schedules is the DRAND distributed slot assignment protocol, presented in Rhee et al. (2006). As the authors state, the problem of obtaining a minimum slot frame size is NP-hard. DRAND is not particularly suited for fast broadcast or fast convergecast,
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