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FP-MAC: A distributed MAC algorithm for 802.15.4-like wireless sensor networks

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Abstract

In this paper we focus on the problems of high latency and low throughput arising from the periodic operation of MAC protocols for wireless sensor networks. In order to meet both design criteria we propose an energy-efficient, low delay, *fast-periodic* MAC algorithm, namely FP-MAC, that is exclusively designed for 802.15.4-like networks utilizing in full the standard's physical layer. Our proposal relies on the short periodic communication operation of the nodes comprising the WSN. This is achieved by decreasing the actions that a node needs to perform at the start of every communication period and by incorporating a variable radio-on operation. Moreover, the algorithm introduces differences in nodes' scheduling to further reduce delay. Local synchronization and the crucial task of determining the proper timing for transmission and reception of data is achieved through the periodic broadcast of special synchronization frames at the beginning of each on-period. FP-MAC is evaluated and compared to S-MAC and T-MAC through extensive simulations, showing a significant improvement in terms of low energy consumption and average MAC delay.

Keywords: Wireless sensor networks; Medium access control; Energy and latency efficiency

1. Introduction

Wireless sensor networking is an emerging technology that has a wide range of potential applications including environmental control, home automation, military sensing and health monitoring [1]. The recent release of standards in the field, such as the IEEE 802.15.4 [2] for low-rate wireless personal area networks (LR-WPANs), brought the technology out of research labs and stimulated the development of numerous commercial products. Since its proposal in 2003, the IEEE 802.15.4 protocol has been attracting more and more research work enforcing its deployment in wireless sensor networks (WSNs). Also, many manufacturers of the WSN technology (namely all the ZigBee Alliance members [3]) are shifting towards this standard

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solution due to its increasing popularity and interesting technical features [4]. The provision of low cost and low power wireless connectivity within short ranges of up to 20 m, are some of the characteristics that make the 802.15.4/ZigBee protocol particularly suited for WSNs.

A typical WSN is a large set of wireless nodes, with sensing, monitoring and processing capabilities, deployed in an *ad hoc* fashion [5]. These wireless nodes are autonomous, battery-operated devices, with limited energy capacity and computational processing capability, mostly designed for unattended operation. These devices require mechanisms to minimize energy consumption, in order to ensure a long-lasting operation without the need for replacement/recharging the battery. Several special mechanisms need to be implemented in all the network layers, from physical to application. In this study, we concentrate on medium access control (MAC) protocols since this gives a fine-grained control to switch the wireless radio on and off and therefore to effectively prolong the network lifetime.

As already mentioned, energy conservation is the primary and most important challenge to meet since it determines the lifespan of a sensor network [6]. Since the power consumption of a transceiver is remarkably high during channel listening, the best way to achieve energy conservation is to turn off the radio electronics on every network node for as long as possible. The crucial challenge is to keep the nodes' radios on only for the time necessary to exchange data. Since there is no "Wake-Up Radio" in the market products developed (i.e. an ideal receiver that wakes-up only when it detects signal at its antenna), the only solution that approaches this, is to periodically switch on and off a node's radio, ultimately to keep the radio on only when communication is needed.

Another concern in the design of an efficient MAC is to fairly and efficiently share communication resources between sensor nodes. Generally, MAC protocols can be broadly classified based on their resource sharing mechanisms in two major categories: (a) schedule-based and (b) contention-based. Both techniques can be used in wireless sensor network applications, albeit with different advantages and disadvantages each. Schedule-based techniques can more easily satisfy WSN's requirements, since they have the inherent capability of power conservation and can lead to collision-free MAC protocols. Contention-based techniques require an additional control stage in order to implement the periodic on and off turning of the radio. Moreover, when several sensor nodes wish to transmit to a common destination they have to contend for the medium during the destination's on-period. This implies that their performance under high contention suffers because of high overhead in resolving contention and collision [7]. From this point of view, schedule-based protocols have natural advantage over contention-based protocols, but, on the other hand, local or global synchronization between network nodes as well as complicated slot assignment procedures are required.

Derived from the above description, novel algorithms are of need, to effectively tackle the unique resource constraints and application requirements of WSNs. The common reference point of the above techniques and the key factor for energy conservation appeared to be the *periodic operation*. As already seen, periodicity can be implemented either in a straightforward way (i.e. in schedule-based MAC protocols) or not (i.e. in contention-based MAC protocols). Yet, whatever of the access technique in use, the selection of a proper *duty cycle*, which is the percentage of on-time with respect to total period duration, is mandatory. Smaller duty cycle values improve power consumption but also lead to higher end-to-end delays which can be a serious drawback, especially in multi-hop systems [5]. This tradeoff between consumption and delay with respect to period selection was the major motivation for this paper.

In this paper, we propose a new MAC algorithm for wireless sensor networks, namely FP-MAC. Current MAC solution is successfully integrated with the IEEE 802.15.4/ZigBee standard and is capable of using small period values by decreasing the actions that a node needs to perform at the beginning of every communication period and by incorporating a variable radio-on operation. The algorithm also incorporates the idea of scheduling the listening times of the nodes, while using contention over the transmission of data during each node's on period with a simple back-off mechanism. The above features together with the algorithm's fast-periodic operation lead to an energy-efficient MAC algorithm that lowers the delay in wireless sensor networks.

The remainder of the paper is organized as follows: Section 2 describes several existing widely accepted access methods proposed for WSNs. In Section 3 we introduce several features of the underlying 802.15.4 standard in order to provide a better