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Survey Paper

Receiver-initiated medium access control protocols for wireless sensor networks

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ABSTRACT

One of the fundamental building blocks of a Wireless Sensor Network (WSN) is the Medium Access Control (MAC) protocol, that part of the system governing when and how two independent neighboring nodes activate their respective transceivers to directly interact. Historically, data exchange has always been initiated by the node willing to relay data, i.e. the sender. However, the Receiver-Initiated paradigm introduced by Lin et al. in 2004 with RICER and made popular by Sun et al. in 2008 with RI-MAC, has spawned a whole new stream of research, yielding tens of new MAC protocols. Within such paradigm, the *receiver* is the one in charge of starting a direct communication with an eligible sender. This allows for new useful properties to be satisfied, novel schemes to be introduced and new challenges to be tackled. In this paper, we present a survey comprising of all the MAC protocols released since the year 2004 that fall under the receiver-initiated category. In particular, keeping in mind the key challenges that receiver-initiated MAC protocols are meant to deal with, we analyze and discuss the different protocols according to common features and design goals. The aim of this paper is to provide a comprehensive and self-contained introduction to the fundamentals of the receiver-initiated paradigm, providing newcomers with a quick-start guide on the state of the art of this field and a palette of options, essential for implementing applications or designing new protocols.

1. Introduction

The Medium Access Control (MAC) layer plays a key role in wireless sensor networks. It is primarily responsible for the establishment of communication links between nodes, that are vital to form the network infrastructure. The MAC scheme then regulates the access to the shared wireless channel by multiple nodes. In contrast to conventional networks where Quality of Service (QoS) and bandwidth efficiency are considered the main priority, energy efficiency remains the primary objective of Wireless Sensor Networks (WSNs), rendering traditional MAC schemes inapplicable. Since the radio communication of a sensor node consumes the highest amount of power [2], the main method of preserving power is to duty cycle the node. Duty Cycles are materialized by alternating the node between active and sleeping states, where the node is operational in the active state and shut down in the sleeping state. This poses a particular problem of finding a rendezvous point between a sender and receiver, in which both of the nodes are in an active state and a communication link can be established. MAC schemes for WSNs take a synchronous or asynchronous approach to solve this problem. Fig. 1, depicts the synchronous and asynchronous

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paradigms for coordinating the receiver and the transmitter in duty cycled wireless communications.

In protocols that follow the *synchronous* approach, like S-MAC [3], T-MAC [4] and DSMAC [5], nodes organize the active and sleeping states to align. Synchronous schemes can be based either on contention or on reserved timeslots. In both cases, a portion of the active state is used to synchronize all the nodes to a global active/sleep schedule. When a source node has data to transmit, it waits until the active state to initiate the data transfer. Synchronous schemes are quite tolerant to schedule misalignment, however, they still require a globally synchronized schedule, which creates an additional energy overhead. Additionally, synchronous protocols have a cost associated with the creation and maintenance of the schedule. Furthermore, the coupling of nodes via a global clock also hinders a node's ability to have a fully independent duty cycle, so that each node can adapt, in a fully distributed way, to the current surrounding conditions.

Asynchronous schemes do not require synchronization, as the nodes sleep and wake-up independently of the others. This leads to the need of techniques on deciding a rendezvous point for nodes to communicate. There are two fundamental asynchronous techniques, namely the sender- and the receiver- initiated. The basic technique used in a sender-initiated asynchronous MAC scheme is called preamble sampling, where the sender transmits a preamble to indicate that there is a pending need for communication. The receiver wakes up occasionally into the active state, to listen to such a preamble transmission. Once the preamble is detected, the receiver replies with a positive acknowledgment to the sender when the preamble transmission stops. This establishes a communication link between the sender and receiver. Most notable examples of MAC protocols that are based on the sender-initiated paradigm are WiseMAC [6], B-MAC [7] and X-MAC [8]. A thorough survey of sender-initiated schemes is performed in [9], concluding with a guideline to select MAC schemes for a given application.

This survey is focused on the latter asynchronous scheme, namely receiver-initiated. In contrast to the preamble sampling technique in sender-initiated schemes, receiver-initiated schemes use another approach to asynchronous communication: instead of long preambles, the sender listens to the channel, waiting for small beacons transmitted by the receiver. The receiver transmits the beacons in a period that is defined by its duty cycle, and is used by the sender to synchronize with the receiver. The receiver-initiated paradigm was originally introduced by Lin et al. in 2004 (RICER [10]) and made popular by

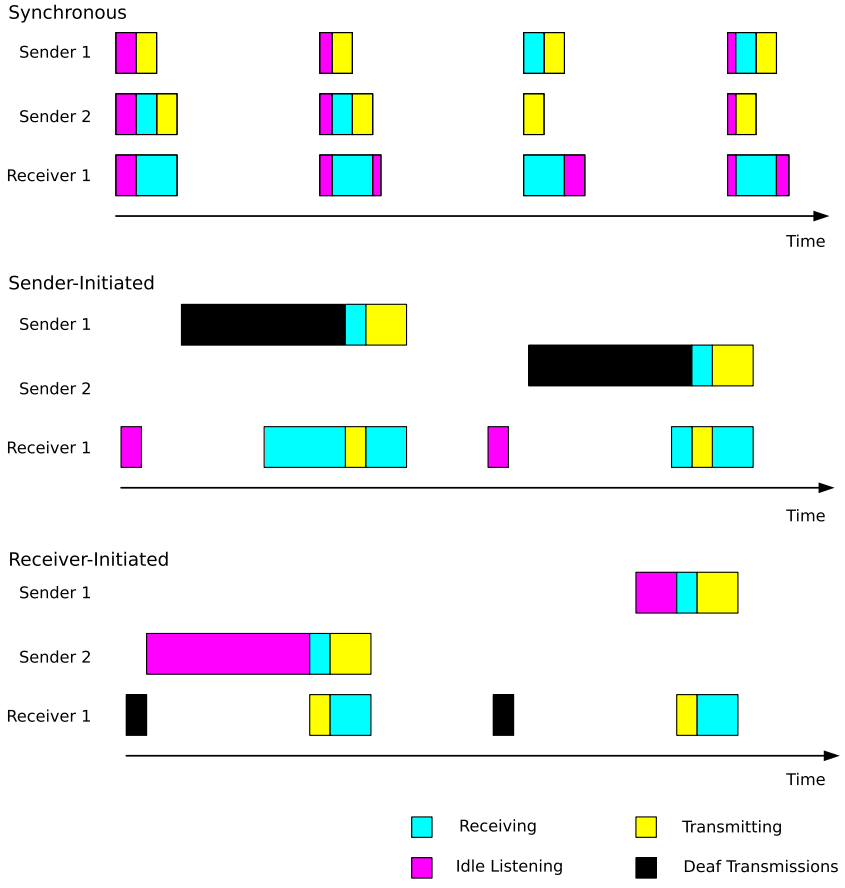

Fig. 1. Different approaches of MAC protocols, from top to bottom: synchronous, sender-initiated and receiver-initiated. Idle listening represents listening without anyone transmitting and deaf transmissions represent transmitting without anyone listening.