Chapter 16
MAC Protocols for Wireless Sensor Networks

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ABSTRACT
The chapter describes related work on medium access control protocols for wireless sensor nodes. We focus on scheduled and contention-based protocols that have been proposed by the research community during the last few years. In particular, we evaluate the potential to save energy of several representative protocols, namely LMAC, TEEM, and WiseMAC. This has been done by measurements of implementations in real sensor networks. The measurement results show that by sophisticated MAC protocol design we can significantly improve the energy-efficiency and increase the lifetime of a sensor node. Real-world measurements are important to determine power consumption parameters of sensor nodes.

INTRODUCTION
Wireless sensor networks (WSNs) use wireless network technologies for exchanging sensor data, signalling messages, management information etc. The wireless medium is shared by the various sensor nodes in a WSN. This requires a Medium Access Control (MAC) layer controlling the access to the wireless medium. Although many MAC layer protocols have been developed for both wired and wireless media, e.g., IEEE 802.11 Wireless Local Area Networks (WLAN), new MAC protocols are required for WSNs, because existing ones do not meet most requirements for sensor networks such as energy efficiency.

The most important task of a MAC protocol is to avoid collisions that occur when multiple nodes are trying to access the network simultaneously. By avoiding collisions valuable network resources are saved, the utilization of the wireless channel is
improved, and the nodes save energy by avoiding useless transmissions. Other sources of energy waste are overhearing and receiving operations. Overhearing occurs when nodes receive packets destined to other nodes and can be dominant in scenarios with heavy load and high node density.

Since overhearing and receiving might not be much cheaper than transmitting, energy-efficient MAC protocols should avoid those operations and switch off the transceiver whenever possible. Other sources of energy waste are over-emitting, i.e., transmissions when receivers are not yet ready to receive as well as excessive control packet overhead.

The complexity of a sensor MAC protocol should be limited, because sensor nodes usually have limited computing and memory resources. Moreover, the MAC protocol should allow fair allocation of the wireless medium among all sensor nodes and aim at high throughput and low delay. In contrast to WLANs, a sensor MAC protocol must support not only small numbers of nodes but scale to hundreds or thousands of nodes depending on the required node density of a WSN by the application. The characteristics of a WSN in terms of size, density, and topology may change quickly requiring a sensor MAC protocol to be automatically adaptable.

The chapter gives an overview of related work in MAC protocols for WSNs including both scheduled and contention-based schemes. After describing the basic principles for MAC protocol operation in WSNs, we describe real-world experiments using implementations on real sensor nodes. The energy-efficiency in terms of sensor node lifetime will be investigated. We show that by proper MAC protocol design, significant energy savings are possible.

**BACKGROUND**

There are two basic classes of MAC protocols for WSNs: scheduled protocols and contention-based protocols. By combining the basic concepts, hybrid protocols can be designed.

Scheduled protocols are either based on polling or multiplexing. With polling a central controller polls other sensor nodes to detect whether they have pending transmissions. This avoids energy waste caused by collisions but introduces polling overhead and delays. In case of multiplexing, channels are pre-allocated based on time, frequency, or code multiplexing. Scheduling based approaches often form clusters with cluster controllers responsible for the channel allocation. Since only a certain number of channels can be allocated the scalability might be limited then.

Contention-based protocols allow sharing channels and allocating channels on-demand. The main problem is that contention can happen in case of dense networks and highly active sensor nodes. Moreover, collision avoidance is rather difficult to achieve in WSNs due to potentially hidden nodes.

**SCHEDULED PROTOCOLS**

**Cluster-Based Approaches**

Scheduled protocols based on cluster formation form clusters with a cluster head acting as base station. The cluster head allocates channels using time, frequency, and / or code multiplexing and assigns the channels to the sensor nodes. Typically, nodes can only communicate with a cluster head. Inter-cluster communication requires special mechanisms and (time, frequency, or code) channels. Cluster heads need to be interconnected to support data forwarding to / from sink, and since the distance among each other is rather high, higher power level for inter-cluster communication is needed.

In case of nodes joining or leaving the cluster, the frame length and the slot assignment need to be adapted. This might generate overhead. If the scheme does not adapt dynamically and uses static
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