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Advertisement-Based Energy Efficient Medium Access Protocols for Wireless Sensor Networks

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One of the main challenges that prevents the large-scale deployment of Wireless Sensor Networks (WSNs) is providing the applications with the required quality of service (QoS) given the sensor nodes' limited energy supplies. WSNs are an important tool in supporting applications ranging from environmental and industrial monitoring, to battlefield surveillance and traffic control, among others. Most of these applications require sensors to function for long periods of time without human intervention and without battery replacement. Therefore, energy conservation is one of the main goals for protocols for WSNs. Energy conservation can be performed in different layers of the protocol stack. In particular, as the medium access control (MAC) layer can access and control the radio directly, large energy savings is possible through intelligent MAC protocol design. To maximize the network lifetime, MAC protocols for WSNs aim to minimize idle listening of the sensor nodes, packet collisions, and overhearing. Several approaches such as duty cycling and low power listening have been proposed at the MAC layer to achieve energy efficiency. In this thesis, I explore the possibility of further energy savings through the advertisement of data packets in the MAC layer.

In the first part of my research, I propose Advertisement-MAC or ADV-MAC, a new MAC protocol for WSNs that utilizes the concept of advertising for data contention. This technique lets nodes listen dynamically to any desired transmission and sleep during transmissions not of interest. This minimizes the energy lost in idle listening and overhearing while maintaining an adaptive duty cycle to handle variable loads. Additionally, ADV-MAC enables energy efficient MAC-level multicasting. An analytical model for the packet delivery ratio and the energy consumption of the protocol is also proposed. The analytical model is verified with simulations and is used to choose an optimal value of the advertisement period. Simulations show that the optimized ADV- MAC provides substantial energy gains (50% to 70% less than other MAC protocols for WSNs such as T-MAC and S-MAC for the scenarios investigated) while faring as well as T-MAC in terms of packet delivery ratio and latency.

Although ADV-MAC provides substantial energy gains over S-MAC and T-MAC, it is not optimal in terms of energy savings as contention is done twice - once in the Advertisement Period and once in the Data Period. In the next part of my research, the second contention in the Data Period is eliminated and the advantages of contention- based and TDMA-based protocols are combined to form Advertisement based Time- division Multiple Access (ATMA), a distributed TDMA-based MAC protocol for WSNs. ATMA utilizes the bursty nature of the traffic to prevent energy waste through advertisements and reservations for data slots. Extensive simulations and qualitative analysis show that with bursty traffic, ATMA outperforms contention-based protocols (S- MAC, T-MAC and ADV-MAC), a TDMA based protocol (TRAMA) and hybrid protocols (Z-MAC and IEEE 802.15.4). ATMA provides energy reductions of up to 80%, while providing the best packet delivery ratio (close to 100%) and latency among all the investigated protocols.

Simulations alone cannot reflect many of the challenges faced by real implementations of MAC protocols, such as clock-drift, synchronization, imperfect physical layers, and irregular interference from other transmissions. Such issues may cripple a protocol that otherwise performs very well in software simulations. Hence, to validate my research, I conclude with a hardware implementation of the ATMA protocol on SORA (Software Radio), developed by Microsoft Research Asia. SORA is a reprogrammable Software Defined Radio (SDR) platform that satisfies the throughput and timing requirements of modern wireless protocols while utilizing the rich general purpose PC development environment. Experimental results obtained from the hardware implementation of ATMA closely mirror the simulation results obtained for a single hop network with 4 nodes.