Performance Evaluation of Adaptive and Energy-efficient MAC Protocols for Wireless Sensor Networks

Torsten Braun, Philipp Hurni
Institute of Computer Science and Applied Mathematics
Universität Bern
3012 Bern, Switzerland
braun@iam.unibe.ch, hurni@iam.unibe.ch

***Abstract*—The paper describes an energy-efficient medium access control protocol for wireless sensor networks and proposes a metric to compare it with other protocols. A software-based scheme to estimate the energy consumption of a sensor node has been developed. This scheme resulted in rather accurate results compared to hardware-based energy measurement schemes.**

Keywords: Wireless Sensor Networks, Energy-efficient Protocols, Medium Access Control

I. Introduction

Medium Access Control (MAC) protocols are essential for the energy consumption of wireless sensor nodes. Dependent on how long the transceiver can be switched off, the energy of the sensor node can be reduced. Wireless sensor network (WSN) MAC protocols can be classified into scheduled and contention-based protocols. In case of scheduled protocols, strong time synchronization is required among nodes such that nodes only wake up at certain time periods, in which they then can communicate. Contention-based protocols do not require synchronization, but allow nodes to compete for network access, typically using carrier sense multiple access / collision avoidance (CSMA/CA) techniques. In many contention-based protocols nodes also wake up periodically, but do not synchronize with others. In these cases, sending nodes have to be sure that during a transmission the receiver is awake. The WiseMAC protocol ensures this by transmitting a preamble, which is longer than the maximum time between two wake-ups, followed by the packet transmission. In order to avoid long preambles, WiseMAC nodes can learn about the wakeup schedule of other nodes and try to minimize preamble transmission. One problem of those protocols is that they have their rather fixed wakeup schedule, which limits the maximum throughput and might introduce significant delays.

II. Maximally Traffic-Adaptive MAC Protocol

The maximally traffic-adaptive MAC protocol (MaxMAC) [1] addresses the problem of limited adaptivity to application requirements. It is based on the same principles as WiseMAC, but measures continuously the traffic arriving from other nodes. Starting from a base state with a periodic wakeup schedule, the duty cycle can be doubled by halving the time between wakeups, when a certain threshold has been reached. After reaching another threshold, the duty cycle can be increased further until it is worth that the node is permanently awake. When the traffic has decreased again, the node can fall back into one of the previous states dependent on the observed traffic. A node announces to remain in a state for certain time duration and piggy-backs this information in acknowledgment packets such that other nodes can take advantage of the increased duty cycle and increase their transmission rate accordingly.

III. Evaluation Metric

Traffic-adaptive protocols should meet several application requirements in terms of throughput, delay, and energy-efficiency. However, these issues somehow contradict, since an increase of the duty cycle will increase the throughput and reduce the delay, but will also result in higher energy consumption. In order to compare the various WSN MAC protocols proposed by different researchers, we have developed an evaluation metric, which maps each protocol configuration into a multi-dimensional Euclidean space (here: three dimensions for throughput, delay, and energy-efficiency) [2]. A protocol configuration depends on variable parameters for each protocol such as duty cycle and wakeup interval. As a reference we defined the IdealMAC protocol, which puts a node into active state only during transmission and reception. The protocol magically knows when transmissions will happen. Therefore, IdealMAC cannot be implemented in reality but only simulated. IdealMAC has minimal delays as well as highest throughput and energy-efficiency (measured in bit per J). As a measure for each protocol we define the Euclidean distance between a protocol configuration and IdealMAC. Different application-dependent weighting factors can be applied for the three evaluation parameters, but it turned out that MaxMAC is outperforming all other protocols that have been considered.

IV. Energy Measurments

Simulation-based protocol evaluations are valuable for initial design phases, but for more accurate and meaningful evaluations, implementation and measurements in real testbeds is needed. An important issue for WSN protocols is their energy-efficiency. The energy consumption could be measured by dedicated measurement hardware, e.g., by connecting current meters to the sensors. However, connecting each sensor in a WSN to a current meter is quite costly and might not be feasible in out-door scenarios. Related work has proposed to use software-based measurements. In this case, the state of the sensor node and its time in each state is recorded. By measuring the current in each state and calculating the overall time spent in each state, the overall energy consumption of a node can be determined. However, known software-based energy estimation schemes have significant inaccuracies compared to hardware-based measurements of more than above 5 %. By accurately analysing currents in the different states and during state switches we developed a more accurate model for energy consumption [3]. In particular, we found that current flow is going down during state switches. Considering this fact and applying ordinary least square regression analysis, we could reduce the inaccuracy of software-based estimation of energy consumption to 1 %.

V. OUTLOOK

In subsequent works we have implemented MaxMAC in our Wisebed WSN testbed [4] and used the software-based energy estimations to evaluate MaxMAC in realistic settings. This allows us to gain more insights and further optimize the energy consumption of the protocol.

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