Accurate Power Profiling for Sensor Network Simulators

Joakim Eriksson, Fredrik Österlind, Niclas Finne, Adam Dunkels, Thiemo Voigt
Swedish Institute of Computer Science
{joakime, fros, nfi, adam, thiemo}@sics.se

Abstract—Power consumption is the most important metric in wireless sensor network research, but existing tools for measuring or estimating power consumption are either impractical or have unclear accuracy. We present a practical simulation-based tool for network-scale power estimation based on experience with Contiki’s built-in power profiling mechanism, the COOJA sensor network simulator and the MSPSim sensor node emulator. We quantify the accuracy of the tool by comparing simulation results with experimental testbed results.

I. INTRODUCTION

Power consumption is the most important metric in wireless sensor networks because reduced power consumption leads to increased network lifetime. Many different mechanisms for reducing the power consumption for sensor networks have been proposed. Most power-saving mechanisms focus on reducing radio on-time because radio communication is the most power-consuming task in wireless sensor networks [9]. To evaluate the efficiency of such techniques, researchers must be able to measure or estimate the energy consumption at the network scale.

To do network-scale power profiling in testbed experiments, we have previously developed a software-based on-line power profiling mechanism for the Contiki operating system [3]. The mechanism measures the time during which components are switched on and uses pre-measured current draw of system components to accurately profile the power consumption of each node. The low overhead of the mechanism allows power profiling to be done on a network-scale.

Unlike simulation, the scale of testbed experiments is quickly limited by both time and money. Testbed experiments are also limited to experiments in a single physical environment whereas simulations allow the network environment to be freely varied. Furthermore, large-scale experiments consisting of thousands of nodes are impractical and may be too expensive to perform with real hardware.

We build our power simulation system in the COOJA simulator [14] and the MSPSim MSP430 instruction emulator [4]. MSPSim supports detailed emulation of sensor nodes such as the Tmote Sky platform.

II. RELATED WORK

There are many sensor network simulators with energy estimation abilities [5], [6], [11] but their accuracy has only been demonstrated in node-scale experiments. For example, Trathnigg et al. [12] demonstrate the accuracy of PowerTOSSIM, but for a single node only. We are the first to experimentally validate the accuracy of simulated power profiling at the network scale.

III. SIMULATION-BASED NETWORK-SCALE POWER PROFILING

Our tool for network-scale power estimation is a combination of three existing tools: Contiki’s power profiling [3], the COOJA sensor network simulator [14], and the MSPSim sensor node emulator [4]. Contiki’s built-in power profiling mechanism automatically profiles the power consumption of sensor nodes in a testbed, thereby enabling scalable, low-overhead measurements of the power consumption. COOJA is a simulator for networks of Contiki nodes. In contrast to other sensor network simulators, COOJA simulates nodes on different levels in the same simulation run. In one simulation run, COOJA can simulate Contiki nodes on the OS level, non-Contiki nodes implemented in Java or nodes running other operating systems and emulate MSP430-based sensor nodes at the instruction level. COOJA simulates compiled object code using MSPSim, an instruction-level emulator for MSP430-based sensor nodes such as Tmote Sky [8] or ESB nodes [10]. COOJA provides three different radio models for simulating radio-level network behaviour.

To simulate power consumption at network-scale, we have integrated Contiki’s power profiling mechanism in MSPSim. By simulating networks of emulated MSP-based sensor nodes in COOJA, we benefit both from COOJA’s ability to simulate network behaviour and Contiki’s built-in power profiling mechanism. Figure 1 shows a screenshot of our simulator.
By demonstrating that our tool accurately simulates power consumption, we can perform large-scale simulations that provide accurate power profiling in simulated networks.

IV. EVALUATION

To evaluate the accuracy of our simulation-based approach, we compare the results obtained through simulation with results obtained through testbed experiments and Contiki’s power profiling mechanism.

We evaluate our simulation-based power profiling approach on the most typical sensor network setup: tree-based data collection. The evaluation is performed on the Tmote Sky [8] sensor platform with the Contiki operating system [2].

A. Case Study: Data Collection with CoReDac

a) Protocol Overview: For this case study we use CoReDac, a TDMA-based convergecast protocol [13]. In contrast to most other convergecast protocols, CoReDac builds a collision-free collection tree.

![Fig. 2. Staggered communication in CoReDac](image)

Fig. 2. Staggered communication in CoReDac

To achieve low delay, CoReDac borrows the idea of staggered communication from D-MAC [7] as shown in Figure 2. In D-MAC, however, packets from the nodes on the same level can still cause collisions. In CoReDac, parent nodes avoid collisions among packets from their children by assigning time slots for transmission to their children. The information about the assignment is contained in the acknowledgements. In CoReDac acknowledgements play a crucial role as they are also used for synchronization and on-demand slot assignment.

![Fig. 3. On-demand slot assignment to avoid collisions.](image)

Fig. 3. On-demand slot assignment to avoid collisions.

Figure 3 shows how CoReDac assigns transmit slots. The figure shows that the sink announces that N2 receives the transmit slot before N1. The sink’s acknowledgement also signals when the sink’s next receive slot starts, namely in sleept seconds. This way, the acknowledgements contain all information to achieve a collision-free communication schedule between a parent node and its children. This scheme is recursively applied towards the whole tree. In order to avoid collisions between nodes on different levels, we set a maximum number of children per node. Based on this maximum number, its position in the tree and the receive slot of its parent, a node can compute its unique receive slot.

b) Results: We have implemented CoReDac and measured its energy-efficiency both on real hardware using Contiki’s built-in power profiling mechanism [3] and in the sensor network simulator COOJA [14]. Within COOJA we perform power profiling on the node level with the MSPSim sensor node emulator [4].

The top graph in Figure 4 shows the power consumed by the radio in listen mode when running CoReDac. The figure shows that the experimentally obtained power consumption on real nodes matches very well with the power consumption obtained with our simulator. In particular, the difference between the results do not increase with the size of the simulated networks.

The bottom graph in Figure 4 presents the TX power consumption obtained through simulation and with Contiki’s built-in power profiling mechanism. The figure shows that the
power consumption for transmitting packets in CoReDac is less than 1% of the power consumption for listening and receiving packets which confirms the measurements by Dunkels et al. [3]. As for power consumption of the radio in listen mode, the results obtained by simulation and experiments with real hardware match well. Further, the difference between the results does not increase with the size of the simulated networks. These results suggest that simulating the power consumption of sensor nodes in large networks is feasible using our simulator and TDMA-based protocols.

V. DISCUSSION

Our results suggest that the results obtained through simulation match the results obtained through testbed experiments and Contiki’s power profiling mechanism for TDMA-based protocols such as CoReDac. The results indicate that simulations can be used to accurately estimate energy consumption in large-scale networks that are too large to setup in testbed.

Initial results from experiments with low-level MAC protocols such as X-MAC [1] shows that, currently, low-level timing-related behavior is difficult to simulate accurately, indicating important directions for future work.

VI. CONCLUSIONS

In this paper we present a tool that enables simulation-based network-scale power profiling. We show that the results obtained with the tool correspond well with the results obtained through measurements on real hardware.

ACKNOWLEDGEMENTS

This work was financed by VINNOVA, the Swedish Agency for Innovation Systems, and the Uppsala VINN Excellence Center for Wireless Sensor Networks WISENET, also partly funded by VINNOVA.

REFERENCES


