Demo Abstract: Software-based Sensor Node Energy Estimation

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Abstract

Being able to estimate the energy consumption of sensor nodes is essential both for evaluating existing sensor network mechanisms and for constructing new energy-aware mechanisms. We present a software-based mechanism for estimating the energy consumption of sensor node at run-time. Unlike previous energy estimation mechanisms, our mechanism does not require any additional hardware components or add-ons.

Our demonstration shows the energy estimation in practice on a small network of Tmote Sky motes running the Contiki operating system. A PC connected to one of the motes shows the real-time energy estimation of the network nodes and where the energy is spent: CPU active, CPU sleeping, radio transmitting, radio listening, and LEDs.

Categories and Subject Descriptors

C.2.4 [**Computer Communication Networks**]: Distributed Systems—*Network Operating Systems*

General Terms

Design, Experimentation, Measurement, Performance

Keywords

Wireless sensor networks, Energy estimation, Contiki

1 Introduction

Energy is of primary importance in wireless sensor networks. Hence, protocols and mechanisms developed for sensor networks must be energy-efficient. Nevertheless, no practical network-scale methods for measuring or estimating the energy consumption of sensor nodes exist. Hardware-based solutions [4, 5] significantly increase the cost of each sensor node and sometimes require manual intervention with each sensor node [5]. Furthermore, recent work has shown that hardware-based energy measurement mechanisms are not trivial to construct because of the unique characteristics of sensor networks [4].

We have proposed a software-based mechanism for estimating the energy consumption of sensor nodes [3], which we have implemented in the Contiki operating system [2]. With our software-based energy estimation method, an entire sensor network can be instrumented with energy estimation at zero additional hardware cost and with a low run-time overhead. We have evaluated the accuracy of our mechanism by comparing the estimated energy consumption to the actual lifetime of capacitor-powered sensor nodes [3]. Our results show that the energy estimation mechanism has a high accuracy.

Our demonstration shows the software-based energy estimation mechanism in practice. A small network consisting of Tmote Sky motes report their estimated energy to a PC, which displays the estimated energy in real-time. The reported energy is broken down into the different categories on which energy is spent: CPU active energy, CPU sleep energy, radio transmit energy, radio listen energy, and the energy of the yellow LED. No sensors are used in the demonstration. The two other LEDs are used as part of the demonstration and their energy is not estimated.

2 Energy Model

The on-line energy estimation mechanism uses a linear model for the sensor node energy consumption. The total energy consumption E is defined as

$$\frac{E}{V} = I_m t_m + I_l t_l + I_t t_t + I_r t_r + \sum_i I_{c_i} t_{c_i}, \qquad (1)$$

where V is the supply voltage, I_m the current draw of the microprocessor when running, t_m the time in which the microprocessor has been running, I_l and t_l the current draw and the time of the microprocessor in low power mode, I_t and t_t the current draw and the time of the communication device in transmit mode, I_r and t_r the current draw and time of the communication device in receive mode, and I_{c_i} and t_{c_i} the current draw and time of other components such as sensors and LEDs. The energy model does not contain a term for the idle current draw of the board itself; this is embedded in the low power mode draw of the microprocessor.

3 Implementation

The implementation of the on-line energy estimation mechanism requires only small changes to existing operating system source code. We have implemented the mechanism in the Contiki operating system [2] but the mechanism can easily be incorporated into other sensor node operating systems.

The energy estimation module maintains a table with entries for all components, the CPU, and the radio transceiver. Each table entry contains the total time that the corresponding component has been turned on.

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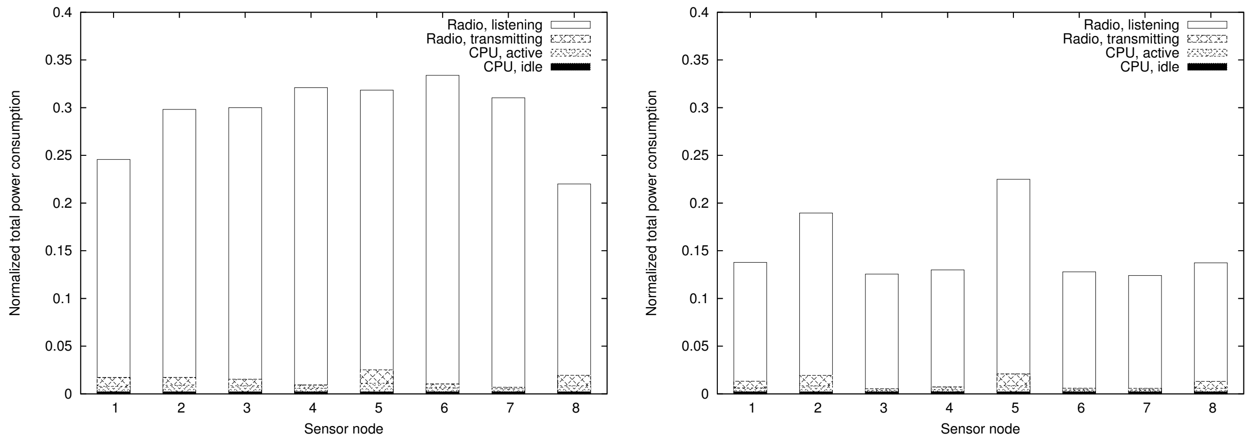

Figure 1. The estimated power consumption of eight nodes running the Contiki data collection protocol with X-MAC. The left graph is without the unicast optimization and the right graph with optimization. The power is normalized to the maximum Tmote Sky power consumption.

Energy estimation is implemented in two lines of code in the device driver for the hardware for which energy is to be estimated. When the component is turned on, the energy estimation module is called to produce a time stamp. When the component is turned off, the time difference from when the component was turned on is computed. The time difference is added to the table entry for the component. To add energy estimation to an existing device driver, only two lines of code needs to be added.

Time measurement is implemented using the on-chip timers of the MSP430. Since the on-chip timers work even when the microcontroller is in low-power mode, the time measurement is non-intrusive. We use the 32768 Hz clock divided by 8, producing 4096 clock ticks per second.

4 Case Study: X-MAC

As an example usage scenario of our energy estimation mechanism, we estimate the energy overhead of the X-MAC duty-cycling radio protocol [1] with our energy estimation mechanism.

The X-MAC protocol switches on and off the radio at regular intervals to conserve the energy of the sensor node. When a node is to send a packet, it first broadcasts a train of short strobe packets. When the other nodes hear a strobe packet, it turns on its radio in preparation of receiving a full packet. As an optimization for unicast packets, the strobe packets include the address of the receiver of the full packet. When the receiver hears the strobe packet, it immediately sends a short acknowledgement packet to the sender of the strobe packets. The sender can then immediately send its full packet. All other nodes that overhear the packets can turn off their radios until the full packet has been transmitted.

We run the X-MAC protocol on nine Tmote Sky motes that form a two-hop network. The motes transmit their energy estimations to a PC connected to one of the motes. The estimated energy is shown in Figure 1. The left graph shows the estimated energy without the unicast optimization and the right graph the estimated energy with the optimization. We see that the optimization is able to obtain a significant reduction in energy consumption. Furthermore, we see that idle listening is dominating the total energy consumption.

Finally, the energy consumption of nodes 2 and 5 is significantly higher than the energy consumption of the other nodes, because nodes 2 and 5 became routing nodes in our particular network setup. This behavior would have been difficult to find with micro-measurements on a single node. Thus a systems perspective is essential when evaluating the energy characteristics of sensor network protocols.

Acknowledgments

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