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An Effective Method for State-of-Charge Estimation in Wireless Sensor Networks

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ABSTRACT
This poster shows the work-in-progress results of an effective method for predicting the residual battery energy in WSN nodes including the battery behavior. This method uses a hybrid approach consisting of a deterministic part by counting credit points for any operation of the sensor node and a model-based State-of-Charge (SoC) estimation based on battery voltage and temperature. It is applied for Li-Ion accumulators on modified Tmote Sky motes. For demonstration purposes the method is used for cluster head selection in a cluster-based topology formation algorithm to ensure equal distribution of the cluster head role among the network nodes based on the residual energy.

Categories and Subject Descriptors
C.2.1 [**Network Architecture and Design**]: Wireless communication.

General Terms
Algorithms, Design, Measurement, Experimentation.

Keywords: Wireless Sensor Network, Battery Modeling, State-of-Charge, Load Balancing, Cluster Topology, Implementation.

1. PROBLEM DESCRIPTION
Wireless sensor networks are currently one of the most promising tools in information technology. One application targeted by WSN technology is logistics, especially monitoring of sensitive and perishable freight during transportation. This is done in the context autonomous logistic processes to enable fully automated supply chains. The WSN is used to gather, aggregate and preprocess the environmental parameters affecting the freight quality inside the transport compartment (e.g. a container). At the base station the retrieved sensor data is fused into a quality index of the freight to determine the quality leverage during the transportation process under given conditions. An imminent quality loss (e.g. due to failure of a cooling aggregate) may trigger route re-planning to the next available warehouse.

Two key features for the application of WSN systems are energy efficiency and robustness. To ensure robust and long-lived operation of the complete network load distribution within the WSN is an important aspect. There are several approaches to distribute the load within the network, e.g. based on probability [1]. Another reasonable criterion for load distribution is the remaining energy of each of the network nodes. Modeling the behavior of the battery is a prerequisite for this.

2. SOC ESTIMATION
Most of the previous work in the field of battery modeling originates from the area of ad-hoc networking for laptop-class systems (e.g. [2]). This class of systems imposes load currents to their batteries in the range of amperes. The battery models applied here inhibit load-dependent effects (e.g. charge recovery). But these effects are negligible for WSN systems, where peak load currents are in the range of tens of milliamperes. Due to these boundary conditions, a much simpler battery model for the prediction of battery condition may be used which is also more suitable for computation on small microcontrollers. The proposed model is based on the following two assumptions:

The battery's EMF (Electro-Motoric Force) which is the open-loop voltage of the battery, is known to be a robust measure for the relative State-of-Charge (SoC) of the battery [3]. The load current of a WSN node with RF communication switched off is close to this open-loop condition of the battery.

As batteries are electrochemical systems, the available amount of current drawn from a battery reduces with decreasing temperature (especially in the sub-zero regime). This is especially the case for logistics of refrigerated perishable goods.

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The estimation itself is based on a piecewise interpolation of mean discharge behavior measurement series performed for the given battery type. Using temperature and battery voltage, the remaining relative SoC can be estimated. In order to keep the computational overhead small, linear interpolation for the SoC-V-relation is used. Preliminary evaluation shows a difference between the model and measurement series of less than 5% in the temperature interval from 23°C to -20°C. The highest difference occurs for low SoC estimates.

3. HYBRID APPROACH

In order to reduce the overhead imposed by the SoC estimation (e.g. usage of ADC) we propose a hybrid approach by also assessing the energy consumption per each action of the WSN node similarly to HEED [1]. A sensor node usually has a finite set of operations (e.g. transmitting a message, receiving, sensing, etc.) with specific energy consumption E_{OP} for a given operation *OP*. The model for the total energy consumption is the sum of the individual E_{OP} as shown in equation (1).

$$E_{total} = \sum E_{OP} = E_{Transmit} + E_{Recieve} + E_{Sense} + E_{Sleep} \quad (1)$$

The consumed energy per operation is represented by a proportional number of credit points and also the total remaining energy of the battery is represented in credit point units within a counter. This counter is decreased with the operation-specific number for every operation carried out. The numerical values for E_{OP} are taken from off-line characterization of the hardware platform and the application. By combining this credit point counting with the previously described method for SoC estimation, battery behavior can be included in modeling remaining energy of WSN systems. This is done by updating the remaining credit points counter of the battery with the SoC estimate in a certain time interval (e.g. every hour). In order to update the battery counter using the relative SoC value the maximum capacity of the battery must be known.

4. IMPLEMENTATION

The proposed method for battery monitoring has been implemented on Moteiv Tmote Sky motes. As a battery a lithium-ion accumulator (Panasonic CGA103450) is used. The measurement of the battery voltage is done using a voltage divider because the ADC reference (2.5V) is less than the battery voltage (up to 4.2V). In order to avoid current drawn by the divider when not in use, its path can be opened using a switch. In software the deterministic credit point counting is implemented by subtracting operation-specific values from the battery counter value after each operation resulting in minimum overhead. In a fixed time interval, the battery counter is updated by the results from the SoC-estimation mechanism.

5. PROOF OF CONCEPT

As a proof of concept the battery energy estimation method has been integrated into a cluster-based topology formation protocol. The relative remaining energy is used as the criterion for cluster head election in a round-based manner. At the beginning of each round all nodes may announce themselves as cluster heads while listening for announcements of other nodes. The higher the remaining energy, the earlier a node will send its cluster head announcement. After the first node has sent an announcement all other nodes within reception range will join this cluster head. After a given time interval the current cluster head closes the current round and retriggers the cluster head election process.

For evaluation of the SoC estimation method, a scenario was selected where one node was placed in a climate chamber at -20°C while the other nodes were operated in room temperature. The cooled node has less maximum available energy and is proportionally less often selected as cluster head than the other nodes at room temperature.

6. FIRST RESULTS AND FUTURE WORK

Preliminary results for a computationally effective method for on-line SoC estimation were shown and applied in cluster-based topology control. In contrast to previous work the presented approach includes temperature behavior of batteries, which is especially important in refrigeration applications. The information provided by this method may be used for e.g. load balancing in various high-level applications. Future work will focus on extension to other battery chemistries (e.g. Ni-MH), inclusion of self-discharge effect of batteries, analyzing improvement by using other interpolation techniques and automatic detection of the absolute available battery energy.

7. ACKNOWLEDGMENTS

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