Poster Abstract: Using Batteries Wisely

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Abstract
We describe early results from a program of experiments to characterize battery operation in the WSN regime.

Categories and Subject Descriptors
C.4 [Performance of Systems]: Measurement techniques
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wireless sensor network, energy efficiency, battery-aware

1 Introduction
We study the discharge behavior of cheap, non-rechargeable batteries operating with low duty cycles, timing intervals of 10-1000’s of ms, and loads up to 10’s of mA. Our goal is to characterize the battery and investigate the feasibility of designing WSN applications that take battery internals into consideration.

maximize rest time?
load minimize load duration?

Figure 1. Batch operations or separate them?

For example, consider a (trivial) device that schedules two periodic operations: Should it schedule them sequentially, maximizing the rest time between loads, or should it separate them, minimizing the continuous load on the battery?

2 Background
The energy efficiency of WSN’s is typically evaluated in terms of total energy consumption, which is treated as a proxy for battery lifetime. This is true not only for simulations but also for on-device methods that are based on operation counting or coulomb counting. All of these techniques estimate the amount of charge drawn from the battery, without considering its electrochemical properties. But the way that charge is drawn from the battery affects how much can be extracted before the cut-off voltage is reached.

Modeling and optimization of battery discharge patterns is an active area of research for high-end, rechargeable batteries, such as electric vehicles and mobile devices. However, very few studies of the low-end batteries commonly used in WSN scenarios have been published.

Paper [2] reports a 52% improvement in the efficiency of CR2354 (LiMnO2) coin cells for radio transmission on MICA2DOT motes. However, these experiments used duty cycles of 25-50% and the results were largely based on DU-ALFOIL, which does detailed electrochemical modeling of Li-/Na-ion and NiMH rechargeable batteries. Paper [3] reports similar improvement for the same batteries and a RFM DR3000 radio and AVR micro-controller, focusing on the operation of the DC/DC voltage regulator.

3 Experiments
Our experiments are intended to abstract away the complexity of loads associated with operation of sensor nodes and efficiently measure large numbers of batteries. We have developed custom hardware that allows us to periodically schedule simple resistive loads on up to 40 batteries and record the voltage response. Our test batteries are Panasonic CR2032 (LiMnO2) coin cells, with 225 mA-h nominal capacity. The testbed is described in detail in [1].

When a load is applied to the battery (Fig. 2), there is an immediate drop in voltage, followed by a more gradual decrease ($V_{load}$). When the load is removed, the voltage partially recovers ($V_{recovery}$). As the battery’s residual capacity decreases, the voltage drop becomes larger and the recovery smaller (Fig. 3(a)). Finally, the battery reaches a (circuit dependent) cut-off voltage and can no longer support its load.

We use $V_{load}$ as a function of the total mA-h consumed for our proxy for battery lifetime. (Time is not used directly...
4 Results

We first created a set of reference batteries that were discharged for a known load and time (Fig. 3(b)). The state of charge (SoC) is a function of the open circuit voltage (OCV), which is approximated by measuring a fully rested battery.

It is well known that lower load consumes capacity more efficiently than a higher one. This rate-capacity effect is confirmed in our testbed, especially for very high loads (Fig. 4(a)). It is also well known that an intermittent discharge is more efficient than a continuous one. This is due to charge recovery in the battery during the resting interval. Figure 4(b) shows that loads of 120Ω (25 mA) with a 1.2% duty cycle are able to consume over 200 mA-h to a cut-off 2.3 V, while the continuous load can consume only about 10 mA-h.

The latter effect is particularly interesting because WSN’s are also designed to operate at a low duty cycle. For example, there have been many optimization studies of the energy-communication tradeoff for beaconing and listening intervals for LPL-based MAC protocols. A long-term goal of this work is therefore to investigate whether it is useful to include optimization of charge recovery in protocol design. Figure 4(c) shows four loads with similar average rate (250-300µA): The 300Ω (10mA) and 714Ω (4.2mA) traces show clearly the rate-capacity effect, but it also seems that their short (200ms) period takes a toll, compared to the higher 120Ω (25mA) loads with longer recovery times. In general, the total mA-h that can be consumed before reaching some cut-off voltage depends on both the load and the cut-off value. However, the data from these exploratory scenarios is still too limited to draw quantitative conclusions.

We also observe that manufacturing variability is quite high. Figure 3(a) shows a wide 95% CI for batteries with identical load histories. Some 1% of batteries also failed, a rate that may affect large deployments.

5 Conclusion

We have motivated a program of experiments measuring battery discharge behavior. Our first exploratory results suggest that battery effects may indeed be significant in the sensor network regime. However, further experimental work is needed to form strong quantitative conclusions.

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6 References

