Demo Abstract: Leakage-Aware Energy Synchronization on Twin-Star Nodes

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Abstract: Starting from the features and impact of energy leakage in ultra-capacitor powered systems, this demonstration highlights the design of a capacitor-only *Twin-Star* node, and a leakage-aware energy synchronization methodology.

Categories and Subject Descriptors: C.2.4 [Computer Communications Networks]: Distributed Systems

General Terms: Measurement, Design, Algorithms

Keywords: Leakage, Twin-Star, Energy Synchronization

1. INTRODUCTION AND MOTIVATION

Slow development in battery technology and rapid advances in ultra-capacitor design have led the research community to investigate the possibility of using capacitors as the sole energy storage for wireless sensor nodes. Compared with rechargeable batteries [1, 2, 3], capacitors owns several advantages: (i) more than 1 million recharge cycles; (ii) predicable remaining energy independent of discharge modes; (iii) more robust to temperature changes, shock, and vibration; and (iv) high charging and discharging efficiency. However, there is one major challenge in the capacitor only systems: *the energy leakage of ultra-capacitors is high when they reach their full capacity*, as shown in Fig.1. In other words, energy would be wasted if ultra-capacitors are not used appropriately.

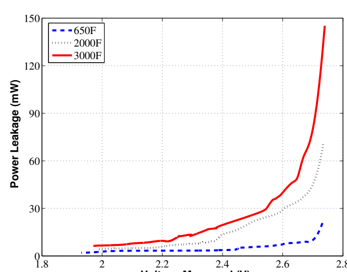

Figure 1: Leakage Rate vs. Voltages

In order to make the best use of available energy harvested from the environment, we propose and demonstrate a *leakage-aware energy synchronization* design for wireless sensor networks. As the first in-depth work to investigate the leakage behavior of ultra-capacitors and related control design, we model the leakage of ultra-capacitors using adaptive sampling methods. This model allows us to predict the lifetime and control the duty cycle of a node to achieve an equilibrium between energy supply and demand, namely synchronizing the

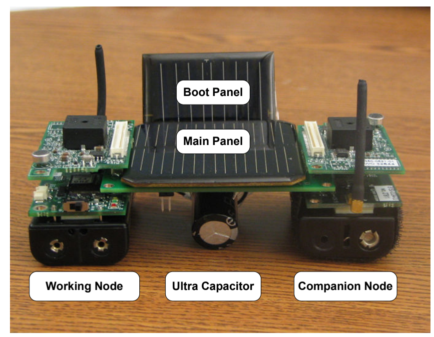

Figure 2: TwinStar Node Platform

behaviors of the node according to its current leakage state and energy level. In addition, in order to verify the modeling and scheduling design, we build the *Twin-Star* node, shown in Fig.2, as an add-on energy harvesting and management device using only ultracapacitor as energy storage device for existing sensor nodes. Twin-Star node provides several unique features for energy harvesting, monitoring, and control, such as a unique dual-panel design for stability and a companion node for visibility.

In the following, we firstly introduce the design of the Twin-Star node, and then present the idea of leakage-ware energy synchronization.

2. TWIN-STAR PLATFORM

Currently, solar energy is considered as the most durable choice for sensor networks for its high energy density and low fabrication cost comparing to other candidates such as wind, kinetic, vibration and etc. On Twin-Star nodes, solar panels are used for energy harvesting, as shown in Fig.2.

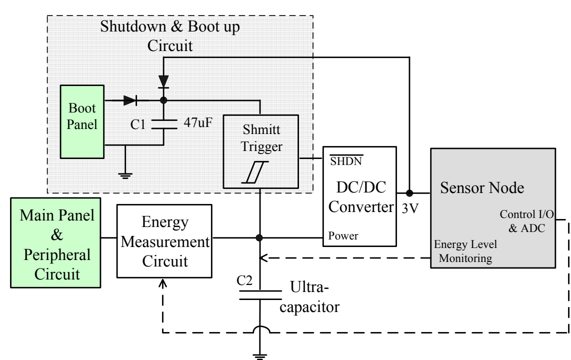

Figure 3: Example Circuit Schematics

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As the key part in the node design, a smart power storage and supply solution is designed as shown in Fig.3. It integrates an ultra-capacitor, DC/DC converter, and boot up circuits for avoiding DC state oscillation, node malfunction and energy waste. The basic idea for the design is that during the charging state, the DC/DC converter is kept shut down until the ultra-capacitor accumulates sufficient energy and reaches a voltage much higher than the DC/DC converter's working threshold; during the discharging period, the DC/DC converter is turned off when the voltage of the ultra-capacitor approaches the threshold. However, there is one issue that no appropriate power supply for the control circuit itself is available before enabling the DC/DC converter. This problem is solved by using a secondary small solar panel combining with a small ceramic capacitor to power the Shmitt trigger module, which is extremely energy efficient and used to control the on/off status of the DC/DC converter.

In the Twin-Star platform, several switches are reserved for supporting realtime measurement of remaining energy in the ultra-capacitor as well as the energy harvested from the environment. As an important option, a second node, powered separately from the all other parts, is able to be attached to the platform as an accompanying node for online measurements, data processing and recording in the experiments.

3. LEAKAGE-AWARE ENERGY SYNCHRONIZATION

Leakage-aware energy synchronization is achieved by embedding a *control layer* between the hardware and the application layer, as shown in Fig.4. The control layer predicts the lifetime of a node based on the energy harvesting, leakage, and consumption rates. The difference between the predicted lifetime and user-specified lifetime is used as the control signal to the duty cycle controller, which *suggests* a certain percentage of duty cycle change to the application. The control layer deals with two conditions: energy oversupply and undersupply. In the case of oversupply, the controller prevents the ultra-capacitor from charging to its limit, hence reducing the waste caused by leakage. In the case of undersupply, the controller signals the running program to reduce the energy consumption so as to ensure the aliveness of the sensor nodes.

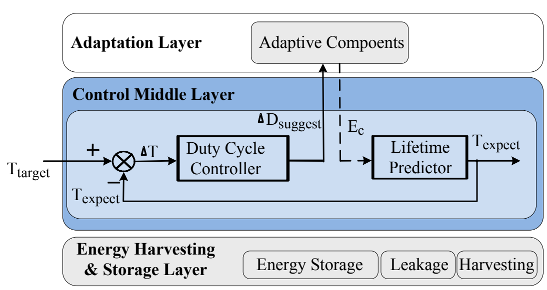

Figure 4: System Architecture

Specifically, sustainability T_{target} is defined as the duration a node can survive without ambient energy. We treat it as a configurable parameter, set by users according to the environment in which sensors are deployed. For example, in energy-rich environments such as deserts, users can set a smaller T_{target} to consume energy aggressively. On the other hand, in energy-poor and unpredictable environments, a large T_{target} is desired to ensure the aliveness of sensor nodes. Once T_{target} is chosen, it is used as the set point in the feedback control based design as shown in Fig.4. The difference between the target lifetime T_{target} and expected lifetime T_{expect} from the lifetime predictor is used as the input to the duty cycle controller, which suggests a certain percentage of duty cycle change to the adaption layer. Unlike conventional control designs, the duty cycle is *suggested* by the scheduler to the adaptation layer, which allows more flexibility in the design of the application layer. The rationale behind this is that the short-term duty cycle available might not always be synchronized with the activity demanded. For example, a node should not stop sending critical control messages disruptively simply because there is brief drop in energy supply. Short-term mismatching is tolerable because the energy storage unit(e.g., ultra-capacitor) can serve as a buffer.

4. DEMONSTRATIONS

Several prototype Twin-Star nodes are available for exhibition. A lamp is used for the light source of the demo and a oscilloscope is setup for signal monitoring, shown in Fig.5.

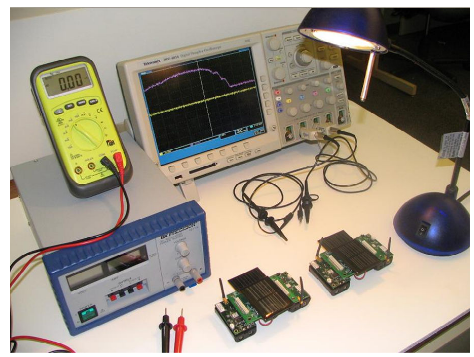

Figure 5: Demonstration Setup

In the demonstration, two levels of experiments will be performed according to the audience's requests.

- **Level 1: Life Show.** The testing node accumulates environment energy, then blinks the red LED with different frequency according to the energy level in the ultra-capacitor, and finally depletes the energy. The accompany node measures the energy in the capacitor and sends it to a laptop.
- **Level 2: Control Show.** Essential control signals are displayed in the oscilloscope for revealing the boot-up and power-down procedure of the testing node.

Level 1 demo is an application level example for depicting the concept of energy synchronized control and also demonstrate the functionality of the system. Level 2 is an advanced demo illustrating details of the control signals for boot-up and power-down.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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