2022 21st ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN) | 978-1-6654-9624-7/22/$31.00 ©2022 IEEE | DOI: 10.1109/IPSN54338.2022.00033

An Energy Supervisor Architecture for Energy-Harvesting Applications

Nurani Saoda
University of Virginia
saoda@virginia.edu

Wenpeng Wang
University of Virginia
wangwp@virginia.edu

Md Fazlay Rabbi Masum Billah
University of Virginia
masum@virginia.edu

Bradford Campbell
University of Virginia
bradjc@virginia.edu

ABSTRACT

Energy-harvesting designs typically include highly entangled application-level and energy-management subsystems that span both hardware and software. This tight integration makes developing sophisticated energy-harvesting systems challenging, as developers have to consider both embedded system development and intermittent energy management simultaneously. Even when successful, solutions are often monolithic, produce suboptimal performance, and require substantial effort to translate to a new design. Instead, we propose a new energy-harvesting power management architecture, ALTAIR that offloads all energy-management operations to the power supply itself while making the power supply programmable.

ALTAIR introduces an energy supervisor and a standard interface to enable an abstraction layer between the power supply hardware and the running application, making both replaceable and reconfigurable. To ensure minimal resource conflict on the application processor, while running resource-hungry optimization techniques in the supervisor, we implement the ALTAIR design in a lower power microcontroller that runs in parallel with the application. We also develop a programmable power supply module and a software library for seamless application development with ALTAIR.

We evaluate the versatility of the proposed architecture across a spectrum of IoT devices and demonstrate the generality of the platform. We also design and implement an online energy-management technique using reinforcement learning on top of the platform and compare the performance against fixed duty-cycle baselines. Results indicate that sensors running the online energy-manager perform similar to continuously powered sensors, have a 10× higher event generation rate than the intermittently powered ones, 1.8-7× higher event detection accuracy, experience 50% fewer power failures, and are 44% more available than the sensors that maintain a constant duty-cycle.

KEYWORDS

Energy-harvesting System Design, Dynamic Power Management

1 INTRODUCTION

The ubiquitous vision of the Internet-of-Things is greatly hampered by the "battery problem". As reliable power sources like wall power are not always available where IoT devices are deployed, many devices use batteries as their main power source. Batteries, due to their limited cycle count [5, 35], potential long recharge times [32, 47], and hazardous nature [25, 29] have become a less attractive option as a power source for applications that require low maintenance and life-long service. To eliminate these drawbacks, certain ubiquitous applications which previously relied on batteries as their power source, have adopted energy-harvesting power supplies as an alternative. Such applications include building and home automation, smart industrial monitoring, and smart wearable applications. Recent works have even pushed the boundaries of smart sensing by introducing energy-harvesting medical implants [16, 31], wearable activity tracker [28, 42, 46], micro-satellites for space observation [27], and industrial and residential monitoring [1, 9, 14]. Though energy-harvesting systems are making their way into mainstream sensing applications, a vast majority of the commercial off-the-shelf IoT sensors still rely on batteries [10, 20]. Unfortunately, converting a battery-powered application to energy-harvesting is not as straightforward as replacing the battery with a harvester. Harvestable energy is usually very limited, intermittent, and unpredictable which requires special hardware and software support to achieve useful operation [8, 11, 17, 48].

The operating principle of battery-less energy-harvesting applications can be broadly categorized into two approaches: intermittently-powered and energy-neutral. The first category of sensors harvest energy from the environment through solar, RF, thermal, and kinetic sources, store the energy momentarily in a capacitor, operate until the capacitor is depleted, and repeat this cycle continuously, while the latter store energy for future use and regulate the operational frequency of the sensor to ensure that the outgoing energy roughly matches the combined incoming and stored energy. Various designs implement these techniques to realize energy-harvesting systems, including hardware-based [12, 18, 24, 49] and software-based solutions [7, 11, 26, 36]. In both cases, however, energy-harvesting systems typically consist of a single processor along with an energy-harvesting front-end and application peripherals, where the processor is responsible for both energy management tasks (i.e. tracking the amount of energy stored, controlling the wake-up time interval, turning on peripherals at specific voltage levels, etc.), and application-specific tasks (i.e. sampling, computation, and transmitting radio packets). While this monolithic architecture can be simple and efficient for the intended application, adopting these platforms to build new applications can be quite difficult due to tightly-coupled implementations of energy-management code and application code. The intertwined application and energy management requires the developer to be responsible for understanding not only how to manage energy and correctly implement the application, but also how the two halves might interact.

978-1-6654-9624-7/22/$31.00 ©2022 IEEE
DOI 10.1109/IPSN54338.2022.00033