Demonstration of an Energy-Aware Task Scheduler for Battery-Less IoT Devices

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ABSTRACT

Tiny energy harvesting battery-less devices present a promising alternative to battery-powered devices for a sustainable Internet of Things (IoT) vision. The use of small capacitors as the energy storage, along with a dynamic and unpredictable harvesting environment, leads these devices to exhibit intermittent on-off behavior. As the traditional computing models cannot handle this behavior, in this demo we present and demonstrate an energy-aware task scheduler for battery-less IoT devices based on task dependencies and priorities, which can intelligently schedule the application tasks avoiding power failures.

CCS CONCEPTS

• **Computer systems organization → Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

KEYWORDS

battery-less, energy harvesting, energy-aware, task scheduler, sustainable IoT

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1 INTRODUCTION

Currently, most Internet of Things (IoT) devices rely on batteries, which can provide stable power, but even when rechargeable, are short-lived with a lifetime limited to a few years at best. These batteries are bulky, temperature sensitive, and potentially dangerous if not carefully protected. As the number of IoT devices increases, maintaining, replacing, and disposing of billions of hazardous batteries becomes expensive and environmentally unacceptable.

To overcome all these battery-related issues and achieve the sustainable IoT vision, battery-less IoT devices that completely depend on harvested energy from their environment have been presented. The available energy is stored in small capacitors, which are cheaper and last longer compared to batteries due to their resistance to capacity degradation. With all advantages and improvements, power failures can still occur at any time, as the harvestable power sources are usually weak and unreliable.

Traditional computing models and static sequential applications assume a stable power supply during the execution and cannot handle such behavior, losing the data and forward progress. To solve this problem, different task-based computing models and schedulers [5] [3] have been proposed. However almost none of them make use of energy-related information (e.g., capacitor voltage, harvesting power, energy consumption) to make more intelligent scheduling decisions.

In this demo, we present an energy-aware task scheduler for battery-less IoT devices that can intelligently decide when to execute each application task considering the harvested and available energy, energy cost of the task, as well as its priority. We validate our scheduling approach based on a real implementation in a battery-less prototype device, and evaluate it based on emulated experiments.

2 SYSTEM OVERVIEW

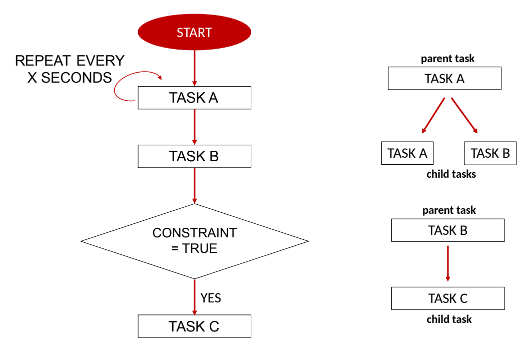

Figure 1: Atomic task order considering constraints and parent/child relationships

The application is implemented as a directed graph of tasks, representing the parent/child relationship, as shown in Figure 1. Each task can have one or more child tasks, which are selected and executed based on different constraints such as task periodicity, required number of samples, data availability, or a mathematical comparison on output data. In the example, the scheduler starts with Task A, which is the initial (parent) task. It has two child tasks, Task A that can be considered as parent and child task of itself due to its periodicity, and Task B. Task B has only one child task, Task C, which will be executed only if the constraint is satisfied.

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When multiple tasks are available to be executed at the same time (e.g., after executing Task A, the scheduler could execute either Task A or Task B), the task with the highest priority will be executed first. Nevertheless, the scheduler could also be extended with more elaborate scheduling algorithms, that, for example, consider long-term task execution rate rather than just immediate priority [2]. When a task is finished, its child tasks are added to the task list, but only if constraints are satisfied, and subsequently, the process is repeated. As we consider the energy awareness in our scheduler, the required capacitor voltage threshold for each task must be calculated, and only when the required threshold is reached and all constraints are satisfied, the task will be executed.

It is important to note that our energy-aware task scheduler stores all the necessary data in flash, preventing their loss in case of a power failure. It tries to avoid power failures as much as possible, and they will only occur if the harvested energy is insufficient to keep the device powered during its lowest power state (i.e., deep sleep state).

3 DEMONSTRATION USE CASE

The battery-less low-power node, nRF52840 [4], will start with measuring the temperature, which is a periodic task, and will be rescheduled every 1 second. When the device measures the temperature, the value is put in an array, with a predefined size, and stored in the flash. When the required number of samples are collected, the device calculates the average temperature value. After the compute task is finished, the device is ready to send the data to the receiver node. In order to enable the communication, both devices are equipped with a Bluetooth Low Energy (BLE) radio supporting the BLE mesh features. After the data is successfully sent, as a confirmation, the LED will turn on, after which one application cycle ends.

To emulate the use of energy harvesting and a capacitor, the environment emulator (EE) [1] is used. It is connected to the battery-less node, providing a variable voltage to it in line with the voltage that would be provided by a real capacitor. The EE acts as a virtual capacitor, and is able to emulate a wide range of energy harvesting and energy storage configurations.

4 EXPERIMENTAL RESULTS

For the EE experiments, we considered two main strategies: (i) the constant harvesting rate during the full time of the experiment, and (ii) different harvesting rates that are switched every 35 seconds during the experiment to check if our scheduler is able to dynamically react to environmental changes. Based on the defined IoT application and manually set configuration of the EE, we performed different experiments, considering different capacitor sizes and harvesting rates in order to validate our approach.

The energy-aware task scheduler is able to react to environmental changes, and adapt the execution based to the new situation, as shown in Figure 2. The experiments was performed using the capacitor of 4.7mF. The capacitor acts based on the provided harvesting power and calculated voltage threshold, and as the harvesting rate increases more task cycles (presented as black dots) will be executed. As the LED task is the highest energy consumer, it will deplete almost all the available energy, and force the device to sleep until the next voltage threshold for the new cycle is reached. With the properly defined voltage thresholds for each application task, our energy-aware task scheduler can keep the device on during the full experiment, completely avoiding power failures.

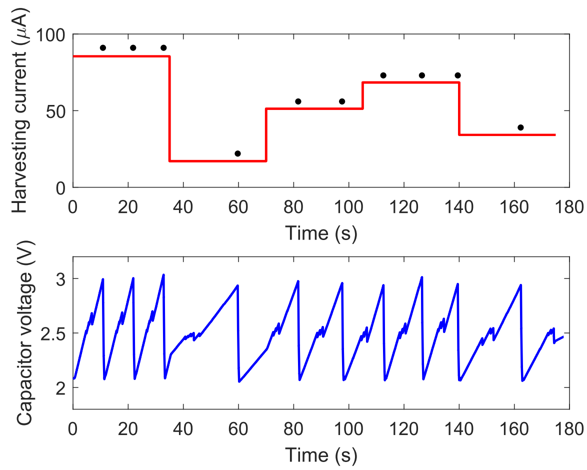

Figure 2: Capacitor voltage behavior when executing different tasks considering different energy harvesting rates during the experimental time

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REFERENCES

[1] Pieter De Mil, Bart Jooris, Lieven Tytgat, Ruben Catteeuw, Ingrid Moerman, Piet Demeester, and Ad Kamerman. 2010. Design and Implementation of a Generic Energy-Harvesting Framework Applied to the Evaluation of a Large-Scale Electronic Shelf-Labeling Wireless Sensor Network. *EURASIP J. Wirel. Commun. Netw.* 2010, Article 7 (2010), 12 pages. https://doi.org/10.1155/2010/343690

[2] Carmen Delgado and Jeroen Famaey. 2021. Optimal energy-aware task scheduling for batteryless IoT devices. *IEEE Transactions on Emerging Topics in Computing* (2021), 1–1. https://doi.org/10.1109/TETC.2021.3086144

[3] Josiah Hester, Kevin Storer, and Jacob Sorber. 2017. Timely Execution on Intermittently Powered Batteryless Sensors. In *Proceedings of the 15th ACM Conference on Embedded Network Sensor Systems* (Delft, Netherlands) *(SenSys '17)*. Association for Computing Machinery, New York, NY, USA, Article 17, 13 pages. https://doi.org/10.1145/3131672.3131673

[4] Nordic Semiconductor. 2021. nRF52840 DK - nordicsemi.com. https://www.nordicsemi.com/Products/Development-hardware/nrf52840-dk

[5] Kasim Sinan Yildrim, Amjad Yousef Majid, Dimitris Patoukas, Koen Schaper, Przemyslaw Pawelczak, and Josiah Hester. 2018. InK: Reactive Kernel for Tiny Batteryless Sensors. In *Proceedings of the 16th ACM Conference on Embedded Networked Sensor Systems* (Shenzhen, China) *(SenSys '18)*. Association for Computing Machinery, New York, NY, USA, 41–53. https://doi.org/10.1145/3274783.3274837