Demo Abstract: Energy-Aware Battery-Less Bluetooth Low Energy Device Prototype Powered By Ambient Light

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ABSTRACT

Bluetooth Low Energy (BLE) is emerging as an Internet of Things (IoT) technology that effectively connects small devices and sensors. It can enable many smart building use cases such as automation and control, environmental condition monitoring, and indoor location services. The BLE mesh standard provides a friendship feature to support Low Power Nodes (LPNs). We demonstrate how these BLE LPNs can support communication (uplink, downlink, or bidirectional) when powered by ambient indoor light using a mini solar panel and a small capacitor for energy storage. Being batteryless, it can exhibit intermittent behaviour with periodic ON and OFF states. However, with the knowledge of the capacitor voltage, an energy-aware LPN can try to avoid the OFF state. It can delay the execution of upcoming tasks by switching to an SLEEP state (consuming minimum energy) and provide some time to recharge the capacitor. We consider an example use case of monitoring temperature and room occupancy. The mesh nodes in the network can send instructions (such as turn-on an LED or a buzzer) to the batteryless LPN that should be executed by it. We study the use-case with real experiments on the communication feasibility of an energy-aware BLE LPN in a network and characterize the capacitance behaviour by placing a 6 W light bulb at 120 cm from the solar panel.

CCS CONCEPTS

• **Computer systems organization** → *Embedded software*; • **Networks** → *Network management*; • **Hardware** → **Renewable energy**.

KEYWORDS

Bluetooth low energy, Batteryless low power node, Energy harvesting, Light energy

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1 INTRODUCTION

Smart buildings are the perfect use case for the Internet of Things (IoT) technologies. Usually, one of its requirements is to enable energy-constrained devices to interact with each other reliably at a low cost. The Bluetooth Low Energy (BLE) mesh network standard, which supports a wide range of IoT use cases, provides a friendship feature. This feature allows Low Power Nodes (LPNs) (traditionally battery powered) to rely on another node in the network known as friend node (FN) to receive incoming packets and temporarily buffer them [1]. Meanwhile, the LPN can be turned-off or switch to SLEEP state and periodically wake up to poll the FN to receive the buffered packets. This enables downlink communication at very low power consumption.

As batteries have limited lifetime and recharge cycles, they need to be replaced manually and frequently. Thus, the maintenance cost of the network increases. To reduce this, we power the BLE LPN using indoor ambient light and a small capacitor to store energy. The batteryless BLE LPN can be either unaware of available voltage of its capacitor or aware of it. An energy-unaware LPN always tries to execute the task and can go into an OFF state if not enough energy is available, resulting in intermittent behaviour. Whereas, an energy-aware LPN can avoid this intermittent behaviour by executing the tasks only if it has enough energy stored in the capacitor to execute the task. This work demonstrates an energy-aware batteryless BLE LPN that can bidirectionally communicate with other nodes in the mesh network. We use off-the-shelf low-cost hardware to design the prototype. The LPN harvests from a small 4x2 cm^2 solar panel to power the BLE device. One of the benefits of such batteryless LPNs is that the existing infrastructure does not need any changes. The LPNs are fully compliant with the BLE mesh standard and only needed to be associated with the network using the network and application keys.

2 SYSTEM DESIGN

The batteryless LPN design requires a power management board (PMB) that enables charging of the capacitor, regulating the output voltage to the load, and extracting maximum power from the solar cell. Figure 1 shows the prototype of the demonstrator network and batteryless LPN. In indoor IoT scenarios, natural sunlight is often not available (e.g., during nighttime, or in rooms/corridors without windows). Therefore, we evaluate the feasibility of harvesting energy from artificial light (i.e., a 6 W Warm White LED light bulb).

A 6-cell mono-crystalline solar panel (ANYSOLAR-SM141K06L) is chosen due to its high efficiency (25%) and life. The panel is connected to the Epeas-AEM10941 PMB [2] which is configured to supply a stable voltage of 3.3 V. The PMB supplies the output voltage only when it charges the connected capacitor to a specific turn-on

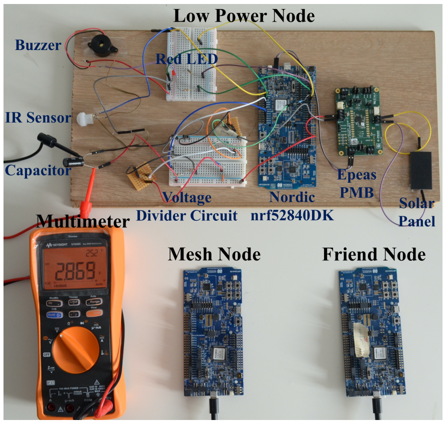

Figure 1: Network Setup and Batteryless LPN Prototype

voltage (can be configured between 2.30 V and 4.04 V). It stops the supply when the capacitor voltage goes below the turn-off voltage (can be configured in a range from 2.2 to 3.60 V). We chose small capacitors of capacitance 1, 4.7 and 10 mF, which can be configured to be charged up to 4.5 V by the Epeas PMB. The BLE nodes are built on top of the Nordic nRF52840 DK board [3] running Mesh SDK v.4.2.0. We modify it so that the LPN saves the context of the associated FN during the friend establishment phase so that it avoids reassociation on restart. It can be observed from Figure 1 that three Nordic boards are used, of which two are powered by USB. These USB-powered boards act as a mesh node and a friend node. The third Nordic DK board, which act as the batteryless LPN, already has a temperature sensor; additionally, a buzzer, an LED, and an IR motion sensor are attached to its General Purpose Input/Output (GPIO) pins. Moreover, an additional circuit imitating a voltage divider is also attached to an Analog to Digital Converter (ADC) pin to sense the capacitor voltage. This circuit is required because the ADC pin can read inputs only up to the maximum operating voltage (3.3 V). Moreover, to reduce the continuous current consumption due to the added resistors, MOSFETS are used as a circuit switch. Additionally, a multimeter is connected to the capacitor to log its voltage variation in real-time for debugging purposes.

3 DEMONSTRATION USE CASE

We demonstrate that a batteryless LPN can send the temperature sensor data to a Mesh node at a fixed interval. It also captures the IR motion-detection events and sends relevant data about them to the Mesh node. The BLE Mesh node can send a command to turn-on the LED or the buzzer, depending on if it receives a certain number of temperature sensor readings or the IR sensor indication, respectively. As these DL instructions are destined to the LPN, they are first temporarily buffered at the FN. Based on its available energy, the LPN periodically wakes up and polls the FN to receive those instructions. If there are no data packets saved at the FN, it indicates this by sending a Friend Update (FU) message. A video of our demo can be found on YouTube [4].

4 EXPERIMENTAL RESULTS

The experiments are performed to check the variations in the capacitor voltage for different capacitor sizes. The temperature sensing interval is fixed to 10 s, and the polling interval to 25 s. We initiate the IR events manually by moving our hand in front of the sensor at an interval of 15 s. The Mesh node should send instructions on receiving 5 temperature data or IR events. The Epeas board is configured such that it charges the capacitor to a maximum of 4.5 V with turn-on and turn-off voltage of 3.67 V and 2.8 V, respectively.

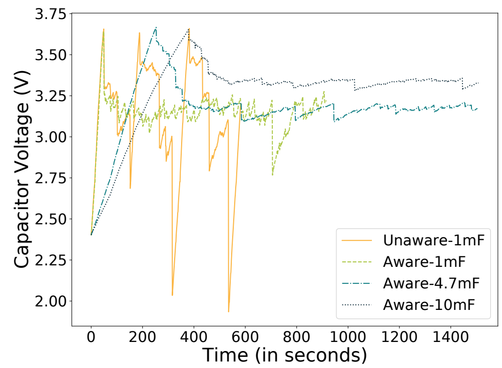

Figure 2: Capacitor Voltage Variation for different capacitance values

Figure 2 shows the results for three capacitor sizes 1, 4.7 and 10 mF for a light bulb placed at 120 cm. At this distance, the solar panel harvests 250 μW power. From Figure 2, it can be observed that the capacitor voltage of an energy-unaware LPN periodically drops below the turn-off voltage (2.8 V) and remains in an OFF state until its voltage reaches 3.67 V. However, the energy-aware LPNs with different capacitor sizes are always in an ON state, and their voltages stay above the turn-off voltage. Furthermore, the smaller the capacitor size used, the faster it can charge and discharge. Therefore, a 1 mF capacitor is able to charge faster to the turn-on and threshold voltage.

5 CONCLUSION

In this demo, we demonstrated a working prototype of energy-aware batteryless BLE LPN supporting bidirectional communication, which operates by harvesting power from indoor light. It is observed that the energy-aware LPN maintains an ON state while supporting the use-case of monitoring temperature and room occupancy.

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