No Batteries Needed: Providing Physical Context with Energy-Harvesting Beacons

Nurani Saoda
University of Virginia
ns8nf@virginia.edu

Bradford Campbell
University of Virginia
bradjc@virginia.edu

Abstract

Battery-powered digital beacons have played a significant role in shrinking the gap between physical and digital world. At the same time, ubiquitous sensing encourages tiny, unobtrusive, energy-harvesting devices to eliminate the limited lifetime of battery-powered devices. In this paper, we design a new fire-and-forget room number broadcaster beacon to investigate the feasibility and performance of such a design point. We study how several factors including different deployment spaces, the storage capacity of the harvester, indoor light intensity levels, and spatial position of the receiver impact the performance in three real-world deployments. We find that the 95th percentile of inter-packet reception time is 35 s or less in a lab space with exposure to sunlight and indoor lights, 29 s or less in an industrial plant with indoor lights, and 405 s or more in office rooms. With strategic beacon placement and a light intensity level of only 390 lx, performance can be improved by 61%. We believe that these results will help guide future energy-harvesting beacon deployments. We also outline possible improvements for future energy-harvesting beacon designs.

CCS Concepts

• **Computer systems organization → Sensor networks**; **Embedded systems**.

Keywords

Energy Harvesting Systems, Bluetooth Low Energy Beacons, Deployment

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1 Introduction

Energy-harvesting sensors and other wireless devices that scavenge their own energy are becoming more prevalent as avoiding battery replacement is seen as necessary to enable scaling up the number of Internet of Things devices. With the increased growth and interest in this area, a range of energy-harvesting system designs encompassing both hardware and software has emerged as potential solutions to the intermittency and unreliability inherent to using harvested energy sources. Researchers have proposed schemes with supercapacitor buffers [11, 14, 16], multi-tier energy backup [9, 11], software checkpointing [1, 8, 15], purely intermittent operation [3, 5], and energy-adaptive operation [4], among other techniques, and at least in the near future it is unlikely that a single platform will emerge as the de-facto energy-harvesting standard. Even with battery-powered devices designs span from fixed primary cells to rechargeable batteries [12, 13].

A variety of energy-harvesting approaches may be viable, and different architectures may be well suited for different applications. In this work we study a particular design point, namely fire-and-forget devices with a simple operating principle: harvest a usable amount of energy, perform some useful and complete operation, and then resume harvesting. This design point prioritizes simplicity to reduce both hardware and software costs. Our goal is not to advocate for this approach instead of alternatives, but to investigate the performance of this approach in different environments and contexts to understand its viability (or lack thereof) for different applications. This will help guide future system developers when considering energy-harvesting options for their application.

These simple energy-harvesting sensors that push towards nearly-invisible, stick-on or smart dust devices can be quite useful as digital beacons that periodically chirp sensor data, proximity information (as in iBeacon or Estimote), pointers linking the physical and digital worlds (as with Eddystone), or heartbeat packets. We extend this concept by introducing an energy-harvesting device designed for office settings that periodically sends the room number physically dialed in on the device itself. This provides a digital counterpart to the ubiquitous room number familiar to occupants, and can provide rough indoor location information to user-carried devices or other sensors in the environment.

While the room-number transmitter and other beacons can easily be, and often are, battery powered, will they work as small, indoor photovoltaic powered energy-harvesting devices? How long will a listener have to wait for a beacon? How many beacons should be deployed in a space, and what is the impact of the placement? How do office environments compare to more industrial environments? How do the ambient lighting level and on-device energy reservoir affect the performance? Understanding the answers to these and other questions will inform the utility of this approach and the results will set a benchmark for future deployments considering this approach.

Our study consists of deploying several of the fire-and-forget sensors in various environments and analyzing the resulting stream of beacons. We find that 95% of the time a listener has to wait 35

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