Energy efficiency and accuracy of solar powered BLE beacons

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A R T I C L E   I N F O

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A B S T R A C T

In the last decade, there has been an exponential growth in the numbers of wireless devices which connect to the Internet. At the same time, the networks size have grown larger than ever before. Bluetooth Low Energy (BLE) beacons are an attractive solution for a plethora of Internet of Things (IoT) applications, from micro localization to advertisement and transportation. BLE beacons are small, low cost devices that are capable of providing contextual and locational information to the users. In the fifth generation (5G) ecosystem, many BLE beacons are expected to be deployed among other devices. In 5G wireless networks era, sustainable and energy aware networks are vital to usability and performance. An appealing solution for energy efficiency is energy harvesting for wireless devices. To reduce the maintenance and increase the lifespan of networks that include such devices, solar powered beacons can be used. In this paper, the performance of solar powered BLE beacons is examined in terms of energy efficiency and accuracy. A comparison between the solar powered BLE beacon and battery powered beacon is also discussed. Experimental results shown that solar powered BLE beacon is a promising solution with minimum energy requirements and high accuracy.

1. Introduction

The substantial growth in the Internet of Things (IoT) over the last few years has resulted in the development and popularity of many new wireless devices. One device in particular that has grown in popularity is the Bluetooth Low Energy (BLE) beacon. BLE beacons are small, low cost, low power consuming, and configurable devices. Many of the applications best suited for these beacon devices is indoor localization, using Received Signal Strength Indicator (RSSI) techniques [1–3]. They operate by simply broadcasting identifiers at a specified transmit power and interval. However, as wireless technology improves and hardware decreases in price, more and more devices continue to add to the density of all wireless networks, both indoors and outdoors. As the added devices take up more resources there is a lack of available bandwidth.

The issues regarding resource limitations and available bandwidth leads to the continuous development of mobile network standards and thus, the fifth generation (5G) is the next mobile wireless system to emerge. 5G aims to support more users, increase capacity, and lower latency and power consumption to better accommodate developments within the IoT. Specifically, energy consumption, is a vital aspect to the 5G ecosystem. The large density of devices and high throughput, relies on sustainable and energy aware design. If devices are unable to keep up with the power demands of the network, loss of service, network degradation, or even failure could occur. Current technological advancements have been made specifically with energy consumption in mind, both in software and hardware.

A common example of hardware energy-aware design is energy harvesting using solar power [4–7]. Solar powered devices rely, to varying degrees, on sunlight energy as a power source rather than conventional battery or wired technology. To their advantage, they do not require power maintenance in the form of replacement or recharging, common to most wireless devices. Once deployed, the average solar cell has a lifespan of 20 years while maintaining 80% rated power production [8]. This in turn increases the lifespan of the wireless network substantially, although solar power may only be suitable in applications where sufficient light is available.

Bluetooth Low Energy (BLE) is an example of energy-aware design that leans more towards software [9]. BLE is a wireless standard developed by Bluetooth Special Interest Group for the purposes of low power consumption. It operates on the 2.4 GHz band and maintains a large amount of data. Common applications for BLE include smart office energy management, museums, and attendance management. Frequently these applications are implemented with beacons [11–13].

With the fifth generation of wireless systems soon to deploy, a mix of energy aware technologies are being implemented into devices to meet the energy requirements of various networks. A great example of this is...
solar powered BLE beacons. These beacons can be used for indoor location services, among many other beacon applications that are able to provide sufficient light energy.

This paper focuses on the feasibility of utilizing solar powered BLE beacons. It evaluates the energy efficiency and accuracy of a solar powered beacon and compares it to a battery powered competitor.

The main contributions of this paper are:

- Experimentation and comparison of a solar powered BLE Beacon and a battery powered BLE Beacon in terms of energy consumption and localization accuracy. Two levels of transmission power were examined for each beacon.
- Design and implementation of a simple Android application to collect the Received Signal Strength Indicator (RSSI) of each beacon.
- Through comprehensive performance evaluation, the efficiency of each beacon at a complex indoor environment is demonstrated.

The rest of this paper is organized as follows; In Section 2, an overview of the background and related works regarding BLE devices is discussed. Section 3 introduces the experimental setup for the energy efficiency and accuracy measurements followed by Section 4 with the experimental results and analysis. Finally, the conclusion is in Section 5.

2. Background and related work

In this section, the related work in the area regarding BLE beacons is reviewed, followed by a brief description of the iBeacon protocol.

2.1. Related work

There are a multitude of BLE beacon hardware devices and manufacturers. The Estimote [14], Gimbal Series 10 [15], Glimworm [16], and Kontakt.io [17] are among the wide variety of beacons available on the market [18]. These devices, and many like them, tend to implement Apple’s iBeacon protocol [19] and/or Google’s Eddystone protocol [20]. These beacons are fully wireless and operate on coin cell batteries, or in some cases even solar power. BLE Beacons are a popular solution for indoor location [21–23], tracking [24].

In [23], the authors focused on achieving unambiguous user positioning using practical BLE beacons with multiple discrete power levels. A novel denoising autoencoder-based BLE indoor localization (DABIL) method is proposed in [22], to provide high-performance 3-D positioning in large indoor places. A detailed study of BLE fingerprinting is provided in [21]. BLE beacons for indoor localization was also examined in [25,26].

BLE beacons have limited energy resource, hence energy harvesting approaches should also be examined [27–29]. The literature on the topic of solar powered BLE beacons is limited. Much of it may have to do with the lack of solar powered beacons available on the market. In [30], the authors attempt to determine the feasibility of solar powered beacons. In their experiment, they modify a Yunzi BLE beacon to utilize a third party solar panel as a power source. The experiments determined that with a transmission power of 0 dBm and an advertising interval of 800 ms, the Yunzi beacon can be powered by a 300 cm² solar panel. The work presented in [31] outlines the development of an inkjet printed solar powered beacon device. Although it is not a BLE beacon that operates on the 2.4 GHz bandwidth, the ideas and concepts in this research are still relevant. The end device is a flexible, low cost wireless beacon that operates on solar power and transmits packets at 800 MHz.

The fifth generation of communications is emerging in the near future. New challenges and characteristics of such networks will have to be understood and overcome. Specifically, the density of devices in a 5G wireless network will be very high. The work presented by [32] investigate beacon collisions and avoidance mechanisms in dense Wi-Fi networks. The research considers both the 2.4 GHz band as well as 5 GHz, making the findings relevant for current networks and future 5G developments.

2.2. iBeacon technology

iBeacon is a packet layout format designed specifically for BLE beacons [19]. It was first introduced by Apple in 2013. The packet information was designed in such a way to make geofencing and regioning simple.

There are three distinct fields defined in the iBeacon packet format:

- A Universally Unique Identifier (UUID), which is a unique identifier for a proximity region (16 bytes), for instance the beacons that are used in a specific building.
- A Major value (2 bytes), helps to differentiate beacons of a specific brand ‘X’ present in a location such as a city ‘Y’.
- A Minor value (2 bytes), helps to identify the beacon of any brand ‘X’, in city ‘Y’ and department ‘Z’

These three fields are configurable by the application developer, and are generally used to region, and sub-region areas with BLE beacon devices. User devices that are BLE enabled and running either iOS 7.0+ or Android 4.3+ operating systems can be used for beacon related services [19].

3. Experimental setup

In this section, we initialize experiments on the energy consumption and the accuracy of the solar beacons and compare the results with a popular battery powered beacon.

3.1. Equipment

Although there is a multitude of BLE beacon devices, there are limited choices of solar powered beacons in comparison. For the following experiments, the Cyalkit-E02 solar powered BLE sensor, developed by Cypress is used, shown in Fig. 1. The price of Cyalkit-E02 BLE beacon is competitive with some of the higher end beacon devices on the market, such as the Estimote BLE beacons [14].

The E02 BLE beacon is able to operate on any light source greater than 100 lx. It is small in size at only 25 mm in diameter, and the included solar cell on the beacon measures at 15 mm × 15 mm. The E02 also includes two sensors: temperature and humidity. The beacon is fairly configurable, though unlike many of the battery powered beacons that configure wirelessly, it must be configured via the debug board, shown in Fig. 2. A full guide for beacon configuration and setup can be seen in [34].

An important insight when working with the E02 is that one field in particular, the transmission interval, cannot be configured. This is because an on-board power management chip governs the transmission interval based on the available light energy. At most, it will transmit every 3 s. Hence, this is a limitation when it comes to comparison with other beacons.

The transmit power however is configurable, and is capable of transmitting up to +3 dBm. The full Power Management Integrated Circuit (PMIC) specifications can be referenced in [35].

![Fig. 1. Cyalkit-E02 BLE beacon [33].](image-url)
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