Whitepaper

Supercharging Beacons with Bluetooth 5

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In this paper, we discuss advertising extensions and other significant features added in Bluetooth 5 that can be used to build second-generation beacons with expanded capability, and thereby enable more feature-rich proximity-aware applications.

Introduction

Bluetooth® Low Energy (BLE) beacons have been deployed in the market for several years now and have become a leading technology choice for proximity-aware applications. The low power and simplicity of BLE, coupled with its ubiquitous use in smartphones, make low-cost, battery-powered beacons achievable and enables the broad adoption of beacons for location-based services embedded in smartphone apps. Until now, BLE beacons relied on the structure of advertising packets originally defined in Bluetooth v4.0, stuffing beacon content into a limited 31-byte payload. Bluetooth 5 introduced several major enhancements for BLE, including new PHY layers and Advertising Extensions. These enhancements add significantly more functionality and flexibility to the advertising mechanisms, including much larger advertising packet capacity. In this paper, we lightly review beacon basics and then discuss these new Bluetooth 5 features and how they enable second-generation beacons with fuller, richer content. A recommended prerequisite for this paper is the introductory paper from Wireless Congress 2016 titled Developing Beacons with Bluetooth Low Energy Technology [1].

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A Brief Review of Beacon Basics

What Are Beacons and How Are They Used?

In general terms, a beacon is a small, inexpensive wireless device, often battery-powered, that uses Bluetooth Low Energy to advertise its presence. A beacon is often described as the RF version of a lighthouse, repeatedly broadcasting an identifier that is recognized by other devices within its range. A smartphone or tablet can use the beacon's identifier to trigger actions based on the knowledge that it lies within the beacon's proximity. The notion of proximity is important because beacons do not directly provide information about their exact physical location; a device receiving the beacon is only aware that it's near the beacon1. Beacons can also be moveable.

It is important to note that the Bluetooth Special Interest Group (SIG) does not define a beacon standard. Instead, there are various beacon pseudo-standards from the large operating system providers like Apple's iBeacon™ and Google's opensource Eddystone™, and there are many proprietary beacon formats that are used in closed systems.

Two Beacon Usage Models

Beacons are typically used in one of two scenarios. The first and most common was described above, whereby beacons placed either in a fixed location or attached to a movable object, are detected by a smartphone/tablet and trigger behaviors based on their proximity. An example of this is suggesting web content relevant to physical context, such as presenting the schedule at a bus stop. Another example is providing indoor navigation by using a network of beacons installed strategically around a large facility like an airport or hospital

The second scenario uses a fixed scanner node to monitor objects tagged with beacons as they pass through its monitoring area. The scanner typically is part of another network that reports these beacon IDs to a back-end application. This model might apply to geofencing for expensive tools and equipment, counting the movement of livestock, or tracking cargo.

Proximity-Aware Example Applications

Both usage scenarios described above rely on proximity awareness. In the first scenario, a user's smartphone comes into proximity with a beacon. In the second, beacons come into proximity with a beacon-scanning node. Both models are finding applications in retail and commercial businesses.

The earliest applications for iBeacons focused on the retail shopping experience. Beacons distributed throughout a store allowed loyalty apps to present notifications to users with personalized messages based on their purchasing history and location within a store. Some beckon passersby with enticements on special sale items. Most large retailers today are either using beacons actively or testing them in field trials to measure ROI.

Other applications include point-of-sale systems, such as vending machines. For example, when a customer approaches a beacon-enabled vending machine, the customer's smartphone can display links to a website suggesting favorite items or a menu of secure payment options. A similar use case is in trials at fast-food drive-throughs. If customers already used a restaurant's app to pre-select their order, the beacon allows the app to detect when they have arrived at the restaurant, and where they are parked, ready to pick up the order.

Commercial uses for beacons are also gaining momentum. As mentioned above, beacons can be used to track and manage important assets like expensive power tools. A beacon-enabled tool allows it to periodically broadcast "I'm here" so that the inventory management system can determine when it is located in a tool bin, on the shop floor, or not in range at all. Since all beacons can be designed to also support normal BLE data services (connection-based), they can incorporate other useful features besides the beacon itself. For example, the inventory system can read a tool's battery status, operating hours, and motor performance history. This has obvious beneficial implications for managing the tool's utilization and service life. Some back-end systems can even locate tagged assets when they're not in range of the owner by using beacon data collected by another user who is.

An interesting new application for beacons is emerging with the rise in popularity of Bluetooth mesh in commercial lighting applications. Lighting vendors are beginning to recognize the synergy of combining the mesh-based lighting controls in each fixture with integrated beacons (or beacon scanners) to provide other services, such as indoor navigation, or for tracking boxes or pallets in a warehouse.

Beaconing with Bluetooth 4.X

Bluetooth Low Energy 4.x Advertising Packets

The specification for Bluetooth Low Energy in version 4.x defines forty 2 MHz wide channels in the 2.4-2.5 GHz ISM band. Three channels are reserved for advertising (channels 37, 38, and 39), and the other 37 are data channels (0 through 36). Both advertising packets and data packets use the same format with a variable size payload and are only distinguished by the channel being used. Advertising packets are sent with clear text and data channels may be encrypted. In version 4.0, both advertising and data packets had a maximum 31-byte payload. Version 4.2 increased the data channel payload to 255 bytes but kept the advertising packet the same.

A fully utilized advertising packet will take 376 µs to transmit. When advertising, the same packet is sent on all three of the advertising channels to increase the likelihood of a scanner receiving one of them. Thus, an entire advertising event typically takes just over one millisecond.

Beacons work by taking advantage of BLE's advertising channels to broadcast known beacon identifiers. They use the standard advertising packet format but then further sub-format the payload to follow a predefined structure for the beacon pseudo-standard it follows. A beacon identifier typically includes a Universally Unique Identifier (UUID), which allows an individual beacon to be uniquely distinguished from any other.

In a conventional BLE application, connectable advertising packets provide information identifying the advertising node and are followed by a listening period in which a scanner can request access to that node's data. By contrast, beacons typically use non-connectable advertising, broadcasting but never listening, thus they provide all of their useful information in the advertising packet itself. A hybrid device that supports both beacons and other services may interleave connectable advertising packets with non-connectable packets. The type of packet being transmitted is identified by a PDU Type field in the PDU header, which is the key to adding Bluetooth 5.0's extended advertising capabilities while maintaining backward compatibility.

Challenges and Limitations

The biggest limitation for BLE v4.x beacons is the small advertising packet. With only a 31-byte data payload, the v4.x advertising packet limits how much information that a beacon can provide. Apple's iBeacon used this limited payload to provide a unique beacon ID. Google's URIBeacon used it to broadcast compressed URLs pointing to Internet resources, and the Eddystone beacon used multiple different frame types to accommodate the needs of various beacon uses cases.

Another challenge comes from the desire to create general-purpose beacons supporting multiple formats. Suppose one wanted to support both iBeacon and Eddystone-UID, and possibly a third proprietary format containing beacon health data, without having to use three different physical beacons? To accomplish this, devices needed to broadcast each of the different beacons separately, interleaving each of the different formats. This succeeds in creating multiple virtual beacons from a single physical device, but since the interleaving is managed at the application level by an active processor, it causes a much faster drain on limited battery resources.

Range can also be a limitation. In denser beacon environments like retail stores, short range is desirable because it provides better accuracy for proximity services. But some applications need longer range, such as large university or corporate campuses, or airports.

Another emerging challenge is due to the success of BLE itself; the three advertising channels are becoming crowded. This will be especially more acute in environments using Bluetooth mesh, which uses the three advertising channels for all mesh communication.

Bluetooth 5.0 Enhancements

Bluetooth 5 introduced enhancements to several elements of the Low Energy standard, including for the first time, new PHY definitions for the LE radio. It also added an alternative channel selection scheme for the frequency hopping algorithm, higher transmit power, and multiple changes to the advertising mechanisms, collectively called Advertising Extensions. All of these enhancements are designed to maintain backward compatibility with the v4.0 standard.

A. Two New PHYs

Two new physical layer definitions were added, the LE 2M PHY, which transmits at 2 Mbps, and the LE Coded PHY which transmits at either 125 kbps or 500 kbps. The LE 2M PHY doubles the previous 1 Mbps data rate which was part of the original BLE spec in v4.0. The resulting higher throughput provides a much-improved user experience for applications that transfer large amounts of data over the air, such as a firmware update. The higher data rate has a trade-off with RF range, reducing it by approximately 20 percent, but has a beneficial impact on power consumption (since the radio is on-air for less time).

The LE Coded PHYs, as the name implies, use additional encoding and forward error correction to improve reliable signal reception on the receiver end. Two optional encoding schemes are used, effectively providing 2-4x the range of the 1M PHY. The longer range comes at the expense of throughput, however, since each data bit is converted by the encoder into multiple symbols for RF transmission. The Coded PHYs also increase power consumption since the radio is on-air longer.

B. 10x transmit power

Prior to Bluetooth 5, BLE transmit power was limited to a maximum of 10 mW (+10 dBm), and with Bluetooth 5 the maximum is increased to 100 mW (+20 dBm). 2 However, it should be noted that in some locations, notably EU countries, using +20 dBm is not possible without using the new Channel Selection Algorithm (CSA#2), also added in Bluetooth 5. CSA#2 imposes a minimum limit on the number of channels which can be used by the adaptive FHSS algorithm in order to ensure that RF power spectral density remains below regulatory limits. These two spec enhancements together enable BLE transmitters with 10x the transmit power previously allowed, resulting in range more than twice that of the original BLE spec.

C. Advertising Extensions

Bluetooth 5 brought substantial enhancements to the simple advertising packet that has been in use since BLE's inception in v4.0, including:

- Secondary Advertising Channels
- Advertising Packet Chaining
- Advertising Data Sets
- Periodic Advertising
- High Duty Cycle Advertising

The legacy advertising packet keeps the same structure, with its 31-byte maximum data payload. But the three original advertising channels are now defined as Primary Advertising Channels, and in addition to the three advertising channels, the 37 data channels can also be used for advertising. These are defined as Secondary Advertising Channels. Secondary Advertising Channels can carry a much larger data payload, up to 254 bytes, and make use of any PHY, including the new 2M and Coded PHYs.

All BLE advertising events still begin on the three Primary Advertising Channels. But to enable the enhanced advertising capability while also maintaining backward compatibility, new advertising PDU Types have been added, including one for a new type of advertising packet on the Primary Advertising Channels. This new packet is short, containing only a header that indicates the rest of the data will be provided on a Secondary Advertising Channel (using the new extended packet format). It contains a pointer specifying which channel and PHY will be used, and when the new packet will be transmitted. This arrangement provides the added benefit of not only supporting larger advertising packets but also offloading traffic from the three Primary Advertising Channels.

The larger advertising packets for Secondary Advertising Channels can include a pointer to a subsequent advertising packet on yet another channel (using the same PHY). This is known as Advertising Packet Chaining and allows for the creation of advertisement payloads even larger than 254 bytes.

The addition of Advertising Data Sets allows the BLE link layer to interleave multiple advertising events, each with different sets of advertising payloads, without involving the host processor. Each of these advertising events is a separate instance of the advertising state in the BLE state machine, and each Data Set can have different advertising parameters (PHY, packet format, advertising interval, power level, etc.). This allows a single physical beacon for example, to more elegantly support multiple types of beacons following different standards. Offloading the interleaving task from the host processor to the link layer frees up host resources and makes it much more power efficient to support multiple beacon formats.

Bluetooth 5 also introduces the ability to use deterministic timing between advertising events on the Secondary Advertising Channels, which is known as Periodic Advertising. In version 4.x, the interval between advertising events included a randomization factor to ensure that no two devices could ever inadvertently synchronize to one another with recurring collisions on the RF channel. With Periodic Advertising, a scanning device can perform its scans on a known, fixed timing interval, allowing it to more efficiently manage the RF receiver's active time and in turn reducing power consumption. The advertiser periodically sends new advertising events on the Primary Advertising Channels, which point to the synchronization data, thus allowing new scanners to sync up to the periodic advertising interval. Periodic Advertising can be beneficial in applications which use beaconing tags for asset tracking. It also, not coincidentally, paves the way for using the BLE radio to transmit audio in a broadcast fashion.

In Bluetooth 4.x, the minimum allowable interval between non-connectable advertising events was 100 ms, and Bluetooth 5 reduces this to 20 ms. This is known as High Duty Cycle Non-Connectable Advertising. As discussed in [1], a shorter beaconing interval provides better location accuracy and response time, especially for moving objects.

Finally, although not a direct change to advertising packet formats, Bluetooth 5 also added support for scan event reporting. This allows an advertiser to report a scan request to the host processor (received from another device as a result of an advertisement). With a positive indication that the advertisement was successfully heard, the host application can take appropriate actions, such as turning off subsequent advertising events for a period of time. This can be particularly beneficial for managing battery life in beaconing asset tags.

Advanced Beacons

The wide-ranging enhancements implemented in the Bluetooth Low Energy advertising mechanisms in Bluetooth 5 open innumerable possibilities for more advanced beacons.

One obvious and immediate benefit is that beacons can take advantage of the larger advertising packets, or chained packets, so that more content can be provided in an advertising event. Consider the case of the current Eddystone format, which defines four different frame formats depending on the information needing to be broadcast. While each format still has benefits when used individually, there is also a strong case for efficiency if some of them are combined – for example combining the UID frame with the URL and TLM frames. A beacon could send its ID, a contextually relevant URL, and health data (temperature, battery charge, tamper data, etc.) all in one beacon event. The Eddystone-URL beacon could also benefit from larger advertising packets since URL compression becomes unnecessary. Using normal URLs improves network security (shortened URLs can disguise malicious target addresses and bypass content filters).

Another benefit was highlighted earlier – the ability for a single physical beacon to support multiple beacon standards, each with different packet timing and formatting, using Advertising Data Sets. They can even support a mixture of beacons that use the legacy advertising packet (iBeacon, Eddystone, AltBeacon, etc.) with beacons based on the new extended advertisements since the new PDU Types are backward compatible with legacy PDU Types. This means existing apps based on Bluetooth 4.0 beacons can still be compatible with Bluetooth 5 beacons, allowing a smooth transition while upgrading to more enhanced capabilities.

Beacons built to take advantage of Secondary Advertising Channels will benefit every environment where BLE is used, whether with beacons or otherwise, by offloading traffic from the three Primary Advertising Channels. This helps reduce the chances of RF collisions and improves reliability, especially in installations that use both beacons and Bluetooth mesh, which as previously noted, exclusively uses the three Primary Advertising Channels for all network communication.

Beacons that require long range are only a small part of the larger beacon market, but with the added support for higher transmit power and the addition of the LE Coded PHY, Bluetooth 5 will enable beacons with more than four times the range previously possible. These are important for applications where proximity is measured in hundreds of meters rather than tens of meters, like airline cargo container tracking for example.

Interestingly and importantly, the Advertising Extensions in Bluetooth 5 do not require upgrading to new chips. As long as a chip has enough memory, does not have the stack pre-programmed in ROM, and supports firmware updates, then upgrading to support Advertising Extensions on existing hardware is a matter of a simple firmware update. This of course depends on the chip vendor and whether or not they choose to support Bluetooth 5 features on existing chips with their software development tools.

Summary

The Bluetooth SIG touts Bluetooth 5 for achieving 2x the speed, 4x the range, and 8x the broadcast capacity of previous versions. All of these enhancements benefit the beacon market, but especially the Advertising Extensions, which significantly expand the advertising capabilities that lie at the core of beacon technology. At the time of this writing, the author is unaware of any second-generation beacons being announced to the market that take advantage of these enhancements, but the specification changes are still relatively new and there is substantial inertia with the deployment of beacons based on v4.0. In addition, many applications outside of retail that provide proximity-based services are still largely experimental, and the general public is only slowly becoming accustomed to having these services. Nonetheless, the market potential remains quite large and is therefore attracting a lot of competition. This will stimulate the drive for innovation and with the building blocks now available to create advanced beacons using Bluetooth 5, the inevitable early adopters will be “beaconing” in the market soon.

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