Bluetooth based technology for industrial personnel local positioning

I M Daudov¹, M N Orobey² and I V Ignatev³

¹Chechen State University, 17а, Dudaev Boulevard, Groznyy, 364015, Russia
²Irkutsk National Research Technical University, 83, Lermontov str., Irkutsk, 664074, Russia
³Bratsk State University, 40, Makarenko str., Bratsk, 665709, Russia

E-mail: ibr024@mail.ru

Abstract. The article presents the implementation of radio beacon functions in Bluetooth technology. The architecture of Bluetooth Low Energy technology is considered. The stages of development of Bluetooth technology from version 4.0 to version 5.2 are given. Advertising channels used by the beacon in the frequency range 2402-2480 MHz are shown. Functions and application of Bluetooth beacons are described.

1. Introduction

To ensure the safety of operations in dangerous industrial environment it is crucial to track the location of personal. There are number of various options to track person in the indoor-environment [1]. The most inexpensive and affordable tracking system is one that based on common devices as smartphones. Here the option with Bluetooth Low Energy beacons is discussed.

Bluetooth Low Energy Technology (BLE-Bluetooth Low Energy), sometimes called Bluetooth Smart, is a lightweight subset of classic Bluetooth that was introduced by the Bluetooth SIG consortium (Special Interest Group) as part of the basic Bluetooth 4.0 specification. This is Wireless Personal Area Network (WPAN). There are many wireless protocols available for engineers and product designers, but the main feature of BLE is the ability to communicate with very low power consumption. Currently, this is by far the easiest way to develop applications for interacting with any modern mobile platform (iOS, Android, Windows phones, etc.). The BLE architecture is shown in Fig. 1 [2, 3].

The BLE stack consists of two main architectural components: a host (master) and a controller. Each of them contains different stack layers.

Physical Layer (PHY). The transmitter uses GFSK (Gaussian frequency shift keying) modulation and operates in an unlicensed 2.4 GHz frequency band. Using this PHY layer, BLE provides a data rate of 1 Mbps to 3 Mbps (Bluetooth v5.0). It uses a frequency hopping transceiver. Two variants of the PHY level are indicated, namely uncoded and encoded data. The time division duplex (TDD) topology is used in both PHY modes.
The Link Layer is responsible for advertising, scanning, and creating/maintaining connections. The role of BLE devices is changed in peer-to-peer and broadcast modes. In general, Direct Test Mode is part of the Link Layer.

The Host Controller Interface (HCI) defines a series of commands that the host can use to communicate with the controller and events that the controller uses to communicate with the host. A significant part of BLE intelligence is implemented by the controller. This allows the master to stay asleep longer and wake up to the controller signal.

The Logical Link Control & Adaptation Protocol (L2CAP) is responsible for the multiplexing protocol, flow control and segmentation, and the reassembly of data blocks.

Attribute Protocol (ATT) attributes are one of the main mechanisms by which applications of connected Bluetooth devices communicate with each other using PDUs defined by the protocol and procedures in higher-level specifications. This level allows the BLE device to provide specific data items or attributes.

Security Manager (SMP). This level of Security Manager provides methods for interfacing devices and distributing keys. It offers services for other protocol stack layers for secure connection and communication between BLE devices.

![Architecture Bluetooth LE](image.png)

**Figure 1. Architecture Bluetooth LE**
General Attribute Profile (GATT). This layer is the service structure that defines the routines to use the ATT. Data are exchanged between two BLE devices using these subroutines. Applications and/or profiles will use GATT directly.

Generic Access Profile (GAP). This layer directly interacts with the application layer and/or the profiles contained therein. It manages the device discovery and services associated with connecting BLE devices, and supports the launch of security features.

Applications. The layer controls the device discovery and services associated with connecting BLE devices. The levels of the BLE protocol stack communicate with applications and profiles as needed. Bluetooth applications interact with profiles. A profile defines vertical interactions between layers as well as peer-to-peer interactions between specific layers between devices. All profiles/applications run on top of the GAP/GATT layers of the BLE protocol stack.

BLE is a wireless personal network technology developed and supported by the Bluetooth Special Interest Group (SIG) consortium. To evaluate BLE as a cons, it is important to understand the difference between classic Bluetooth and Bluetooth Low Energy. Classic Bluetooth consumes more power and transmits data over long distances, which is suitable for headsets and speakers. Bluetooth Low Energy transmits less data in a smaller frequency range, therefore consuming much less energy. BLE beacons transmit small amounts of data at regular intervals.

The development of Bluetooth technology has more than 20 years. There are different versions of Bluetooth. Version 4.0 and higher is called BLE. The last of the series is currently version 5.2. The main stages of improvement of this technology, starting with version 4.0, are summarized in Table 1 [4].

| Version | Date | Properties |
|---------|------|------------|
| 4.0     | 2010 | Low power mode, encryption. |
| 4.1     | 2013 | Coexistence with mobile wireless communication. |
| 4.2     | 2014 | Connection level privacy, IPv6 support profile. |
| 5.0     | 2016 | 1, 2, or 3 Mbps, low power consumption, optional 802.11 feature for speeds up to 24 Mbps, mesh network. |
| 5.1     | 2019 | Determine the exact location of the device by analyzing the direction to connected devices. One of the devices must have an array of several antennas. |
| 5.2     | 2020 | Dynamic optimization of transmission power, timing of transmission channels. |

One of the most important aspects of Bluetooth Low Energy is advertising. BLE announcements are also important for beacons, which have become popular for determining the location of objects. By using BLE for advertising, one can reduce power consumption, accelerate connectivity, and increase reliability.

Advertising communication occurs when a BLE device sends packets to all surrounding devices. The receiving device may then act on this information or connect to obtain additional information. Basically, this is what beacons do: they simply transmit packets using advertising channels 37, 38 and 39, as shown in Figure 2 [5].

Channels 37, 38 and 39 are used only for sending advertising packets. The rest is used to exchange data when connecting (this is not the subject of our topic). The 2.4 GHz spectrum for Bluetooth is from 2402 MHz to 2480 MHz. BLE uses 40 channels with a width of 1 MHz, numbered from 0 to 39.

Channels 37, 38 and 39 are distributed over a 2.4 GHz spectrum. If only one advertising channel is blocked, the other channels are likely to be free because they are separated by a bandwidth of several MHz. The long distance between advertising channels helps BLE better cope with interference from WiFi, classic Bluetooth, microwave ovens and other devices to ensure the success of advertising.

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During advertising, the BLE device transmits the same packet through all 3 advertising channels, one after the other. A central device looking for devices or beacons will listen to these channels for advertising packages, which helps it detect nearby devices.

When the BLE device is in advertisement mode, advertisement packages are regularly sent to each advertisement channel. The time interval between a set of packets is fixed with a random delay. The interval is specified between a set of 3 packets. The larger the interval between advertising tags, the less accurate the location of the moving target will be.

2. Bluetooth Beacons Operating Principle
The transmitted data from the low-power Bluetooth device is formatted according to the Bluetooth core specification and consists of the components shown in Figure 3 [6].

The preamble (1 byte) is used to synchronize the transmitter and receiver. This is followed by the Access Address (4 bytes). On all advertising channels, it is the same. Next, a data packet (PDU) (2 to 39 bytes). In version 5.0, the length of the data packet is increased to 257 bytes. Three bytes of checksum (CRC) follow at the end of each advertisement packet.

Although Bluetooth 5.0 is known for its longer range and faster data transfer rates, the Bluetooth v5 promotional extensions extend the technology's capabilities. Instead of simply sending ad data through all 3 advertising channels (as shown in Figure 2), BLE allows you to combine ad packages together and use the remaining 37 channels that did not previously transmit ad data. This is used to obtain advertising data even in conditions of high interference.

Bluetooth 5 also allows the ad package to contain up to 257 bytes of data, which is much more than the 39 packets that were possible in Bluetooth 4.0, 4.1, and 4.2 [7].

In the Internet of Things (IoT - Internet of Things), one of the tasks is to estimate the cost of transmission in terms of power. Depending on transmitter power, Bluetooth devices are divided into three classes:
- Class 1 devices have a maximum output power of 100 mW (20 dBm) and provide communication range up to 100 meters;
- devices of class 2 have power up to 2.5 mW (4 dBm) and provide communication range up to 10 meters;
- devices of class 3 have power up to 1 mW (0 dBm) and communication range up to 1 meter.
The device IoT typically has a limited number of PDUs that it can send before the battery reaches a point where it cannot connect until electricity is restored or replenished. Suppose that the protocol iBeacon is declared in the interval of 600 ms, the packet length is 34 bytes, and the device (IoT) uses a battery CR2025 with a nominal capacity of 240 mA at 3 V. The beacon electronics consume 50 μA at 3 V.

We can now predict the lifetime of the beacon and transmission efficiency:

- power consumption of one beacon is $50 \mu A \times 3V = 0.150 \text{ mW}$;
- the amount of information in bytes per second is $34 \times (1 \text{ s}/600 \text{ ms}) \times 3 \text{ channels} = 170 \text{ bytes/s}$;
- energy per bit is $0.150 \text{ mW}/(1360 \text{ bps}) = 0.110 \mu \text{J/bit}$;
- energy costs per advertisement are $0.110 \mu \text{J/bit} \times 34 \text{ bytes} \times 8 \text{ bits/byte} = 29.92 \mu \text{J/advertising}$;
- energy stored in the battery: $240 \text{ mAhr} \times 3 \text{ V} \times 3.6 \text{ s} = 2592 \text{ J}$;
- battery life is $(2592 \text{ J} \times (1,000,000 \mu \text{J/J})) / (29.92 \mu \text{J/ad} \times (1 \text{ advertisement}/0.6 \text{ s})) \times 0.7 = 36385027 = 421 \text{ days} = 1.15 \text{ years}$.

When an Android or iOS device is within reach of a Bluetooth beacon, it recognizes the signal sent by the beacon and can perform contextual tasks depending on what it receives. The beacon itself does nothing but transmit a signal. It does not receive data from the mobile device. Because it works in one direction thanks to the new Bluetooth 4.0 specification introduced in 2010 [8].

Bluetooth beacons are not really the Bluetooth SIG standard. Instead, they are what might be called "pseudo-standards" or formalized formats for radio-bus applications led by a major provider or group of companies. There are three main market standards for beacons: Apple's iBeacon, Google's Eddystone and Radius Networks' AltBeacon. All three pseudo-standards use the BLE broadcast methodology to place advertising packets on BLE channels 37, 38, and 39 to avoid traffic conflict with Wi-Fi in the unlicensed 2.4 GHz band for industrial, scientific, and medical (ISM) applications. Let us briefly consider the main differences between them [9].

Standard iBeacon. Apple was one of the first adherents of iBeacon technology in 2013. iBeacon defines a 30-byte packet to be broadcast at 100 ms intervals. A protocol developed by Apple that allows applications on smartphones to scan beacons in a certain range and display content when detected. Recommended when companies want to run Bluetooth marketing campaigns through their own apps. The Beaconstac SDK is an easy way to enable marketing and location analysis through an iBeacon-compatible BLE network.

The Eddystone standard was developed by Google Transnational Corporation in 2015. It can support four types of packages, Eddystone-URL, Eddystone-UID, Eddystone-EID, and Eddystone-TLM, until iBeacon supports these packages. The Eddystone-UID package is very similar to Apple's iBeacon, supports additional telemetry data with Eddystone-TLM.

Eddystone-URL is a single resource location. This frame allows the receiver to display web content based on the location of the beacon signal. To activate content, the app does not need to be installed. The content has a variable length and applies unique compression schemes to reduce the size of the URL to a limit of 17 bytes.

Eddystone-UID is a unique 16-byte beacon identifier with a 10-byte namespace and a six-byte instance. It uses the Google beacon registry to return attachments.

Eddystone-EID is a short-lived identifier for beacons requiring a higher level of security. There is no fixed namespace and identifier, identifiers are constantly rotating and require a permitted application for decoding. It uses the Google beacon registry to return attachments.

Eddystone-TLM broadcasts telemetry data about the beacon itself (battery level, time since inclusion, amount of advertising). It broadcasts along with URIs or URL packets.

Standard AltBeacon. Network Radius launched its beacon in 2014. It is an open source machine with a wide range of open devices with different types of beacon applications.
All three standards use the BLE broadcast mechanism to transmit advertising packets over the BLE channel. They use channels 37, 38, and 39 to avoid a Wi-Fi traffic conflict.

3. **Scope of Bluetooth Beacons**

Any Bluetooth mobile phone can be used to detect and view BLE devices. One of the most useful beacon services is that they can be used for advertising wherever there are people: in shopping centers, shops, parks and even at events. To use it, there must be a beacon-compatible device [5].

Bluetooth beacons will have a transformative effect on interaction with the physical world. They provide context awareness based on proximity, using the technology that most people in the world have - a smartphone with applications. The use of wireless technology to detect approximation is not new, but with the introduction of low-power Bluetooth features in 2010, beacons are now deployed on a wide scale. This is an important and significant technology for the IoT [10] and IIoT especially [11].

Bluetooth information can be environmental data (temperature, atmospheric pressure, humidity, etc.), micro-location data (asset tracking, retail, etc.) or orientation data (acceleration, rotation, etc.). These devices are used to transmit data using Bluetooth Low Energy signals. This technology can be used for interaction between autonomous drones, or to create a reference network for correcting the location of drones in unattended or abandoned mine workings [12].

Note that with Bluetooth capability, beacons can locate customers and send messages to their smartphones. Beacons are safe in the sense that they allow access only to applications and websites authorized by the user. This means that the tags only transmit information and provide assistance that has been authenticated by the user, providing user convenience [13-15].

4. **Conclusion**

The introduction of the Internet of Things contributes to the emergence of new technologies and services. One such technology is Low Power Bluetooth (BLE-Bluetooth Low Energy), which allows the use of BLE beacons using the latest advances in cellular mobile endpoints.

The article discusses the BLE architecture, the principles of BLE-beacons, provides an example of calculating the life of the beacon battery, and discusses the scope of BLE-beacons. The depth of consideration of BLE technology is designed for managers involved in advertising distribution.

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