Developing a Beacon-Based Location System Using Bluetooth Low Energy Location Fingerprinting for Smart Home Device Management

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Abstract. This study explores BLE (Bluetooth Low Energy) Beacon indoor positioning for smart home power management. We propose a novel system framework using BLE Beacon to detect the user location and conduct power management in the home through a mobile device application. Due to the BLE Beacon may produce the multipath effect, this study uses the positioning algorithm and hardware configuration to reduce the error rate. Location fingerprint positioning algorithm and filter modification are used to establish a positioning method for facilitating deployment and saving computing resources. The experiments include observing the RSSI (Received Signal Strength Indicators) and selecting the filters; discussing the relationship between the characteristics of the BLE Beacon signal accuracy and the number of the BLE Beacon deployed in space; the BLE Beacon multilateration positioning combined with the In-Snergy intelligent energy management system for smart home power management. The contribution is to allow users to enjoy smart home services based on the location using a mobile device application.

Keywords: Bluetooth low energy beacon · Smart home · Multipath effect · Fingerprint location algorithm · Multilateration positioning

1 Introduction

In recent years, information and communication technology has been increasingly advanced. In order to achieve a more convenient living environment, people began to pursue the ability to make objects intelligent and transmit information, resulting in the IoT (Internet of Thing) concept [1–3]. With the maturity of cloud computing and IoT technology, smart homes have become an important trend in the future [4]. The smart home is an applied case of the concept of IoT to control the appliances in the home via the WSNs (Wireless Sensor Networks) anytime and anywhere, and cloud computing facilitates users to make the home appliances more intelligent to obtain convenient services [4, 5]. In order to detect a human position, people invented satellites to provide GPS (Global Positioning System) positioning. However, as the scope of people

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activities is no longer limited to the unshielded surface on the earth, GPS cannot provide accurate positioning services if people stay in the indoor space or go cross the building. How to detect the location of the people in the indoor space will become an important research topic. Due to the GPS positioning is inappropriate using in the indoor environment, the demand for indoor positioning is generated. Among the indoor positioning technologies [6], for example, ultrasonic, infrared ray, Wi-Fi, RFID (Radio Frequency Identification Device), UWB (Ultra Wideband), and Bluetooth, BLE (Bluetooth low energy) Beacon has micro-positioning and seamless integration. Its features such as mode, power saving, and low cost will be an applied technology worth exploring in indoor positioning [6–8].

However, BLE Beacon technology has not been popularized for indoor positioning because its frequency is based on 2.4 GHz radio band, which is prone to multipath effects and causes errors in positioning [1, 6, 8–13]. In addition, the traditional smart home deploys various sensors, the detection may be inaccurate when sensing. For example, an infrared sensor is used to identify a user's position while the user stays in indoors. However, if the sensor does not detect the movement of the human body for a long time, it performs an automatic configuration process, such as turning off the home appliance power or locking the door which may cause big trouble. The innovation and popularization of mobile device facilitate people obtaining useful messages and performing convenient business operations in a very short time. The mobile devices are almost indispensable auxiliary tools of human life. Therefore, in response to the design of the emerging smart home application, the Bluetooth function built into the mobile device and the BLE Beacon can be used for multilateration positioning, and through various standards of the positioning algorithms [6], for example, the RSSI (Received Signal Strength Indicator), CSI (Channel State Information), fingerprinting/scene analysis, AoA (Angle of Arrival), ToA (Time of Arrival), TDoA (Time Difference of Arrival), RToF (Return Time of Flight), and PoA (Phase of Arrival) of the received signal, to enhance the accuracy of positioning. Then, according to the positioning, the user can remotely manual control the smart home appliance in the room. In addition to the manual remote control, the smart home application automatically turns on the power of the smart home in the room when entering the room. Oppositely, when the user leaves a room for a period of time, the smart home application automatically turns off the appliance to shut down the power to achieve effective power control. It makes people lives becoming more intelligent.

This study explores the BLE Beacon indoor positioning and proposes a novel system framework using BLE Beacon to detect the user location and conduct smart home power management by a mobile device application [14]. Location fingerprint positioning algorithm and filter modification are used to establish a positioning method for facilitating deployment and saving computing resources. The proposed system includes the BLE Beacon positioning system, smart home management server, knowledgebase, mobile device application, smart home gateway, and cloud smart socket for remote control. Through the BLE Beacon-based positioning system combined with the smart home management server, the user location is estimated to provide a friendly and adaptable smart home appliance power control function via smart home gateway and cloud smart socket. Users can use a mobile device application (App) to mutually or automatically control the appliance power anytime, anywhere. The system operation data is stored in a knowledgebase. Therefore, the contribution of this work is to use BLE Beacon multilateration positioning to perform the smart home power management of achieving a user-oriented smart home. The IoT technology solves the problems encountered in human life so that users can enjoy the appropriate smart home services.

The remainder of this paper is organized as follows. Section 2 presents the novel system framework using BLE Beacon to detect the user's location and conduct power management in the home through a mobile device application. Section 3 introduces the positioning algorithm based on the location fingerprinting. The experiments follow in Sect. 4. Section 5 has the relevant evaluation and discussion. Finally, Sect. 6 presents our conclusions.

2 The Proposed System Framework for Smart Home Power Management

This section introduces the BLE beacon-based location system using location fingerprint positioning for smart home power management, including the BLE Beacon positioning system, smart home management server, knowledgebase, mobile device application and In-Snergy intelligent management system [15] for remote control. Based on the indoor positioning to provide smart services to users. Figure 1. shows the proposed system framework workflow, including 5 steps are illustrated as follows.

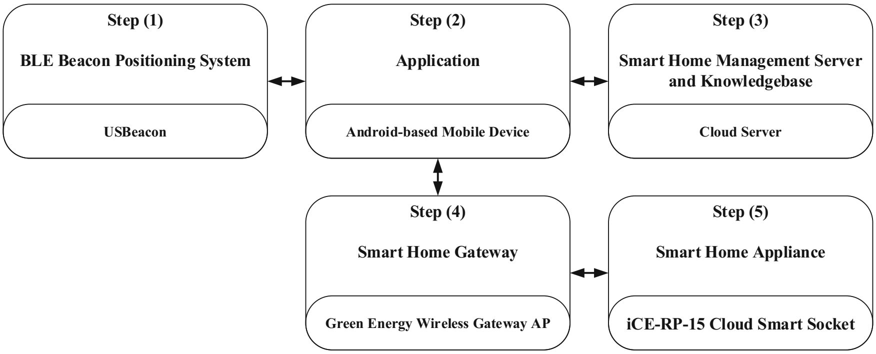


Fig. 1. The system framework workflow

Step (1) BLE Beacons [16] are installed at some fixed positions to establish a coordinate system. The sampling distribution map of BLE Beacons is established and stored in the knowledgebase. BLE Beacons broadcast signals to the Android-based mobile device's App.

Step (2) The Android-based mobile device's App receives the signals, transmits the RSSI values of BLE Beacons and its own location data to the smart home management server, and gives related control instructions.

Step (3) The smart home management server analyses these data and instructions by signal intensity attenuation positioning, triangle positioning and location fingerprint positing algorithm, estimates the mobile device's location, and determines which appliance is being chosen. Then, the server sends data and instructions via the App to the smart home gateway [15]. These data and instructions contain the information of the appliances that need to be controlled and the information of the specific cloud smart socket [15].

Step (4) The smart home gateway analyzes the instructions, confirms the appliance number and sends instructions to the specific appliance.

Step (5) Finally, the chosen appliance is operated under the App control instructions. The control instruction is divided into the active service and passive service. The active service is smart appliance that do not require users to turn on/off. In other words, the smart appliance triggered by the control instructions will automatically turn on/off in the room. The passive service is the appliance that need users to turn on/off, such as fans, TVs, lamps, and air-conditioners, etc. Our proposed system facilitates users to enjoy the appropriate smart home services.

3 Positioning Algorithm Based on the Location Fingerprinting

This section introduces the positioning algorithm based on the location fingerprinting. Referring to Wang et al. [17] formalizing the WKNN (Weighted K-Nearest Neighbors) positioning method, we develop the proposed positioning algorithm. Figure 2 illustrates a use case of location p positioning by three BLE Beacons in the area A which the location is sampling by the maximum and minimum RSSI values.

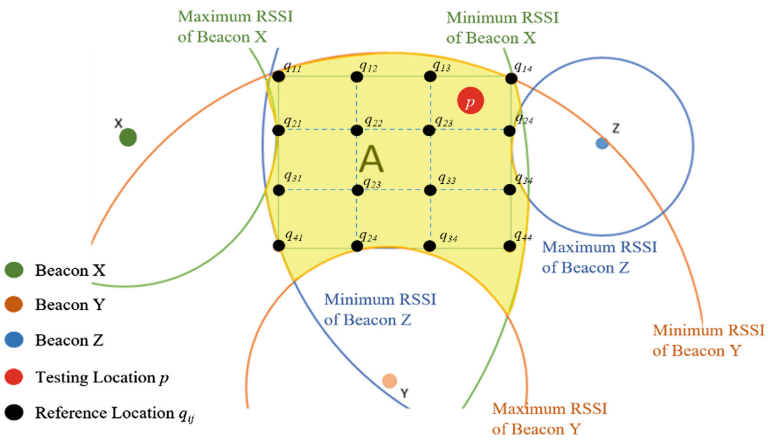


Fig. 2. The positioning diagram

Based on the Eq. (1), let R_p denotes the RSSI data collected at a testing location p over a period of time, is shown as the Eq. (2).

$$RSSI = -10nlog_{10}(d) + A \tag{1}$$

$$R_p = \begin{bmatrix} \alpha_1^p & \ldots & \alpha_n^p \end{bmatrix} = \begin{bmatrix} rssi_{11}^p & \ldots & rssi_{1n}^p \\ \vdots & \ddots & \vdots \\ rssi_{m1}^p & \ldots & rssi_{mn}^p \end{bmatrix} \tag{2}$$

where $rssi_{ij}^p$ is the RSSI value received at a testing location p from the jth BLE Beacon at the ith sampling time, $1 \leq i \leq m$, $1 \leq j \leq n$, m is the number of sampling time, n is the number of BLE Beacons. The RSSI value in the ith row of R_p are collected from the different Beacons concurrently. The RSSI value in the jth column of R_p are received from the same Beacon at different time. The $\bar{\alpha}_j^p$ is the mean vector (using mean filter mentioned in Sect. 4) of the jth column of R_p, is shown as the Eq. (3).

$$\bar{R}_p = [\bar{\alpha}_1^p \cdots \bar{\alpha}_n^p] \tag{3}$$

In the same way, the RSSI data collected at a reference location q over a period time are represented as the Eq. (4), and the Eq. (5) shows the mean vector at a reference location q.

$$R_q = \begin{bmatrix} \alpha_1^q & \ldots & \alpha_n^q \end{bmatrix} = \begin{bmatrix} rssi_{11}^q & \ldots & rssi_{1n}^q \\ \vdots & \ddots & \vdots \\ rssi_{m1}^q & \ldots & rssi_{mn}^q \end{bmatrix} \tag{4}$$

$$\bar{R}_q = \begin{bmatrix} \bar{\alpha}_1^q & \ldots & \bar{\alpha}_n^q \end{bmatrix} \tag{5}$$

Thus, the Euclidean distance d_q is estimated between the testing location p and the reference location q, is shown as the Eq. (6).

$$d_q = \frac{1}{n}\left(\sum_{j=1}^{n}\left|\bar{\alpha}_j^p - \bar{\alpha}_j^q\right|^2\right)^{\frac{1}{2}} \tag{6}$$

The final location is estimated by the Eq. (7).

$$C = \frac{\sum_{q=1}^{K} \frac{C_q}{d_q + \varepsilon}}{\sum_{q=1}^{K} \frac{1}{d_q + \varepsilon}} \tag{7}$$

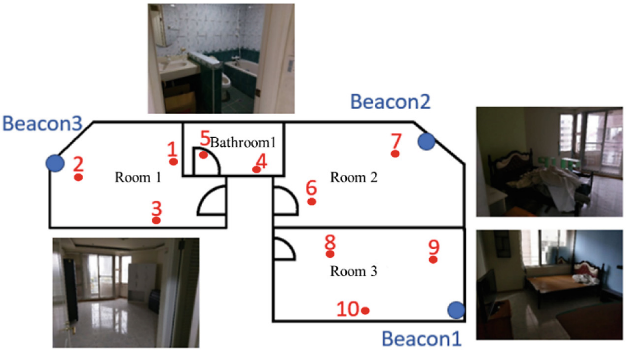
where C_q is the coordinate of the qth reference location among K reference locations, ε is a number used to avoid division by zero.

4 Experiments

This section explores the RSSI characteristics of BLE Beacon and performs the experiments on BLE Beacon multilateration positioning. In BLE specification [18], the GATT (Generic ATTribute protocol) is defined to operate on the upper layers of the BLE stack. In order to monitor the RSSI of BLE Beacon, we developed a mobile device App using Google Android public API Bluetooth GATT [19]. The App can directly observe the packet sent by BLE Beacon, and read the BLE Beacon identification, physical address, and receive it within 1 s. Besides, the relevant information includes the signal strength, average signal strength, TX power value and the derived distance. So that we can enforce the location fingerprint positioning sampling, collect the maximum and minimum RSSI values of the BLE Beacon within the location range and store data in the knowledgebase. According to the room information and the instant receipt of the BLE Beacon signal, the smart home management system has ability to determine the user location. The smart home management system carried out a series of tasks to analyze the characteristics and positioning methods of BLE Beacon. Then it uses the positioning algorithm to estimate the location of the room and transmit the data and control instructions via WebAPI to the smart home gateway. At last, the chosen appliance operates under the mobile device App control instructions. It is expected to find the best deployment for the BLE Beacon in a smart home and use the positioning algorithms to reduce the error rate. The analysis tasks are illustrated in follows.

- **Observation of RSSI signals and selection of the filters**: The purpose of using the filter is to handle the error rate. Since the multipath effect problem of BLE Beacon highlights the importance of the filter, we explore the difference between the mean filter and the median filter. The mean filter is used to execute the experiments. Each experimental location of a BLE Beacon is defined as the reference location which is used in the proposed positioning algorithm mentioned in Sect. 3. Besides, the measured maximum, minimum, and mean RSSI of BLE Beacon signal values are used for location positioning.
- **Explore the characteristics of BLE Beacon**: The deployment of BLE Beacon in indoor positioning has a great influence on the positioning accuracy. We conducted a series of experiments to understand the characteristics of BLE Beacon. The signal transmitted by the USBeacon using the chip-type Bluetooth antenna is directional. When deploying the BLE Beacon, it shall avoid getting the wavy signal to prevent the influence of positioning. In addition, it is recommended to deploy the BLE Beacon in the corner of the area.
- **Single space and multiple spaces positioning experiment**: The single space positioning experiment may require several BLE Beacons deployed in a space of 1.5 m $\times$ 1.5 m to coordinate an experimental space. The positioning by single BLE Beacon is not the good solution and the range of error rate is large. Two BLE Beacons deployment can reduce the positioning error rate. It is recommended to coordinate a rectangular space by deploying more than three BLE Beacons. A multiple spaces positioning experiment is performed using three BLE Beacons to coordinate four spaces, including the Room 1, Room 2, Room 3, and Bathroom 1, are shown in Fig. 3. The experiment results of 10 test locations show that the

overlap area produced by the proposed positioning method. The suggested solution of this status is to deploy the BLE Beacon in the overlap area. Positioning with multiple BLE Beacons can increase the uniqueness of the positioning area and reduce the occurrence of errors.



	Beacon 1		Beacon 2		Beacon 3	
	max	min	max	min	max	min
Room 1	70.8333 dBm	-91 dBm	-77 dBm	-91 dBm	-57 dBm	-80 dBm
Bathroom 1	-75.2 dBm	-89.5 dBm	-61 dBm	-83.75 dBm	-69 dBm	-92 dBm
Room 2	-61.333 dBm	-85.5 dBm	-58.25 dBm	-86.667 dBm	-77 dBm	-95 dBm
Room 3	-44.5 dBm	-71 dBm	-65 dBm	-88.5 dBm	-83 dBm	-99 dBm

Testing Location	Area	Beacon 1	Beacon 2	Beacon 3
1	Room 1	-86.25 dBm	-84 dBm	-74.5 dBm
2	Room 1	-87.33 dBm	-86.75 dBm	-66.4 dBm
3	Room 1	-87.5 dBm	-89 dBm	-61 dBm
4	Bathroom 1	-83 dBm	-75 dBm	-76 dBm
5	Room 1 / Bathroom 1	-88.5 dBm	-78.6 dBm	-74 dBm
6	Room 2 / Bathroom 1	-77 dBm	-70.833 dBm	-88.75 dBm
7	Room 2	-72.25 dBm	-70.6667 dBm	-94.6667 dBm
8	Room 3	-51.4444 dBm	-85.75 dBm	-96.667 dBm
9	Room 2 / Room 3	-64 dBm	-71.6667 dBm	-93.75 dBm
10	Room 3	-54.4289 dBm	-71.6667 dBm	-95 dBm
The measured unit of RSSI is decibel-milliwatts (dBm)				

Fig. 3. Multiple space positioning experiment [14]

- **Smart home power management via mobile device App**: The PHP (Hypertext Preprocessor) combined with In-Snergy WebAPI to implement the proposed system in order to communicate with In-Snergy smart green energy management system. Besides, a mobile device application (App) is developed in an Android platform to facilitate user to manage the appliance power in a smart home. Users customizes and deploys the appliances in App. By integrating the App and BLE Beacon positioning system with the In-Snergy smart green energy management system, the App provides the function of controlling the appliance via smart home gateway and cloud smart socket. After the user is positioned via the BLE Beacon, the In-Snergy Smart Green Management System remotely controls the state of operation of the appliances. Active services of smart appliances turn on/off automatically for users. User can click on the appliance icon to view the details currently used, as shown in Fig. 4. The App can calculate the current power usage of appliances. Passive services are appliances that need to be turned on/off by users. Figure 5 demonstrates an experiment on a fan control of the smart home power management. Users can also set the threshold of the predetermined a power consumption period. Once the threshold is approached or exceeded, a warning will issue to remind users that the current power consumption reaching the budget, and the appliance shall be turned off. The proposed system provides users with a context-aware smart home power management.

Fig. 4. Mobile device App shows the details of currently used appliance

Fig. 5. An experiment on a fan of smart home power management

5 Discussion and Evaluation

BLE Beacon technology has become popular [8]. Chen et al. [7] presents that the BLE beacons have already been deployed in retail industry, showing the proximity of items on the customers' phones and thus creating a more engaging shopping experience. In smart life environment, Nath et al. [3] proposed a voice based location detection system which can be integrated in a smart home environment. The system is suitable for large scale application where user may need to keep track of multiple patients. The contribution is to reduce the burden of learning curve of new technologies on family and caregivers. Liu et al. [5] designed an indoor control system to achieve equipment remote control by using low-energy Bluetooth (BLE) beacon and Internet of Things (IoT) technology. The smart home control system has been implemented by hardware, and precision and stability tests have been conducted, which proved the practicability and good user experience of this solution. Xiong et al. [20] implemented a distinctive system based on indoor location and attitude estimation. They proposed the indoor location algorithm combining image pattern recognition with fingerprint matching. Users can choose the appliances that he wants and control them by touching the screen of the mobile device while the mobile device is pointing to the appliance. This study explores the BLE Beacon for indoor positioning. Through a series of experiments, we realized the characteristics of the chip-type BLE Beacon and the rules for deploying BLE Beacon. Besides, we found that the mobile device cannot receive the BLE Beacon signal when the Wi-Fi access point is turned on. But the mobile device does not be interference when using Wi-Fi to access the Internet. The recommendation is not to open Wi-Fi sharing when using BLE Beacon positioning. According to the experiment results, it is found that the use of the positioning method for indoor positioning is feasible, but this is based on the deployment of sufficient BLE Beacon. The experiment results also present that single BLE Beacon can be deployed in a unit space to maintain the most basic accuracy of positioning. The more BLE Beacons are deployed, the higher the accuracy of spatial positioning.

6 Conclusion

This study proposed a novel system to detect the user indoor location using the mobile device and BLE Beacon Multilateration positioning. An Application (App) is developed to facilitate user to manage the appliance power in a smart home. The proposed system gives users a smart home experience, making home life more comfortable and convenient. Based on the BLE Beacon positioning, the user location is analyzed to get the corresponding power management service. In addition, the system allows the user to realize the power usage in the home and how to achieve power saving optimization. The contribution of this work is to make the home smarter, and its applied field is not limited to smart home. The proposed system can be applied to various situations in the living environment, such as shopping malls, exhibition halls, amusement parks, and facilities, etc., to achieve the benefits of reducing the cost. Future work can improve the system towards integrating artificial intelligence or machine learning with positioning to achieve the best benefits.

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