Development of congestion state guiding system for university cafeteria

Takafumi Doi, Hirotaka Ito, and Kenji Funahashi

Abstract We develop a congestion state guide system for a university cafeteria. This system confirms the congestion state of a cafeteria using iBeacon, and displays it on a mobile device in real time. The purpose of this is to stagger cafeteria use and avoid rush hour. We had a field experiment of this system in a cafeteria, and tested the operation of this system. Using this system, students can know how congested a cafeteria is at any place outside the cafeteria, and have a lunch comfortably when it was not crowded.

Key words: Bluetooth Low Energy, iBeacon, congestion state guide, university cafeteria, staggered lunch time

1 Introduction

In recent years, smartphones have become popular, and services for a smartphone and systems using its location information are widely used. Especially outdoor and wide area location data are utilized that uses GPS, the Internet access point information etc., and many applications are developed [1, 2]. However the number of applications using indoor and local area location data are not so many, because it is difficult to receive GPS signal, and a device usually moves inside one access point

---

Takafumi Doi
Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466-8555 Japan, e-mail: taka@center.nitech.ac.jp

Hirotaka Ito
Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466-8555 Japan, e-mail: ht-itoh@nitech.ac.jp

Kenji Funahashi
Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466-8555 Japan, e-mail: kenji@nitech.ac.jp

area. One of the indoor positioning method estimates position information using beacons that transmit radio waves. WSN (Wireless Sensor Networks) is also similar technology [3, 4]. There is a indoor positioning system study using BLE beacon [5]. In order to improve the accuracy in this study, authors combined a plurality of methods. For example, there is also indoor localization method and open field trial [6]. While indoor positioning systems are gaining attention, iBeacon [7] was proposed by Apple in September 2013. It uses Bluetooth Low Energy (BLE) [8] technology, and smartphone and tablet receive BLE signals. These devices can detect entering into and leaving from beacon area.

Nagoya Institute of Technology has introduced a system to manage attendance of students using ID card and a smart card reader to register their arrival at class. An attendance register subsystem using BLE beacon and their own smartphone has also introduced recently. It is expected that university life become more convenient.

By the way, many university cafeterias have a same problem that most students want to have a lunch at a similar time, and a cafeterias are crowded very much. But it is difficult to enlarge cafeteria space because the number of students is limited and just most students concentrate there between the classes. Although simple solution is to avoid the peak time to use and some students have a lunch before or after designated lunch time, it is difficult to predict the peak because university class schedule with canceled and supplemented classes is unstable. Therefore we expect that they will stagger cafeteria use and avoid rush hour by themselves if they can know the congestion state of a cafeteria before coming there from a class room and laboratory. Introducing internet web cameras there, they probably can know the state if it is crowded. But it needs much cost, and the cameras are only for this purpose. We consider to develop a congestion state guide system for a university cafeteria using our university BLE beacon system also attached at a cafeteria. Aside to that this beacon system is not only for attendance management, but also a guid system for visually impaired person, disaster evacuation guidance, etc. This system informs the congestion situation to students outside a cafeteria in real time. We had a field experiment of this system in a cafeteria, and tested the operation of this system. Using this system, students can know how congested a cafeteria is at any place outside the cafeteria, and have a lunch comfortably when it was not crowded.

In section 2, we explain BLE and iBeacon used in our system. In section 3, we describe the configuration of our system proposed in this paper. In section 4, we describe an experiment and a result. In section 5, we describe conclusion and future works.

2 Bluetooth technology

2.1 Bluetooth Low Energy

In this section, we explain Bluetooth Low Energy (BLE) technology to help to understand our guiding system. BLE is one of Bluetooth standards. BLE is formulated by the Bluetooth special interest group (SIG). BLE is installed after the Bluetooth 4.0 standard, and it is possible to operate with low power. BLE is a specification derived from Wibree which is a proximity communication technology developed by Nokia as its own wireless standard, so it is not compatible with Bluetooth 3.0 or earlier. Therefore, terminals equipped with Bluetooth 4.0 or later are often implemented so that conventional Bluetooth 3.0 can also be used.

Frequency band is used by dividing into 40 channels of 2 MHz width at the 2.4 GHz band. Three channels are allocated to an advertisement channel used for discovery and connection of BLE devices, and the rest channels are allocated to data channels used for data communication. Frequency hopping is used as a method to avoid interference. As a result, even if a specific channel can not communicate, data communication can be continued if the channel is switched after a certain time.

Broadcast and connection are defined in BLE as a method between devices for communication. Broadcast is a communication method for unilaterally transmitting data from one BLE device to other devices. In this communication method, a device that transmits data is called a broadcaster, and a device that receives data is called an observer. It is a characteristic that a broadcaster transmits the same data to unspecified observers at the same time. Connection is a communication method for mutually transmitting and receiving data between a BLE device and another BLE device. Transmission and reception of data is private only between the connected devices.

2.2 iBeacon

We explain also iBeacon in this section. iBeacon is a technology for position detection and proximity detection using BLE proposed by Apple. This technology uses broadcast communication of BLE. The sending terminal is called the peripheral, the receiving terminal is called the central, and advertising that the peripheral sends out information is called the advertisement. Central receives radio waves advertised from peripherals and central processes according to the radio content.

iBeacon has two major functions. These are to detect entering and leaving from the area and to detect the extent of proximity between the peripheral terminal and the central terminal. The entrance and exit of the area is made based on whether or not the radio wave emitted by the peripheral terminal has arrived. For the detection of the degree of proximity, we estimate the approximate distance using RSSI. iBeacon is compatible with iOS 7.0 or later, Android 4.3 or later.

3 System

3.1 Client application

To guide the congestion state of a cafeteria, the server to summarize it is needed. The client application is also necessary for users to know the summarized data. Therefore, our proposed system consists of client application and server software. The client application should have two functions. One of them is to detect entering into and leaving from the cafeteria, and then send the information to the server. Another is to fetch the congestion state of the cafeteria, and then display it on the client mobile device monitor.

In order to detect entering into and leaving from the cafeteria, it is necessary to detect iBeacon. We use AltBeacon library published by Radius Networks [9]. When a client device detects a beacon attached in a cafeteria, the detection process for entering into beacon area is performed, and then the proximity detection of a beacon is performed. Because the distance to the detected beacon can not be known when it detects entering into the beacon area. A client device should judge whether it is inside or outside a cafeteria by using the proximity detection of beacons. Fig. 1 shows the situation when the client device enters into a cafeteria. When it detects some beacons, and the nearest beacon is at a cafeteria, it judges that it is inside a cafeteria. Fig. 2 and Fig. 3 show the situation when the client device leaves from the cafeteria. When it detects some beacons too, and the nearest beacon is not at a cafeteria, it judges that it is outside a cafeteria. And when no beacons are detected, it judges that it is also outside a cafeteria.

The distance to a beacon is used as a criterion of this proximity detection. The distance is obtained from Transmission Power (TxPower) and Received Signal Strength Indication (RSSI) as following equations.

$$A = \frac{TxPower - RSSI}{20} \tag{1}$$

$$distance = 10^{A} \tag{2}$$

The client application judges whether it is inside or outside a cafeteria at 20 second intervals. When the client application confirms entering into or leaving from the cafeteria, it is necessary to send the information to the server. In addition, it also notifies the action to a user for confirmation.

Fig. 4 and Fig. 5 show an example of the application screen. The client displays five items on the screen, and has one button for updating information. The five items are:

- Information on whether the user is inside or outside a cafeteria
- The number of system users in a cafeteria
- The number of people who use cafeteria estimated from the number of system users in cafeteria

- Three levels evaluation of congestion state
- The transition of the estimated number of people in a cafeteria in the past

Fig. 6 shows the process of this system when the button is pressed. The client application sends a request to the server, receives a response from the server, and displays each data.

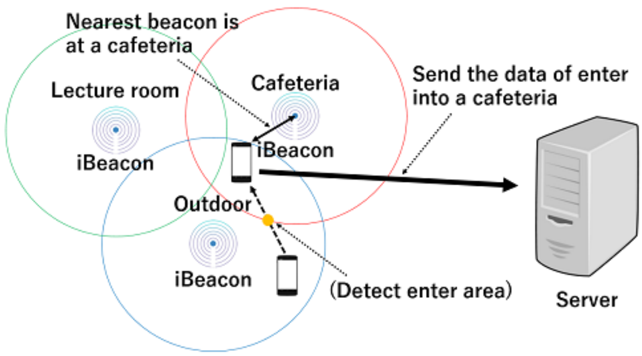

Fig. 1 Situation that client device enters into a cafeteria

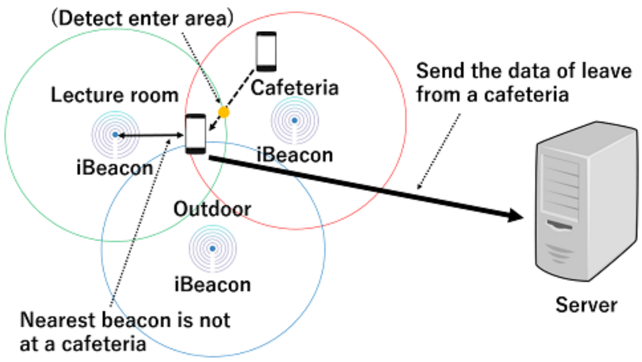

Fig. 2 Situation that client device leaves from the cafeteria

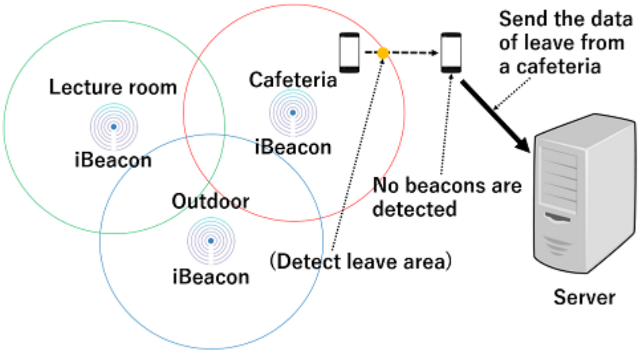

Fig. 3 Situation that client device leaves from the cafeteria and any

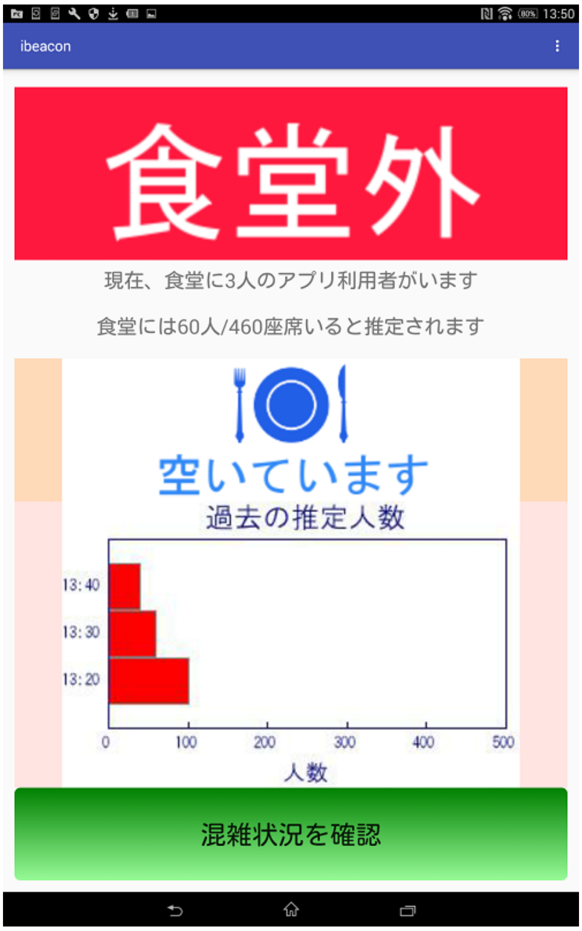

Fig. 4 An example of the application screen (Japanese version)

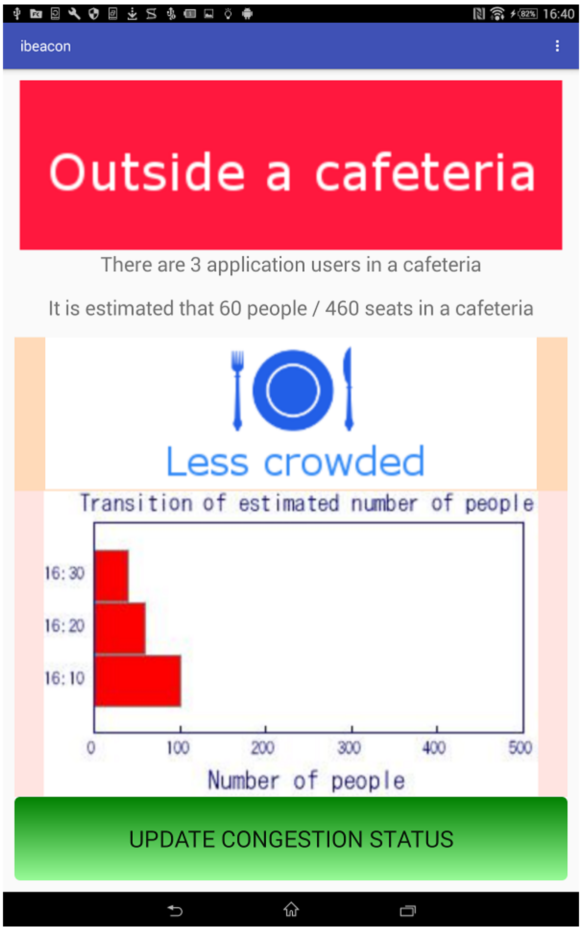

Fig. 5 An example of the application screen (English version)

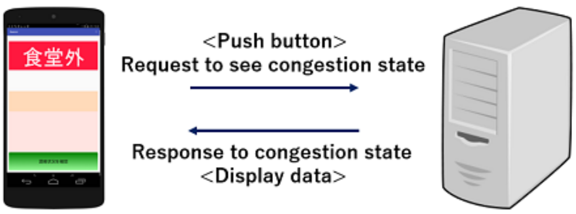

Fig. 6 Process of this system when the button is pressed

3.2 Server software

The server should summarize the congestion state of a cafeteria; the number of cafeteria users, and respond for a request from a client application. We use Apache HTTP Server [10] published by Apache Software Foundation. The response information from a server is requires to be easier to understand. Therefore, this server should estimate and evaluate the congestion state of a cafeteria from the turnover of system users at a cafeteria. The response information should be displayed with not only letters but also figures and graphs.

When a server gets the number of this system users in cafeteria, the number of the actual students having lunch there should be considered. So it estimates the number of student who are in a cafeteria first, and then judges the congestion state in three levels. It also serves the transition of the estimated number of people in the last 30 minutes at 10-minute intervals. The actual number of people there is estimated from both of the number of the system students using the attendance register subsystem using BLE beacon with their own smartphone described above, and the number of the students having classes, it means, using the management system of attendance using ID card and a smart card reader. The usage rate of the BLE beacon attendance subsystem is 5% for example, the estimated number of people in a cafeteria is 20 times of the number of our system users who are detected in a cafeteria. The three level congestion state is decided from the ratio with the number of seats in a cafeteria. It is judged that it is a little crowded with more than 50% of the number of seats, and it is crowded with 80% or more.

4 Experiment

4.1 Experimental method

We had an experiment at a university cafeteria using Android devices with client application. The purpose of this experiment was to test the accuracy of the judgment whether a client is inside or outside a cafeteria, and communication with the server. In addition, it tested the displayed information of the congestion state of a cafeteria at any place outside a cafeteria.

In this experiment, we asked five subjects to move as cafeteria users with Android devices. Each subject had 2 to 5 devices, we used 18 devices totally, and they entered into a cafeteria through the east door one after another. Fig. 7 shows the iBeacon positions, an entrance and an exit. No devices left from a cafeteria until all devices entered. Then subjects left there from the east door one after another. No devices re-entered. We recorded the actual number of the devices in a cafeteria, beacon confirmation status of each device, and communication condition with the serve at every time of device entering and leaving. Each recording time is numbered in order from the beginning of this experiment. Fig. 8 shows the appearance of this experiment at a cafeteria. Subjects held the devices with their hand or put them on a table in a cafeteria. After entering into a cafeteria, subjects sit apart there. At that time we recorded the beacon detection result of each device. When leaving from a cafeteria, the beacon detection results were also recorded. In addition, we checked the server communication log of sent information from each device at each time of entering and leaving. Fig. 9 shows the client device that displayed a subject was outside cafeteria.

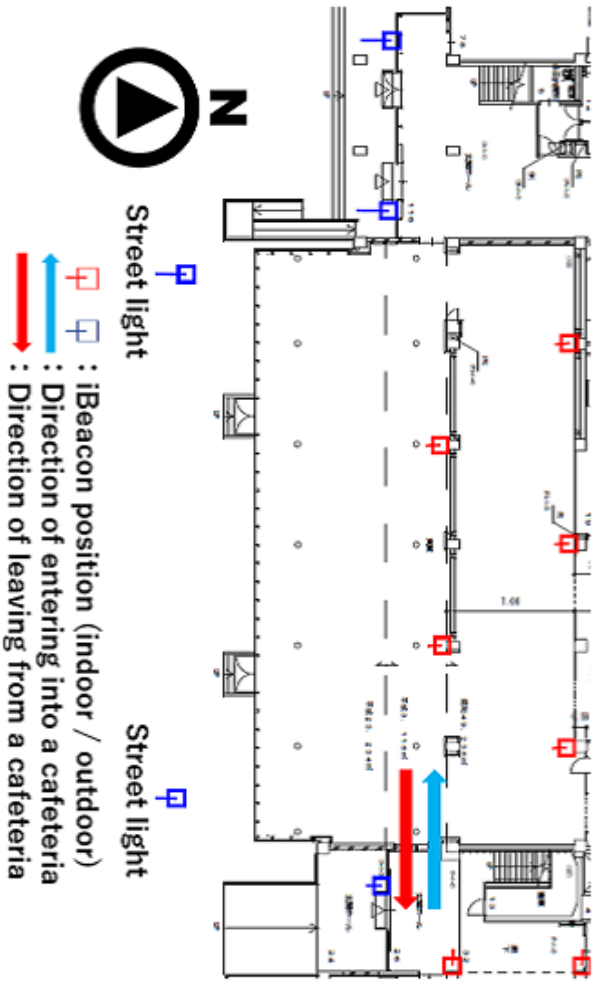

Fig. 7 Entrance, exit and iBeacons

Fig. 8 Appearance of experiment at a cafeteria

4.2 Result and consideration

First we confirmed that the congestion state could be shown on the client screen outside a cafeteria from Fig. 9. Experimental results of entering into and leaving from a cafeteria are shown in Table 1 and Table 2. We used all 18 device data at the entering, and for leaving process we used 15 data of devices that were detected correctly when entering.

Table 1 shows experimental results of entering into a cafeteria. The 16 client devices judged their entering correctly. This means 88% accuracy. We guess that the miss-judging devices were alongside the wall, then the RSSI of the beacon outside a cafeteria was strong. The 10 client devices sent the entering information to the server correctly. This means 55% of all 18 devices, and 62% of the 16 devices that judged their entering correctly. This communication result was far from satisfactory. We consider the reason is that the client application tried to communicate with the server to send the information, before the client woke up from the Wi-Fi sleep completely.

Table 2 shows experimental results of leaving from a cafeteria. The devices that judged leaving from a cafeteria correctly were all devices that judged entering there. This result indicates that entering judgement is more difficult than leaving judgement, especially when a client is alongside the wall, and close to other beacon outside a cafeteria. The 12 client devices sent the leaving information to the server correctly. This means 80% of the target 15 devices, and it was higher than the communication result of the entering. We guess that most subjects left from there before the devices slept down with Wi-Fi.

The client application almost could detect an entering into and leaving from a cafeteria at this field experiment. The comparison of the distance between a device

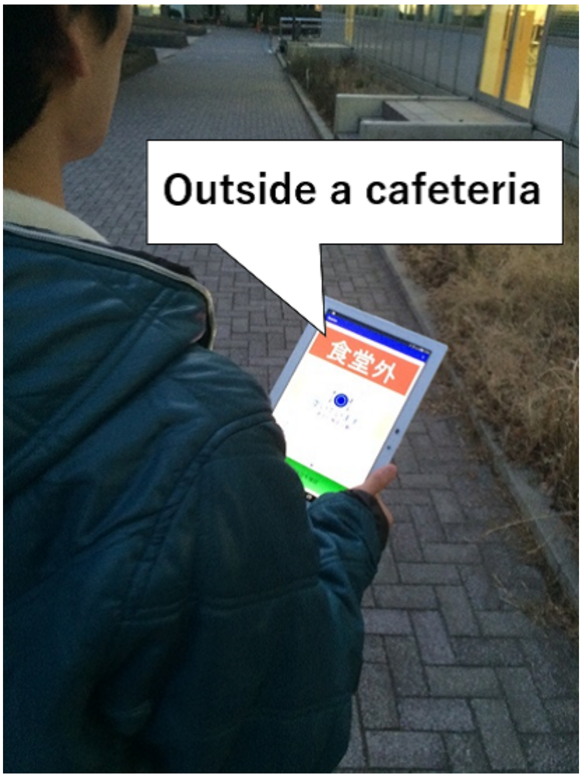

Fig. 9 Appearance of experiment outside a cafeteria

and a detected beacon also worked well to judge whether the device was inside or outside a cafeteria. However, some clients could not send an entering information to a server. It is necessary to solve this problem because the reliability of a congestion state would become wrong. A client should send the data after the confirmation of Wi-Fi communication, and should confirm the acknowledgement from a server, then retry to send it again if necessary. An exact judgement is important of course, and an exact data transfer is also important to make a guidance of congestion state better.

Table 1 Results of experiment when entering into a cafeteria

Recording time number	1	2	3	4	5	6
Total number of devices entered cafeteria	2	7	10	12	15	18
Number of devices judged an entering correctly	2	6	9	11	13	16
Number of devices sent an entering data	2	4	5	8	9	10

Table 2 Results of experiment when leaving from a cafeteria

Recording time number	7	8	9	10	11
Total number of devices left cafeteria	3	5	10	12	15
Number of devices judged a leaving correctly	3	5	10	12	15
Number of devices sent an leaving data	3	5	8	9	12

5 Conclusion

Our final goal is to make a cafeteria more comfortable without waiting time for having lunch. In this paper, we proposed a new guiding system of a congestion state for a university cafeteria using our university BLE beacon system. We built the system that consists of client application and server software. The number of people having a lunch in a cafeteria can be counted, then the congestion state of a cafeteria can be provided onto a mobile device.

We also had an experiment for our proposed system, then the proximity detection of iBeacon worked well to accurately judge whether a client is inside or outside a cafeteria. And the system user could know the congestion state of a cafeteria also outside a cafeteria. Although clients could not communicate with a server to send entering and leaving information of client because of Wi-Fi sleep probably, the experiment result was, on the whole, satisfactory.

For future work, we should consider that a client tries to send entering and leaving information to a server after waking up from Wi-Fi sleep, and a server accurately count the number of people in a cafeteria. After improvement this, we should have an experiment again. We also would like to rebuild an application to save power consumption. The client application described in this paper is only for Android OS. Therefor it is necessary to build an iOS application. Finally we will have a field demonstration, we expect that students will stagger cafeteria use and avoid rush hour by themselves after getting the congestion state of a cafeteria before coming there from a class room and laboratory.

Acknowledgements The authors would like to thank our colleagues in our laboratory for useful discussions. The experiment of this work was supported in part by NTT DOCOMO, INC.

References

1. Fawzi M. Al-Naima, Ramzy S. Ali, Ahmed J. Abid: Design of an Embedded Solar Tracking System Based on GPS and Astronomical Equations, International Journal of Information Technology and Web Engineering, **9**(1), 12-30 (2014)
2. Bin Zhou, Jeffrey Hsu, Yawei Wang: GIS and GPS Applications in Emerging Economies: Observation and Analysis of a Chinese Logistics Firm, International Journal of Information Systems and Social Change, **1**(3), 45-61 (2010)

3. Ruiling Gao, Alva Couch, Chorng Hwa Chang: An Innovative Positioning System with Unsynchronized Interferometric Modulated Signals in Wireless Sensor Networks, International Journal of Networked and Distributed Computing, **5**(2), 101-112 (2017)
4. Zhongwei Zhang: Modeling Performance of CSMA/CA with Retransmissions in Wireless Personal Area Networks, International Journal of Networked and Distributed Computing, **1**(2), 97-107 (2013)
5. Daiki Kudou, Mitsuyoshi Horikawa, Tatsuya Furudate, Azuma Okamoto: The proposal of Indoor Positioning System by Area Estimation Using BLE Beacon, The 78th national convention of Information Processing Society of Japan (IPSJ), **3**,245-426 (2016, in Japanese)
6. Hiroki Ishizuka, Daisuke Kamisaka, Mori Kurokawa, Takafumi Watanabe, Shigeki Muramatsu, Chihiro Ono: A Fundamental Study on a Indoor localization method using BLE signals and PDR for a smart phone: Sharing results of exmeriments in Open Beacon Field Trial, IEICE (The Institute of Electronics, Information and Communication Engineers) Technical Report MoNA (Mobile network and applications), **114**(31), 133-138 (2014, in Japanese)
7. Apple Inc.: iBeacon for Developers,
https://developer.apple.com/ibeacon/
8. Bluetooth SIG: Bluetooth Low Energy,
https://www.bluetooth.com/what-is-bluetooth-technology/how-it-works/low-energy
9. Radius Networks, Inc.: AltBeacon,
http://altbeacon.org/
10. Apache Software Foundation: Apache HTTP Sever,
https://httpd.apache.org/