Experiment of Indoor Position Presumption Based on RSSI of Bluetooth LE Beacon

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***Abstract*—Real-time indoor location estimation needs multiple signals from different sources. To ensure accuracy of estimation, adopting Bluetooth Low Energy (LE) beacon devices as signal sources is a reasonable solution. We have installed a number of Bluetooth Low Energy (LE) beacon devices in and around a room and observed beacons by portable devices with RSSI to achieve fundamental knowledge of beacons and feasibility of location estimation. By applying an estimation method, we have achieved over 95% of correct estimation rate and complete separation that a device is in a room or not.**

I. Introduction

Location information is intended for many applications such as navigation, children or patient monitoring, and disaster recovery. The growing popularity of location information leads a considerable amount of studies about position presumption. In our campus, we aim to improve quality of life of college students with the help of information technology. By having information on student location or behavior, many services such as automated roll call, safety management, and emergency evacuation guidance will be brought into reality. Recently, almost 90% of students in the campus have portable devices such as smartphones, music players, and tablet computers. We focus on the high adoption rate of portable devices and plan to utilize them for position presumption.

Indoor position presumption is a challenging problem since devices cannot obtain enough Global Positioning System (GPS) signals. In addition, instability of wireless signals in a room such as interference, reflection, and diffraction makes indoor position presumption a complex matter. There are numerous indoor positioning techniques and systems as shown in [1]. Some methods have been developed in wireless sensor networks [2] and some in wireless LAN [3], [4], [5]. Among them, fingerprinting approach is widely favored because of its high accuracy and low complexity [6]. Some traditional position estimation methods such as fingerprinting use received signal strength indicator (RSSI), which can be captured easily on common portable devices. However, the estimation accuracy in RSSI-based approach largely depends on source nodes that the installed location is fixed. To achieve certain accuracy of estimation, we need a certain number of source nodes, capturing enough signals, or developing an estimation algorithm with huge amount of RSSI data.

Recently, Bluetooth 4.0 or Bluetooth Low Energy (BLE) has the spotlight of low energy communication. There may appear novel information presentation platforms based on Bluetooth 4.0 or later such as iBeacon [7] in the near future. Bluetooth LE is established as a part of Bluetooth 4.0 on July 2010 [8]. Most of portable devices in the market already have a Bluetooth 4.0 (or later) interface. Thanks to its low energy consumption, a Bluetooth LE beacon device is estimated to work longer than several years with 2×AA battery. It is light, small, and easy to setup, so we can install anywhere. Furthermore, a Bluetooth LE beacon device costs only thousands of JPY. We focus on these attractive features of Bluetooth LE beacon and utilize its RSSI for position presumption. Although Bluetooth signals or beacons have been used for position presumption [9], [10], there is no adequate study based on Bluetooth LE beacon. In this paper, we set up Bluetooth LE beacon devices that act as a beacon emitter and make an indoor position presumption with RSSI of beacons obtained by a portable device. We aim to achieve technical knowledge of certain accuracy of estimation by fundamental observation.

II. Observation of Bluetooth Beacons

Since Bluetooth LE has been released in 2010 and put devices on the market recently, there is no study of position presumption using Bluetooth LE beacon devices. Our first goal is to show the feasibility of position presumption using RSSI of Bluetooth LE beacon. Bluetooth LE beacon device works with battery and needs no fixed infrastructure while wireless LAN access point needs fixed infrastructure such as Ethernet and power line. This feature reduces install, setup, and maintenance costs than similar positioning system equipped with wireless LAN. Furthermore, Bluetooth LE beacon device emits beacons at constant power while wireless LAN access points may operate adaptive control by signal strength or modulation scheme.

We have developed Bluetooth LE beacon devices. Before installing them, we have observed radio characteristics of one of the Bluetooth LE beacon devices at anechoic chamber. In the left-side graphs of Fig. 1, the blue lines which named “field intensity” indicate RSSI in dBm received by a Google Nexus 7(2013) tablet positioned 4m away from the Bluetooth LE beacon device. The rounding angle labels from 0 to 350 in left-side graphs correspond to labels from 1 to 36 in right-side photos, respectively. We should note that we have observed the other Bluetooth LE beacon devices and the result is almost the same.

The observation is done in a 10.5m × 15.6m room. Top view of the room is shown in Fig. 2. The room is located on the 1st floor of 11-story building. We have installed 22 Bluetooth LE beacon devices inside and outside the room. The Bluetooth

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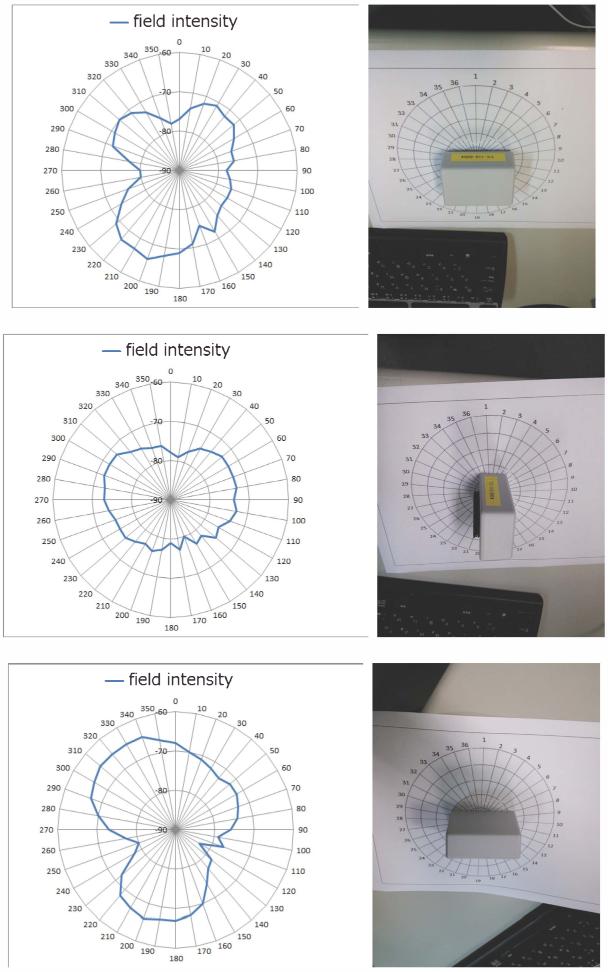

Fig. 1: A Bluetooth LE beacon device (prototype) and its radio characteristics.

LE beacon devices have been attached on the top of the walls for the sake of volatility of radio. Each Bluetooth LE beacon device has a unique ID, which is referred to as beacon ID, numbered 02–17 (inside the room), 45–48 (hallway), 49 and 50 (outside) as shown in blue numbers in Fig. 2. Currently, the Bluetooth LE beacon devices are enough for assured position presumption. Each Bluetooth beacon device emits a beacon every 417.5 ms.

To estimate position of portable device by RSSI of Bluetooth beacons, portable device must have Bluetooth interface to receive signals. We have set up Google Nexus 7(2013) tablets as portable devices, which is the reference model of Android OS. Observation points are indicated by black text numbered i1–i42 (inside the room), i43–i49 (outside), and i50–i56 (hallway). Typically, observation points should be placed in a grid manner for accurate error measurement. In this instance, however, we placed one points for one desk to make observation easy and simple. Any tablets set in the room can obtain beacon signals emitted from Bluetooth LE beacon devices in the room. When a portable device obtains a beacon, it makes "beacon data," which consists of beacon ID and its RSSI. Each portable device collects 50 beacon

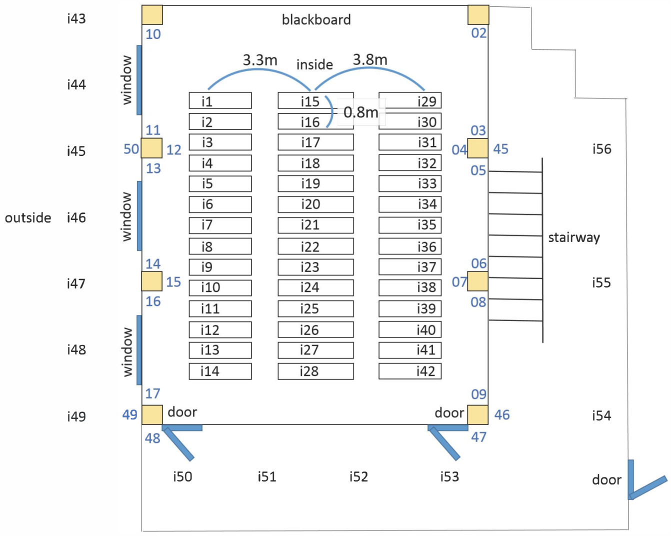

Fig. 2: Position of Bluetooth LE beacon devices and observation point. (Blue: Bluetooth LE beacon devices, black: observation points)

data at one observation trial and wraps them up as a "beacon message." For now, a beacon message also contains place ID, which corresponds to the observation point, to judge whether the result of position presumption is correct or not. Finally, the portable device sends one or some beacon messages to database/estimation server via wireless LAN.

We have gathered over 5800 beacon messages obtained at observation points to the database/estimation server. Fig. 3 shows the mean value of RSSI on each Bluetooth LE beacon installed in the room or outside the room. Blue- and red-color indicates low and high intensity, respectively. X-axis indicates observation point, which corresponds to i1–i56 on Fig. 2. Y-axis indicates beacon ID, which corresponds to 02–17, 45–50 on Fig. 2. We should note that the Y-axis has a discontinuity point between beacon number 17 and 45, i.e. beacon number 18–23 in Fig. 3 corresponds to beacon ID 45–50 in Fig. 2. The left bar (field intensity of i1) is colored by one beacon message captured at i1, which focused on the next section.

We can see from Figs. 2 and 3 that the closer the beacon is, the higher the intensity is. As shown in Fig. 3, we can clearly make a decision whether a portable device is in the room or not.

III. Position Estimation of Portable Device

We take an evaluation and study accuracy of the node position estimation. On the database/estimation server, over 5800 beacon messages have been stored. Each message, which sent by an observation node, contains 50 beacon data and place ID. Each beacon data consists of beacon ID and its RSSI obtained at an observation node. As we mentioned, there are 22 Bluetooth LE beacon devices and each of which emits beacon every 417.5 ms. Thus, one observation takes about 1.0–1.5 s.

To clarify accuracy of each observation, we have examined each beacon data using template matching, also known as RSSI fingerprinting. For instance, we show a sample of RSSI

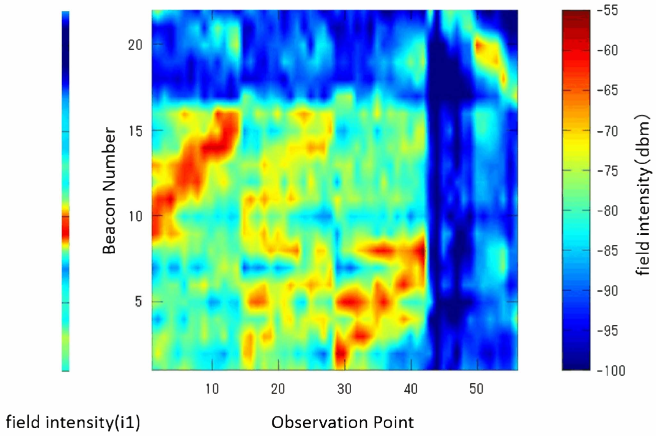

Fig. 3: Mean value of RSSIs.

intensity bar on the left of Fig. 3. Y-axis of the bar corresponds to beacon ID, which corresponds to 02–17, 45–50. Simply, we are to search the most suitable position from observation points in Fig. 3.

In this paper, we use SSD (Sum of Squared Difference), one of the well-known algorithms for template matching. We derive template data T_{bl}, i.e. mean RSSI of beacon ID b at observation point l, by counting all beacon messages. Then, a challenge message is selected from beacon messages. Challenging data I_b, i.e. mean RSSI of beacon ID b, is derived by counting all beacon data in the challenge message. SSD represents dissimilarity of template data and challenging data:

$$R_{SSDl} = \sum_{b \in B} (I_b - T_{bl})^2 \tag{1}$$

where B is the set of obtained beacon IDs.

We determine that it is correctly estimated if observation point l of minimal R_{SSDl} ($l \in$ i1...i56) is equal to place ID of the challenge message. For each beacon message, we calculate whether the result of estimation is correct or not. Then, we derive correct estimation rate of each observation point. From the result, the range of the correct estimation rate is from 0.817 (location: i34) to 1.00 (location: i10, i24, i25, i29, i35). Overall (averaged) correct estimation rate is 0.966 (96.6%).

From the result of the evaluation, we can typically say that the nearer portable device by one or some of the beacon device, the higher the correct estimation rate is. However, the correct estimation rate at some observation point is comparatively low in spite of the portable device is near the beacon device, e.g. i34. The degradation of the correct estimation rate is possibly based on radio influence such as multipath, reflection or interference. We count up the number of estimated location at i34 in Table I. From the result, most incorrect locations (i21, i33, i19) are near the correct location (i34). Although some of the estimation result is wrong for now, we consider that every correct estimation rate is high enough for position presumption.

TABLE I: Number of estimated location at i34.

i34	i1	i7	i17	i19	i21	i22	i23	i31	i32	i33	i35	i36
85	1	1	1	2	5	1	1	1	1	3	1	1

IV. Conclusion

We have studied the accuracy of estimation by fundamental observation. We have gathered over 5800 beacon messages and each of which contains 50 beacon data. By template matching, the correct estimation rate has been achieved 0.966 (96.6%).

We have installed 22 beacons in/around the room to ensure certainty. By taking observation points in a grid manner, we are going to determine the feasible number of beacon devices for each room. Additional observations will be taken on dynamic situations such as crowd people are moving and evaluate the accuracy of estimation. Then, we will assess the correlation of number of beacons and accuracy. Furthermore, we are aiming to improve the accuracy by developing estimation algorithm or increasing observation time.

References

[1] H. Liu, H. Darabi, P. Banerjee, and J. Liu, "Survey of wireless indoor positioning techniques and systems," *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews*, vol. 37, no. 6, pp. 1067–1080, Nov. 2007.

[2] J. Kuriakose, S. Joshi, R. V. Raju, and A. Kilaru, "A review on localization in wireless sensor networks," in *Advances in Signal Processing and Intelligent Recognition Systems*, ser. Advances in Intelligent Systems and Computing. Springer, 2014, vol. 264, pp. 599–610.

[3] P. Bahl and V. N. Padmanabhan, "RADAR: an in-building RF-based user location and tracking system," in *Proceedings of Joint Conference of the IEEE Computer and Communications Societies (INFOCOM)*, vol. 2, 2000, pp. 775–784.

[4] S. Ito and N. Kawaguchi, "Bayesian based location estimation system using wireless LAN," in *Proceedings of IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom)*, Mar. 2005, pp. 273–278.

[5] G. Shen and Z. Xie, "Wi-Fi RSS based indoor positioning using a probabilistic reduced estimator," in *Active Media Technology*. Springer, 2013, vol. 8210, pp. 46–55.

[6] J. Zhu, K. Zeng, K.-H. Kim, and P. Mohapatra, "Improving crowd-sourced Wi-Fi localization systems using Bluetooth beacons," in *Proceedings of IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON)*, Jun. 2012, pp. 290–298.

[7] Apple Inc., "iOS: Understanding iBeacon," available: http://support.apple.com/kb/HT6048.

[8] Bluetooth SIG, "Specification of the Bluetooth system v4.0," 2010, available: http://www.bluetooth.org/.

[9] S. Zhou and J. K. Pollard, "Position measurement using Bluetooth," *IEEE Transactions on Consumer Electronics*, vol. 52, no. 2, pp. 555–558, May 2006.

[10] I. Oksar, "A Bluetooth signal strength based indoor localization method," in *Proceedings of International Conference on Systems, Signals and Image Processing (IWSSIP)*, May 2014, pp. 251–254.