Practical RSSI-Based Indoor Localization Using iBeacon

Tuan D. Vy and Yoan Shin*
School of Electronic Engineering, Soongsil University, Seoul 156-743, Korea
Email: {tuanvyduc, yashin}@ssu.ac.kr
(*Corresponding author)

***Abstract*— We propose a new approach to solve mobile indoor localization using the received signal strength indicator (RSSI) in combination with iBeacon technology. First, we measure RSSI via the radio propagation model from a single iBeacon node to the mobile device, thereby characterizing the corresponding *trusted-range* that can be used for the mobile position. Using this measurement, we propose a model that can estimate the position of the mobile device from a certain number of nearest neighbor iBeacon nodes. Experimental results show the effectiveness of the proposed scheme, which is robust, low complexity and also evaluating accuracy based on iBeacons nodes resolution.**

Keywords—indoor localization; received signal strength indicator; iBeacon; BLE; Bluetooth 4.0

I. Introduction

We consider a problem of received signal strength indicator (RSSI)-based localization for mobile devices in indoor environments using iBeacon. Our goal is to estimate the unknown position of a mobile device from RSSI measurements between the mobile node and some neighboring iBeacon nodes. The iBeacon node that we used is a Bluetooth low energy 4.0 device, which exhibits small size, low cost and low power consumption. It is commonly used for broadcasting small chunks of information. In this paper, we firstly measure the RSSI propagation over the time between the mobile node and one iBeacon node [1]. This information can be used to evaluate the *trusted-ranges* of a single iBeacon node. We then construct a simple localization scheme based on the trusted-range information. In this scheme, we obtain the estimated mobile position by following these steps: (i) taking RSSI measurements from the nearest neighbor iBeacon nodes; (ii) choosing the corresponding geographical shape that offers the best fit of mobile position; (iii) building the trusted-range model and partition zone process; (iv) applying the proposed localization algorithm to establish the position. This approach provides low complexity and very rapid processing.

The rest of the paper is organized as follows. Section II provides general information on the iBeacon node used in our experiments. The results of RSSI propagation measurements are analyzed in Section III. Section IV describes the proposed localization scheme followed by the experimental results in Section V. Finally, Section VI concludes the paper.

II. iBeacon Node

An iBeacon node works like a radio base station, and broadcasts information through the air in the 2.4 GHz industrial, scientific, and medical (ISM) band. Thus, the radio propagation channel is significantly affected by various materials, such as concrete walls, metal, and even the human body. Moreover, the manufacture of iBeacon plays a vital role in designing the resulting radio signal strength. For instance, beacons manufactured by Estimote and Lontakt show distinct RSSI measurements over the same distance [2]. In this paper, we use RedBear iBeacon nodes, since they have a small size that allows for easy installation, and they provide a long battery lifetime of up to 6 months from two AAA batteries working at maximum power consumption [3]. Fig. 1 shows the structure and size of a RedBear iBeacon node. In practice, power consumption depends on the advertising interval and the transmit power. In addition, the more often broadcast messages are sent, the more the battery lifetime runs out. In the case of the Estimose nodes, they can survive 2 years with one coin battery at 10 seconds per message. After examining the RedBear iBeacon nodes, we set up the advertising interval to be 250 msec and the transmit power +4 dBm.

Figure 1: A RedBear iBeacon node with 2 AAA batteries

III. iBeacon Propagation Measurements

A. Single iBeacon Node Measurements

First, we evaluate the RSSI measurements from a single iBeacon node to a mobile device at several distances by deploying them in a room that was a maximum of 10m long and no furniture or people. An iBeacon node was placed at the corner of the room to avoid the reflection or fading of the signals. The RSSI measurements were recorded by an iPhone5 smartphone, starting at 0.5m from the iBeacon node and moving an additional 0.5m every 5 minutes along the edge of the wall until reaching the end of the room. The smartphone continuously recorded the RSSI values from the iBeacon node at 1-second intervals. Fig. 2(A) shows the RSSI ranges recorded at several distances, which can be differentiated in three levels of RSSI ranges: from −65 dBm to −56 dBm at 0.5 m from the iBeacon node; −76 dBm to −66 dBm at 1.0 m; and −85 dBm to −77 dBm at 1.5 m. This kind of phenomena repeats when measuring the RSSIs in a day at various times. For instance, Fig. 2(B) and 2(C) show the measurements at 2 pm and 6 pm, respectively. Finally, based on the recorded RSSI values, we built a trusted-range for each iBeacon node, which is described in the next section.

B. Trusted-range model

Figure 2 in the previous section indicated some interesting relationship between the RSSI values and several distances from an iBeacon node to a smartphone device. We extended the experiment to various times throughout the day to clarify that those three levels of the RSSI range is not a random result. We realized during the experiment that the obtained RSSI values for each level might vary at different times of the day. We selected the reliable RSSI values as *trusted-ranges*, which are denoted at level k as T_k, and defined as

$$T_k = \bigcap_{i=1}^{n} \{B_{ki}\}, \qquad (1)$$

where $i = 0, \cdots, m$, B_{ki} is the set of RSSI values received at k-th level range, and n is the total number of range levels, which is set based on the measured RSSI. Note that each T_k has their standard deviation value σ_k in k level range respectively.

Table 1 shows the observed results at 9am, 2pm, and 6pm. The received signals are classified into five levels in terms of range. Based on (1), we computed the trusted-ranges as shown in the final row of Table 1. When the smartphone receives the RSSI value from the iBeacon nodes, the distance between them is estimated by mapping the trusted-range it belongs to using Table 1. This distance information allows the smartphone position to be estimated.

TABLE 1: RSSI RANGES AT VARIOUS TIMES AND CORRESPONDING TRUSTED-RANGES

Range of RSSI values (dBm)		Distance (m)				
		<0.5	0.5	1.0	1.5	≥2.0
Time	9 am	>−55	(−65,−56)	(−76,−66)	(−85,−77)	<−86
	2 pm	>−54	(−63,−55)	(−71,−66)	(−84,−79)	<−85
	6 pm	>−54	(−68,−55)	(−78,−67)	(−84,−75)	<−85
Trusted-ranges		>−55	(−63,−56)	(−71,−66)	(−84,−79)	<−86

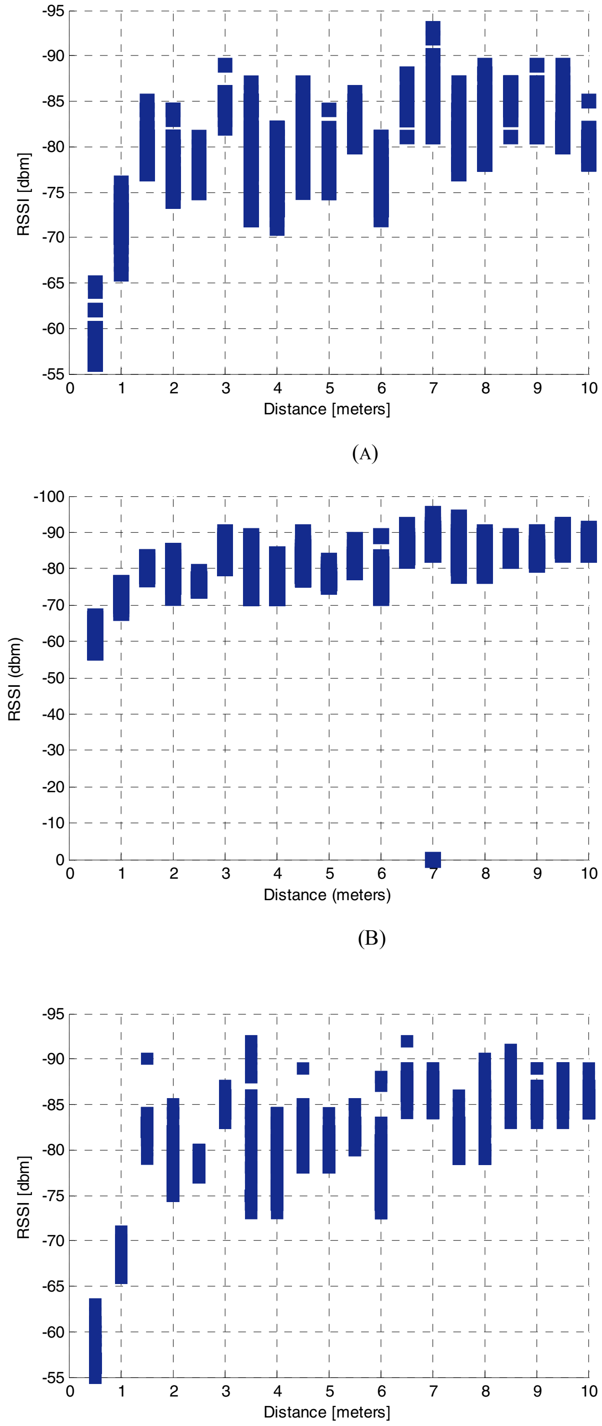

FIGURE 2: RSSI MEASUREMENTS FROM A SINGLE IBEACON TO AN IPHONE5 SMARTPHONE AT (A) 9AM, (B) 2PM AND (C) 6PM.

IV. PROPOSED LOCALIZATION ALGORITHM

A. Partition Zones

Since the iBeacon can return the measurement of distance via accuracy value [5], the localization algorithms based on its RSSI measurement are almost focused on either triangulation or fingerprinting localization. However, there exist some disadvantages when applying these methods. For example, using the triangulation method leads to low accuracy for long-term error and using the fingerprinting method requires a large number of Beacon nodes to obtain a high accuracy. Furthermore, for a short-range signal of Bluetooth, building the radio maps is a quite frustrating procedure when the signals were lost or the service was out of range. Thus, in order to achieve a higher accuracy, we combine the triangulation with the fingerprinting methods, resulting in the partition zone method.

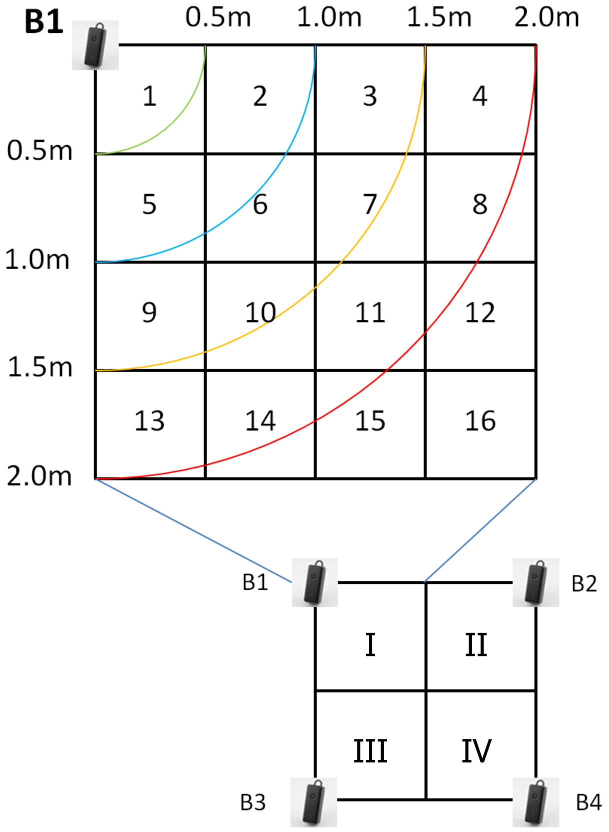

FIGURE 3: AREA PARTITION IN ZONE

We denoted D as the distance interval between two iBeacon nodes. Assume a 4.0 m×4.0 m square area, which means $D = 4$ with a beacon setup at the corner; then the signal broadcast begins. According to the trusted-range, the localization process only performs in a square node distribution where the edge length is 2.0 m maximum. This area is divided into a grid model as shown in Fig. 3, which implies there are 16 zones in total. We consider a human footstep length to be around 0.7m [6]; thus, every change of position inside a zone does not cause a big error. In other words, any position of the smartphone located within one zone area is represented as the center of this zone.

The small size of the iBeacon node allows it to be placed on any surface. In this section, the iBeacon nodes are deployed at grid points within a square area. For a grid of N iBeacon nodes, the unknown position $P(x, y)$ of a smartphone can be estimated.

We divide the area which is limited by four iBeacon nodes into four partitions named (I, II, III, IV). Depending on which iBeacon gives the strongest signal, the smartphone chooses the partition it belongs to. Combining the fingerprinting technique and the trusted-range table, these zones are classified as five groups. Group 1 is zone 1, which positions near B_1 at a range of 0.5 m. Group 2 is as far as 1.0 m away from the iBeacon included in zone 2, zone 5, and a part of zone 6. Zones 3, 7, 6, 9, and 10 are added into group 3. Group 4 is consists of zones 4, 8, 11, 13, and 14, which indicate a distance as far as 2.0 m away. The last group accommodates zones 12, 15, and 16, and represents the "out-of-trusted-range" value that can be calculated by accuracy value returned by the CoreLocation API in [7].

B. Proposed localization algorithm

With the square distribution explained in the previous section, our proposed localization algorithm can easily be processed via the procedure shown in Fig. 4.

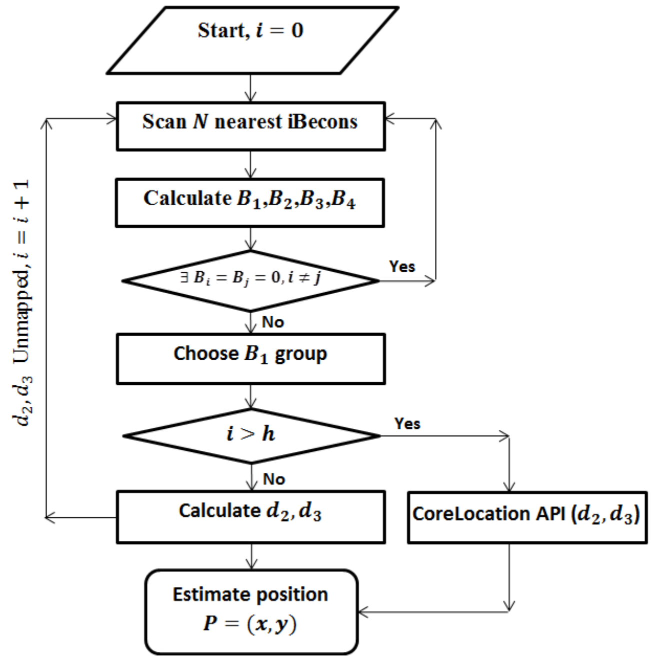

FIGURE 4: PROPOSED LOCALIZATION ALGORITHM

The localization process can be divided into three main steps:

Firstly, we chose the four nearest iBeacon nodes by scanning all the nearest nodes set $B = \{B_i\},\ i = 1, \cdots, N$ and obtained B_k by (2).

$$B_k = \max\{B \backslash B_{k-1}\} \text{ where } B_0 = 0 \qquad (2)$$

Secondly, small areas limited by four iBeacons are divided into four equal quarters by the mid-points of their length and width. The quadrant containing B_1 was chosen. Then the group containing the smartphone was decided based on B_1 by mapping into the trusted-range table. Finally, the zone was decided by comparing the distances from the next two iBeacons, d_2 and d_3 which are calculated by mapping B_2, B_3 with the trusted-range, respectively. In case that B_2, B_3 are out of the trusted-range, zone choosing would be based on the comparison between their values. Denote Δ in (3) as their deviant.

$$\Delta = |B_2| - |B_3| \quad (3)$$

If $\Delta < 0, |\Delta| \leq \sigma_k$ then $P(x, y)$ belongs to the top-right half: included in zones 2, 3, 4, 7, and 8. On the other hand, if $\Delta > 0, |\Delta| \leq \sigma_k$ then $P(x, y)$ is located within zones 5, 9, 10, and 14. And if $|\Delta| \leq \sigma_k$, then $P(x, y)$ belongs to zones 1, 6, and 11. However zone 16 is the special zone where B_1, B_2, B_3 are all out of the trusted-range, so position P is immediately estimated. If one of three distances d_1, d_2, d_3 could not be mapped, the process would then return to the first step. Within the h loop, if d_2 and d_3 still cannot be mapped, the value can be obtained by the accuracy value that is returned by the CoreLocation API. In this paper, we choose $h = 5$ for optimizing the cost of time and the accuracy. However Increasing h will make the result more reliable but cost estimated time.

Finally, if d_2 and d_3 are successfully mapped, the distance from the smartphone is determined based on the location of its zone. If the position of iBeacon node j that is set up in major and minor values is $P_j(x_j, y_j)$, the position of the smartphone is estimated as in (4).

$$P(x, y) = P_1(x_1 \pm d_2, y_1 \pm d_3) \quad (4)$$

If d_2 and d_3 is calculated by the CoreLocation API, which means the mapping failed, the smartphone position $P(x, y)$ is achieved by the traditional triangulation technique after obtaining the distances. The result decides which zone the smartphone belongs to.

V. Evaluation

We investigated a variety of grid resolutions to find the best solution. The experiment was conducted at a lobby (10.0 m×8.0 m) in the engineering school building during the holidays when the building was unoccupied. The smartphone was randomly re-positioned every 5 minutes, and it estimated the position by itself. The density of the iBeacon nodes was reset after 100 runs by changing the distance D. Fig. 5 illustrates the accuracy rate for several node densities. Although the accuracy at 1.0 m is the best result, we think the optimal result happens at 4.0 m of resolution because of the good optimization between the number of nodes and the accuracy.

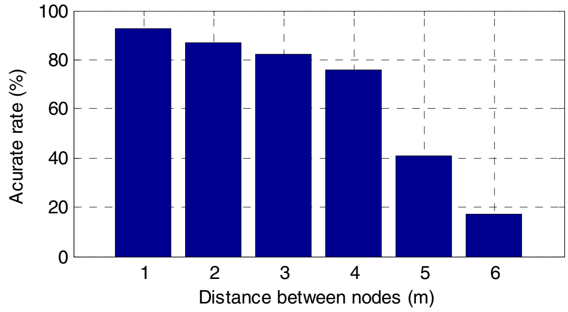

Figure 5: Accuracy rate at various node densities

VI. Conclusion

This paper gives different approach to classify the distance of a smartphone by observing the change of its RSSIs from iBeacon node, which is called *trusted-range*. Moreover, we propose a new indoor localization scheme based on the iBeacon technology. The experimental results show the accuracy of our simple RSSI-based model in several resolutions of iBeacon distributions, which provides efficient, accurate estimates, and can be utilized in numerous environments.

Acknowledgment

This research was supported by the MSIP, Korea, under the Convergence-ITRC support program (IITP-2015-H8601-15-1001) supervised by the IITP.

References

[1] M. S. Bargh and R. de Groote, "Indoor localization based on response rate of Bluetooth inquiries," *Proc. ACM MELT 2008*, pp. 49-54, San Francisco, USA, Sept. 2008.

[2] M. Kohne and J. Sieck, "Location-based services with iBeacon technology," *Proc. IEEE AIMS 2014*, pp. 315-321, Madrid, Spain, Nov. 2014.

[3] "iBeacon instructions," available at http://www.redbearlab.com.

[4] "Getting started with iBeacon version 1.0," available at https://developer.apple. com/ibeacon/Getting-Started-with-iBeacon.pdf.

[5] "The Beacon experiments: Low-energy Bluetooth devices in action," available at http://blog.shinetech.com/2014/02/17/the-beacon-experiments-low-energy-bluetooth-devices-in-action/.

[6] Y. Noh, H. Yamaguchi, U. Lee, P. Vij, J. Joy, and M. Gerla, "CLIPS: Infrastructure-free collaborative indoor positioning scheme for time-critical team operations," *Proc. IEEE PerCom 2013*, pp. 172-178, San Diego, USA, Mar. 2013.

[7] "Core Location Framework Reference" available at https://developer.apple.com/library/ios/documentation/CoreLocation/Reference/CoreLocation_Framework/.