2015 2nd International Conference on Information Science and Control Engineering

Indoor location position based on Bluetooth Signal Strength

Mohamed Er Rida, Fuqiang Liu, Yassine Jadi, Amgad Ali Abdullah Algawhari ,Ahmed Askourih
Tongji University
Shanghai, China
modir721@gmail.com

***Abstract*—nowadays many systems with diverse technologies such as (GPS, Wi-Fi, Bluetooth, ZigBee, Ultra Wide Band, Ultrasounds, Infrared, etc...) can be used for indoor location. One of the biggest challenges in indoor location systems is to determine the actual indoor position of the user using a smart device (Phone, PC, etc...), due to their instability, cost, high-power consumption, low accuracy and low precision. To overcome those problems, we have designed, implemented and emulated an indoor location system based on RSSI (Receive Signal Strength indicator) of the Bluetooth low energy 4.0 (BLE). BLE 4.0 technology is more advantageous in terms of long life expectancy; our approach is based on the deployment of equidistant nodes on the ceiling. The nodes are programmed to broadcast a periodic beacon at a time-pace of 400ms and then to enter sleep mode. When a smart device enters within the broadcasting range, it locates the three access points (nodes) with the highest signal strength. This information can be calculated using one of the several localization algorithms (Trilateration) .The proposed Trilateration algorithm can be easily implemented in the hardware due to its low complexity; the method can be successful even when using a few numbers of nodes. In average the system has about 0.5 ~ 1 meters of error.**

***Keywords*—Nodes; Bluetooth4.0; indoor location; Signal strength, Trilateration.**

I. INTRODUCTION

In recent years, indoor location systems [1] have rapidly increased and become popular. People spend most of their time in indoor environments, and in some countries where the weather is really cold, majority of the activities are carried out in vast indoor environments. In such circumstances, it can be difficult to navigate where you are heading to, forget where you left objects, and difficult to recognize your current position or where you parked the car[1]. This paper presents a new system that could solve these problems at the push of a button.

The idea behind indoor location systems is to be able to provide a better way for objects to be located inside a building, and lead to accurately coordinate where objects have been lifted [2]. Conventional indoor location systems such as Wi-Fi, Radio-frequency identification (RFID), Ultra Wide Band (UWB), Bluetooth and Ultrasound system have achieved a great goal in terms of transferring data within a short range, but when it comes to indoor environment, these systems have a problem due to their cost, high-power consumption, low accuracy and low precision. The satellite-based global positioning system (GPS)[1] has been extensively used for positioning in outdoor environments such as in car navigation, mobile phones, ships, planes, surveying of public works and so on. However, it has a huge energy consumption . Also the additional cost is a setback for these devices to be used on a large scale, where GPS technology does not work precisely [3] [4] , this is due to the attenuation of signals through construction materials in buildings and from other radio sources that lead to large positioning error in indoor environments. The GPS has an accuracy of within 10 meters [4], therefore it can't be used in indoor environment.

Bluetooth 4.0 [7][8][5]has been designed to provide features such as low cost, low power consumption. BLE already exists in various consumer devices such as mobile phones, laptops, and smart TVs.

By deploying nodes on the ceiling we can cover a large area. These nodes are categorized as: beacon nodes (access points APs) are special type of nodes embedded with Bluetooth 4.0, these nodes can also be placed manually at known positions. It is assumed that N numbers of nodes are deployed in the sensing field.

To estimate the mobile position in the indoor environment, the system needs to measure RSSI values between the Smart device and three known reference nodes. The position of any object can be calculated by using the Trilateration Technique [6].

II. SYSTEM STRUCTURE

This paper proposes an indoor position system based on BLE signal Strength. Using Trilateration, we can determine the position of the user. A minimum of three access points (Nodes) are needed to determine the position of the user indoor location.

Nodes broadcasting a short periodic beacon RF signal frame (Bluetooth signal) will, at a certain time, change to sleep mode in every 400ms. The RF signal carries important information such as spaces id. Each Node provides coverage of about 15 m and a distance of six meters between each node we have deployed nine nodes on the ceiling, as per the illustration in figure 1. The position of Nodes are assumed as (X_1,Y_1) , (X_2, Y_2)... (X_9,Y_9).

978-1-4673-6850-6/15 $31.00 © 2015 IEEE
DOI 10.1109/ICISCE.2015.177

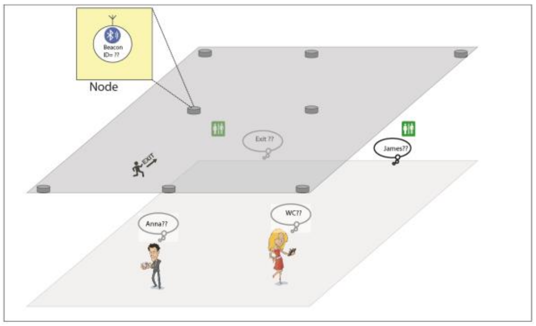

Fig. 1. Indoor location scenario.

The Smart device collects the signal strength (RSSI) of the three nearest connected adjacent nodes through RSSI measurement. By using Trilateration algorithm the smart device can know the distance between itself and the three nodes.

A. Hardware Architecture

The hardware is composed of two parts:

1) Transmission Unit: We developed a Node with CC2540 (Bluetooth technology 4.0), as shown in Fig.2.

The Node consists of three parts:

- Power supply 3.7V(battery)
- LED (indicator)
- CC2540 which is produced by Texas Instrument Microcontroller, is highly suited for systems where ultra-low power consumption is required. This is achieved by various operational mode, short transition times between these nodes to further ensure low power consumption.[7],[8]

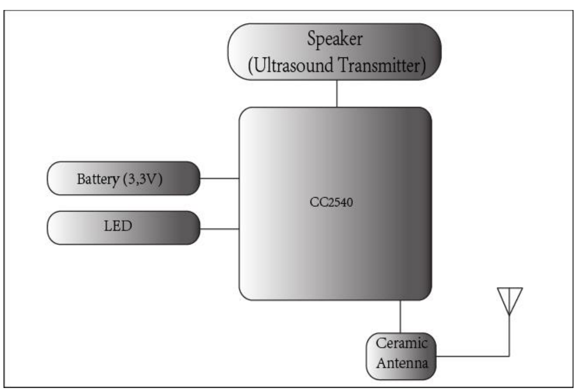

Fig. 2. Block diagram of Node (AP).

Nodes are capable of broadcasting a periodic short beacon .RF frame each 400ms, for instance, “Hi, I am here”. Each node has its own id as shown by the flowchart in Fig.3

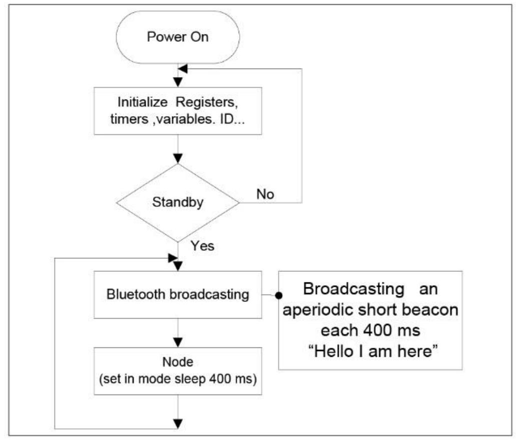

Fig. 3. Flowchart of Node (AP).

2) Receiver Unit (Smart device): By using the smart device; the Android 4.1 Developer (Samsung) has a Bluetooth 4.0 (BLE).The smart device measures the RSS and finds the three nearest nodes. By using the Trilateration technique, the smart device can calculate the distance between it and each three nodes.

III. Algorithm Testing

This section presents the principle of position estimation which is uses the measurement of the RSSI [9] and algorithm Trilateration.

Indoor location system is divided into two parts, which depends on the function, that is, the broadcasting part Nodes (APs) that is fixed on the ceiling, and the processing part smart device (phone).

In order to determine whether the algorithm that has been developed is reliable or not, we tested it by introducing real scenario parameters. Then, we calculated the real Euclidean distances (between the node and the smart device) values between three APs and a smart device by using the Trilateration algorithm

A. RSSI Measurements:

The RSSI (Received Signal Strength Indicator) is defined in IEEE 802.11 standard, which is the ratio of the transmitter power and the received power presented by dBm unit. The RSSI has the characteristic that it can decrease exponentially according to the increase of distance [10]. Due to these characteristics, RSSI attenuation model was used as (1):

$$RSSI_{dBm} = -10.\mathrm{n}.log_{10}(\mathrm{d}) + \mathrm{A} \qquad (1)$$

Where, n: signal propagation constant, also named propagation exponent; d: distance from the sender; A: received signal strength at a distance of one meter.

The relationship between d and RSSI

$$d_m = 10^{\frac{RSSI-A}{-10.n}} \qquad (2)$$

B. Techniques Trilateration to estimate the position :

Trilateration is used to determine the position using distances to known reference points [10][11]. For instance, a smart device may localize itself by evaluating distances to a certain reference points, e.g., Node, using the principle of trilateration, as shown in Fig.4.

In figure 4, two dimensional (2D) positioning of Smart device (S), can be realized using three reference points, here reference Nodes. Assuming the Smart device is able to exactly determine its distance $r_i \forall\, i \in \{1, 2, 3\}$ to each of the Nodes, a circle is drawn around each Node with a radius equal to the measured distance r_i. The intercept point of the three circles with radii $r_1 \ldots r_3$ indicates the position of S. If the positions of the reference Nodes are known, the smart device may determine its position by solving the set of equations

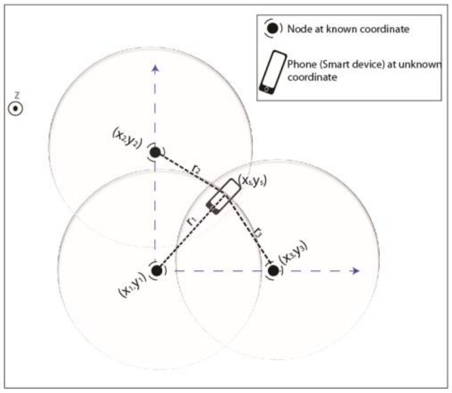

Fig. 4. location estimation using trilateration with nodes reference.

$$\sqrt{(x_S - x_i)^2 + (y_S - y_i)^2} = r_i \tag{3}$$

$$(x_S - x_i)^2 + (y_S - y_i)^2 - r_i^2 = 0 \tag{4}$$

(x_s, y_s) is the position of the Smart device, which shall be estimated and $(x_i, y_i) \forall\, i \in \{1, 2, 3\}$ is theposition of each of the reference Node points respectively. Solving the set of equations in (3) for three reference points yields;

$$\begin{pmatrix} x_s \\ y_s \end{pmatrix} = \begin{pmatrix} a_{1,2} & b_{1,2} \\ a_{1,3} & b_{1,3} \end{pmatrix}^{-1} \begin{pmatrix} g_{1,2} \\ g_{1,3} \end{pmatrix} \tag{5}$$

With

$$a_{1,i} = 2(x_i - x_1), \quad i \in \{2,3\} \tag{6}$$

$$b_{1,i} = 2(y_i - y_1), \quad i \in \{2,3\} \tag{7}$$

And

$$g_{1,i} = r_1^2 - r_i^2 - (x_1^2 + y_1^2) - (x_i^2 + y_i^2), \quad i \in \{2,3\} \tag{8}$$

$$\bar{A} = \begin{bmatrix} a_{1,2} & b_{1,2} \\ a_{1,3} & b_{1,3} \end{bmatrix} \tag{12}$$

$$\bar{B} = \begin{bmatrix} g_{1,2} \\ g_{1,3} \end{bmatrix} \tag{9}$$

Hence, the object's coordinates are concluded as

$$\begin{bmatrix} x_s \\ y_s \end{bmatrix} = (\bar{A}^T \bar{A})^{-1} * (\bar{A}^T \bar{B}) \tag{10}$$

In the case of three-dimensional (3D) positioning, a minimum of four reference points is necessary to unambiguously determine the exact position.

Based on the trilateration algorithm, Han et al. [12] further improved localization performance by taking into account the layout of the three reference nodes. The proved that the trilateration algorithm can best demonstrate its advantages when the three reference nodes are deployed in the vertices of equilateral triangles. Yang and Liu [12] considered the effect of noisy environments, and used different confidence coefficients for three nodes to guarantee the quality of trilateration

IV. Experiment Result

Design and development of nine CC2540 development boards integrated with BLE function as the BLE reference nodes in positioning was successfully done The RSSI sampler on smart phones, which is able to measure the RSSI and defined location of the user in indoor locations was also developed. We have implemented our hardware Fig.5, and software (using an android platform) [13]

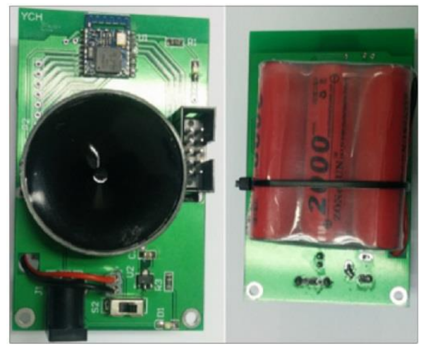

Fig. 5. Node hardware.

To find out the relationship between the physical distance and the RSSI values, we inserted all data and presented it to Matlab software. Table 1 shows RSSI attenuation as distance. To evaluate the performance of the estimated model, we conducted sampling experiments every 100cm in the location environment [0-12m], and repeated it 50 times for each point. After filtering the wrong data, we recorded the maximum, minimum and mean value of RSSI respectively.

TABLE I. The average measurement of the RSS value from node.

Real Distance (m)	*Average of RSSI Value(dBm)*
1	-42
2	-52
3	-73
4	-80
5	-80
6	-79
7	-85
8	-88
9	-86
10	-87
11	-94
12	-91

For each transmission power level and distance, we calculated the mean of the RSSI at the receiver. Then we identified an exponential curve to fit the data. We also ran this step off-line using MATLAB and provided a simple lookup table for any real-time calculations. The curve fits for power level 3 in indoor experiments as shown in Fig.6. The indoor data for the same power level can be seen in (11)

$$P= [-0.1105 \quad 2.7307 \; -22.9094 \; -21.0808] \tag{11}$$

$$RSSI = -0.1105 + 2.7307 - 22.9094d^2 - 21.0808d^3 \tag{12}$$

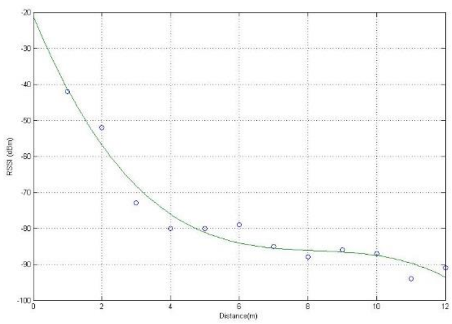

Fig. 6. Relation between Distance and RSSI.

In practical situations, many factors that can affect RSSI values exist, such as furniture, walls and people. These factors can produce signal scattering and multi-path effect. It also can result in positioning error. In order to reduce positioning error, proper parameter determination is necessary

$$\text{LE} = \sqrt{(X_{est}^i - X_a^i)^2 + (Y_{est}^i - Y_a^i)^2} \tag{13}$$

The error is not that much, and is usually caused by distance error which normally depends on the RSSI values between the nodes and the smart device.

TABLE II. THE RESULTS OF THE EXPERIMENT. THE RSSI AND THE LOCATION

(X_a,Y_a) (m)	$Node_1(0,0)$ (dBm)	$Node_2(0,9)$ (dBm)	$Node_3(9,0)$ (dBm)	$Node_4(9,9)$ (dBm)	(X_{est},Y_{est}) (m)	Error Location (m)
(1,1)	-42	-88	-86	-94	(1.2,0.9)	0.22
(1,5)	-80	-81	-89	-86	(0.8,5.4)	0.44
(1,8)	-88	-40	-94	-88	(1.4,7.2)	0.89
(4,2)	-81	-86	-80	-80	(452,1.58)	0.52
(4.5,4,5)	-78	-80	-77	-81	(6.21,1.34)	0.69
(6,2)	-79	-87	-73	-73	(6.37,1.74)	0.45
(6,6)	-87	-79	-78	-79	(6.2,5.7)	0.36
(8,1)	-89	-94	-41	-89	(8.3,1.5)	0.86
(8,8)	-94	-87	-89	-44	(7.8,7.4)	0.6

As given in table 2 the location error obtained by the experiment is not out of range of location error [0, 1m]

During the experiment more than 30 tests were chosen randomly, the experiments took place in the lab at Tongji University. The floor plan of the experiment of the experiment area is shown in Fig.7. The reference points (marked as the black dots in figure 7) we have used a Smartphone.

In the experiment region, signals were received from a total of nine Nodes.

The pink circles and the estimated location with an error of 85cm . The error in the location between actual and estimated location is calculated by equation (13):

Fig. 7. Building showing And APs locatiolazion .

V. CONCLUSION

We have implemented a prototype system showing that the proposed system and obtained better results by using both Trilateration technique and RSSI measurement. Through the implementation and experimentation of the indoor location system based Bluetooth BLE 4.0 access points with, we found that BLE 4.0 fits the Lower energy consumption criteria and is easy to deploy in different indoor environment scenarios. The degree of accuracy of the system in locating objects is acceptable and high when compared with other systems working in indoor environments.

ACKNOWLEDGMENT

This work was supported by a Key Program of National Natural Science Foundation of China (Grant No. 61331009) and the Fundamental Research Funds for the Central Universities (0800219236) in addition to the collaboration of Shanghai Yong Chang Information Technology Co, Ltd.

REFERENCES

[1] Y. Liu and Z. Yang, Location, Localization, and Localizability. Location awareness Technology for Wireless Networks, Springer, 2010.

[2] Yanying Gu, Anthony Lo, Ignas Niemegeers, "A Survey of Indoor Positioning Systems for Wireless Personal Networks", IEEE Communications Surveys & Tutorials, vol. 11, no. 1, 2009, Pages:13-32

[3] Y. Gu, A. Lo, and I. Niemegeers, "A survey of indoor positioning systems for wireless personal networks," IEEE Communications Surveys and Tutorials, vol. 11, no. 1, pp. 13–32, 2009.

[4] http://indoorpositioningsystem.files.wordpress.com/2014/03/single-room-indoor-positioning-system-final-report-1.pdf

[5] http://en.wikipedia.org/wiki/Bluetooth_low_energyA.

[6] N. Aida Mahiddin, N Safie, E. Nadia, S.Safei, E.Fadzli"indoor postion detectetion using wifi and trilateration technique," Faculty of Informatics, University Sultan ZainalAbidin,Terengganu, Malaysia

[7] CC2540/41 System-on-Chip Solution for 2.4GHz Bluetooth low energy Applications—User's Guide

[8] Texas Instruments CC2540 BLE Software Developer's Guide, version 1.0

[9] Oguejiofor O.S., Okorogu V.N., Adewale Abe, Osuesu B.O "Outdoor Localization System Using RSSI Measurement of Wireless Sensor Network " International Journal of Innovative Technology and Exploring Engineering (IJITEE) ,ISSN: 2278-3075, Volume-2, Issue-2, January 2013

[10] E. Elnahrawy, Xiaoyan Li, and R.P. Martin. The limits oflocalization using signal strength: a comparative study. 2004First Annual IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks, pages 406 – 414, October 2004.

[11] G. Han, D. Choi, W. Lim, "A Novel Reference Node Selection Algorithm Based on Trilateration for Indoor Sensor Networks", IEEE Intl Conf. on Computer and Information Technology, 2007, Pages:1003-1008

[12] Zheng Yang, Yunhao Liu, "Quality of Trilateration: Confidence based Iterative Localization", IEEE ICDCS, June 2008, Pages: 446-453.

[13] CC2540F128/256 Datasheet