Indoor Localization System using RSSI Measurement in Wireless Sensor Network Based on ZigBee Standard

Ratana Priwgharm , Krit Srivilas and Panarat Cherntanomwong

Department of Computer Engineering, Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Email: s1061023@kmitl.ac.th, krpanara@kmitl.ac.th

ABSTRACT

This paper presents the studies and experiments of indoor object localization system using wireless sensor network (IEEE 802.15.4). The system is defined upon the analysis of the models of maximum likelihood estimation and received-signal-strength indicator (RSSI) by a novel method for localizing a stationary object in an indoor office environment. The proposed method utilizes the RSSI of radio signals radiating from fixed reference sensors and move target sensor placed at known positions to generate a precise signal propagation model. The performance of the system is evaluated using the experimental data. The experiments were done by increasing the number of reference sensors in the system. Results show that the increasing number of reference sensors can reduce the object location error as expected.

Index Terms-- *Wireless Sensor Network; Localization; RSSI; Maximum Likelihood Estimation*

1. INTRODUCTION

Radio localization has been extensively researched because of its importance to many wireless applications. The accuracy of the location estimation and the reliable localization system are the main factors required. Nevertheless, the relatively simple and low cost system is also preferable. To deal with these requirements, many localization techniques related with the recent technologies have been proposed in the literature. The localization techniques can be mainly categorized as range-based and proximity-based [1]. The former is defined by algorithms that use absolute point-to-point estimated distance (range) or estimated angle for calculating the target location. The latter makes no assumption about the availability or validity of such information. Instead, the unknown location of the target is inferred from the references with known locations. The range-based technique can be generally divided into: (i) time based, e.g., time of arrival (TOA), time difference of arrival (TDOA), (ii) angle based, i.e., angle of arrival (AOA), and (iii) received signal strength indicator (RSSI). Among these techniques, RSSI-based approaches are widely applied due to its well tradeoff between hardware cost and localization accuracy.

Wireless sensor networks (WSNs) are networks composed of numerous small, independent, self-contained, often battery-powered nodes including a wireless transceiver, sensors, and micro-controller which are capable to self-organize in a communication network. The most common modern WSN applications are the area of surveillance and monitoring, home control, logistics, as well as office and industrial automation. Localization in WSN often uses the RSSI-based localization system. Some nodes are placed at known locations and referred to as beacon nodes (sometime called anchor nodes). By measuring the signal strength between beacon nodes and other non-beacon nodes (called unknown nodes), the system can then calculate the locations of unknown nodes based on radio signal propagation models.

ZigBee [2], [3] is the standard which follows the rules of IEEE 802.15.4. Moreover, for ZigBee, the distance between nodes can be calculated from RSSI. It is a challenge to propose a new localization algorithm based on the RSSI parameter. Furthermore, ZigBee technology has a good number of advantages such as originally lower cost than other wireless technologies, low data transfer, easily covers wide range and able to be any network topology e.g. star, mesh, ad-hoc, and hybrid forms. Comparing to other wireless technologies such as Bluetooth, Zigbee has not only a low-power output but also a short latency time. Therefore, we would like to propose a relatively simple method for the localization system using ZigBee-based WSNs. The maximum likelihood estimation is utilized to support estimating the location of the object. To evaluate the performance of the proposed method, the experiments are conducted and used for location estimation.

2. DESCRIPTION OF ALGORITHMS MODEL

2.1. RSSI and distance

The relationship between and distance and RSSI can be determined according to the following formular based on Friis transmission equation

$$RSSI[dBm] = -[10 \cdot n \cdot \log_{10}(d) + A], \qquad (1)$$

where n is the path loss exponent,
d is the Distance from sender and
A is the Received signal at 1 meter distance.

2.2. Maximum likelihood estimation localization algorithm

In this section, we show the localization algorithm using the maximum likelihood estimation, which is based on transmitter-receiver RSSI measurement. Node distance related information is obtained through measurement of the RSSI under the circumstance without additional node hardware design. Figure 1 illustrates the flow diagram of the classical location estimation algorithm using the Zigbee system, while figure 2 illustrates the flow diagram of the location estimation algorithm applied by the maximum likelihood algorithm and using the Zigbee system.

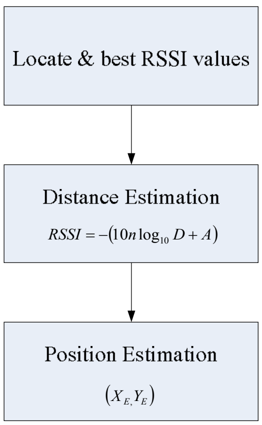

Figure 1. Classical Location Estimation Algorithm

Suppose coordinates of beacon nodes $B1(x_1, y_1), B2(x_2, y_2), \ldots\ldots\ldots, Bn(x_n, y_n)$, and coordinate of unknown node with position to be determined $O(x, y)$, distance between unknown node and the beacon nodes are $d_2, \ldots\ldots\ldots, d_n$, respectively. A group of non-linear equation [4]-[5] can be obtained according to the calculation formula for distance in a two-dimensional space, as shown by Eq. (2)

$$\begin{cases} (x-x_1)^2 + (y-y_1)^2 = d_1^2 \\ (x-x_1)^2 + (y-y_1)^2 = d_2^2 \\ \vdots \\ (x-x_n)^2 + (y-y_n)^2 = d_n^2 \end{cases} \tag{2}$$

When the last equation was subtracted from the other equations in turn beginning from the first equation, equation (2) becomes

$$\begin{cases} x^2 - x_n^2 - 2(x_1 - x_n)x + y_1^2 \\ - y_n^2 - 2(y_1 - y_n)y = d_1^2 - d_n^2 \\ \vdots \\ x_{n-1}^2 - x_n^2 - 2(x_{n-1} - x_n)x + y_{n-1}^2 \\ - y_n^2 - 2(y_{n-1} - y_n)y = d_{n-1}^2 - d_n^2 \end{cases} \tag{3}$$

Linear equation in equation (3) can be shown as $AX = b$ where

$$A = \begin{bmatrix} 2(x_1 - x_n) & 2(y_1 - y_n) \\ \vdots & \vdots \\ 2(x_{n-1} - x_n) & 2(y_{n-1} - y_n) \end{bmatrix},$$

$$b = \begin{bmatrix} x_1^2 - x_n^2 + y_1^2 - y_n^2 - d_1^2 + d_n^2 \\ \vdots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 - d_{n-1}^2 + d_n^2 \end{bmatrix},$$

$$X = \begin{bmatrix} x \\ y \end{bmatrix}.$$

The error of the node estimated location can be obtained by applying standard minimum mean square error as shown by equation (4) as

$$\hat{X} = \left(A^T A\right)^{-1} A^T b. \tag{4}$$

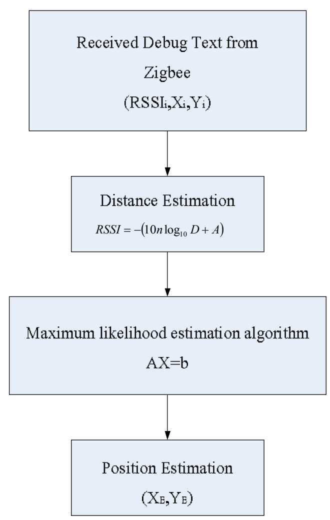

Figure 2 Location Maximum likelihood Estimation Algorithm

3. RESULT AND DISCUSSION

3.1. Experiment Setup

For the experiment, the ZigBee modules used are the XBee and XBee-PRO OEM RF Modules with frequency of 2.4 GHz. Localization systems of this paper were designed to estimate the location of target where reference sensors are installed in different areas. The reference sensor receiving the request message will send value of the intensity of the signal to the target sensor. The target sensor will then collect all data (RSSI) from reference sensors and forward data to the computer for estimating the target sensor location. Equipment for localization system is shown in figure 3.

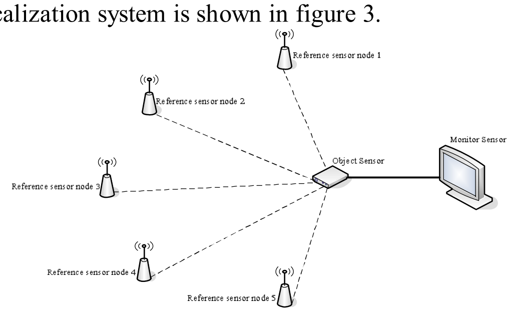

Figure 3. Equipment setup for localization system

Experiments were conducted on the sample locations by moving the target sensor and then displaying results from the developed location estimation algorithm. Three conditions of experiments were considered. Each condition is different from one another by a number of reference nodes that are 3,4 and 5 reference nodes for each condition. The sample observed locations are 30 locations by moving the unknown node to each observed location for each measurement. The signal intensity received from each reference node will be recorded and then used to calculate the location of target node. Then, the location estimation errors at each observed location are calculated.

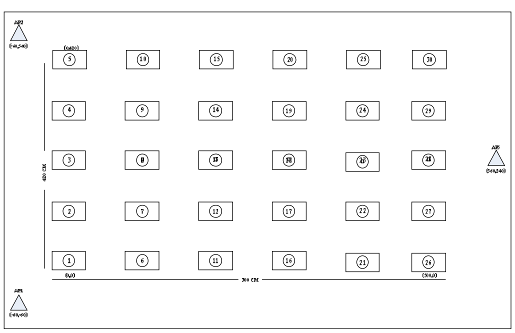

Figure 4 The layout of the experiment setup of 3 reference sensor nodes.

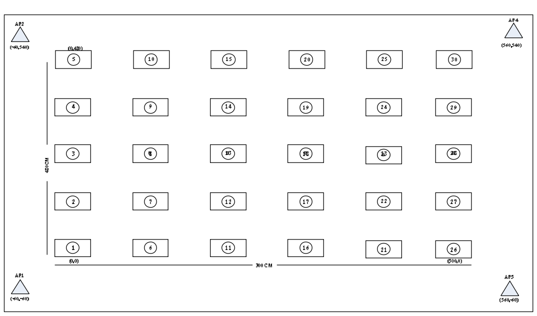

Figure 5 The layout of the experiment setup of 4 reference sensor nodes.

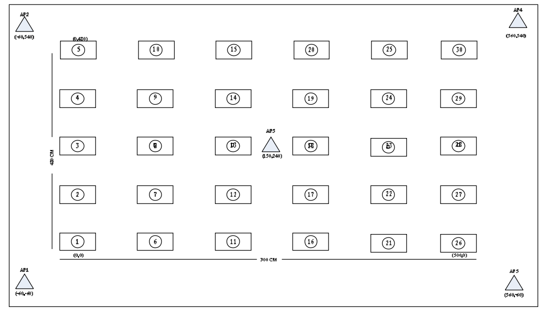

Figure 6 The layout of the experiment setup of 5 reference sensor nodes.

The layouts of experiment setup of 3,4 and 5 nodes are shown in Figure 4,5 and 6, respectively. These reference nodes thus form a rectangular test area with physical dimension of 4.8m x 3m. During the experiment, we carry the target node and walk from an indoor starting point with coordinate (0,0) to an ending point with coordinate (300,480). The experiment was conducted at a time when the interference from human activities was minimal. Before the experiment was carried out, the available radio frequency channels were scaned to avoid interference from wireless LAN at the area.

The accuracy of the propose system with refining algorithm was found by comparing the position estimated by this system with the predicted position calculated mathematically.

The experiments were conducted in the seminar room with relatively not many obstracles. Figure 7 demonstrates the Zigbee node which can be used as reference sensors and target sensor. Figure 8 also demonstrates the Zigbee node and shows the layout of the observed locations, marked on the floor.

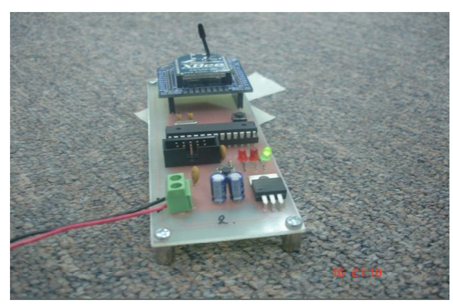

Figure 7 Zigbee Reference Sensor & Target sensor.

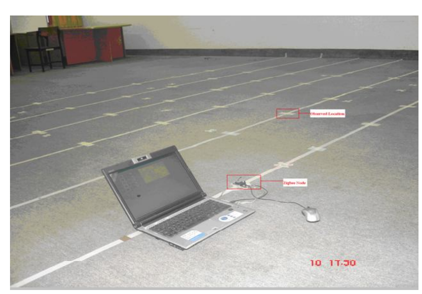

Figure 8. The marks of observed locations on the floor.

3.2. Experiment Result

The objective of this work is to estimate the location of the target node in the indoor environment using the proposed method. The intensity of the signal from each reference sensor is measured and used to estimate the target location. It is well known that in indoor environment; it is difficult to analyze the signal intensity because it is much fluctuated. To help improving this, a number of reference nodes may be used as the space diversity. It can be found from the results that the more number of reference nodes, the better location estimation accuracy.

Figure 9 demonstrates the relationship between the measured RSSI and the distance for the condition of three reference nodes. It follows the theory that when the node is far, the RSSI value is small. Figure10 compares the location estimation error between conditions of 3, 4, 5 reference node. It is found for the most observed location that when the number of reference nodes increase, the location estimation errors decrease.

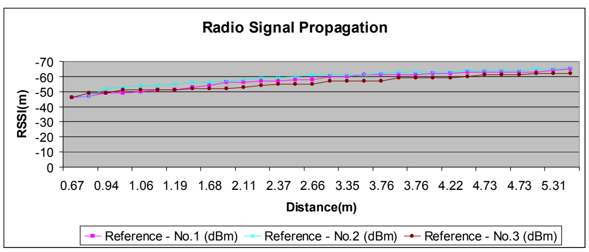

Figure 9 Relationship between communication distance and RSSI value for the 3 reference node condition.

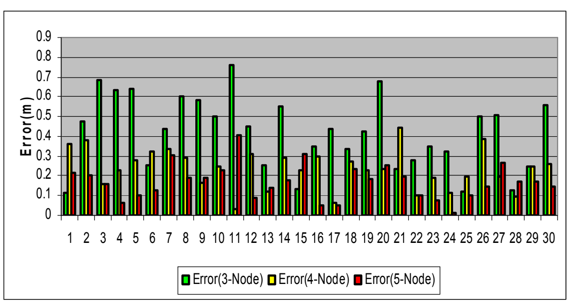

Figure 10 Location estimation Error for the conditions of 3, 4, 5 reference sensors involved in localization.

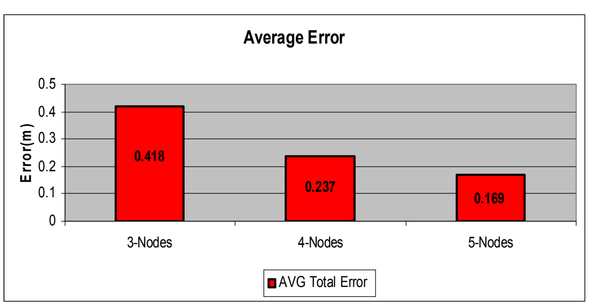

Figure 11. Average estimation error compared to 3,4,5 reference sensor

Table 1. Localization error statistics table

Number of Sensor	Min Error (m)	Max Error (m)	AVG Error (m)
3 Node	0.115	0.763	0.418
4 Node	0.031	0.445	0.237
5 Node	0.0134	0.404	0.169

Figure 11 shows the results of the average location estimation error calculated from all observed location. It is also found that when the number of reference nodes increase, the average location estimation errors decrease. Table 1 summarizes the minimum, maximum and average location estimation errors for three conditions of 3, 4, 5 reference nodes, respectively.
It is also observed from figure 11 and Table 1 that the average location estimation error is less than 50 cm which is an applicable range in practice.

4. CONCLUSIONS

This paper presents a method of calculating the location of the target sensor using the maximum likelihood algorithm. The proposed method is evaluate using the experimental data. The results show that the more number of the reference nodes, the better accuracy of the location estimation. Moreover, it is observed that the average location estimation error is less than 50 cm which is an applicable range in practice. Therefore, the proposed method using in the indoor environment can be practical used in the real location estimation system.

REFERENCES

[1] H. Liu, H. Darabi, P. Ganerjee, and J. Liu, "Survey of Wireless Indoor Positioning Techniques and Systems," *IEEE Trans. on System, Man, and Cybernetics-Part C: Applications and Reviews*, pp. 1067-1080, Vol. 37, No. 6, November 2007.

[2] F. Sottile, R. Giannantonio, M. A. Spirito, and F. L. Bellifemine, "Design, Deployment and Performance of a Complete Real-time ZigBee Localization System," Wireless Days, 2008. WD '08. 1st IFIP, pp. 1-5, November 2008

[3] A. Noh, W. Lee and J. Ye, "Comparison of the mechanisms of the Zigbee's indoor Localization algorithm," Ninth ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing, pp.13-18, August 2008

[4] XUE Feng, LIU Zhong, QU Yi. Decentralized Algorithm for Target Passive Tracking in Wireless Sensor Networks, Beijing, China: Journal of System Simulation,2007.8,19（15）, 3499-3503

[5] Sun Li-min, Li Jian-zhong, Chen Yu, et al. Wireless sensor networks. Beijing: Tsinghua university press, 2005,138-14 5035 Authorized licensed