High-Precision RSSI-based Indoor Localization Using A Transmission Power Adjustment Strategy for Wireless Sensor Networks

Jiing-Yi Wang[1,2], Chia-Pang Chen[2], Tzu-Shiang Lin[1], Cheng-Long Chuang[1], Tzu-Yun Lai[1], and Joe-Air Jiang[1,2,*]

[1]Intel-NTU Connected Context Computing Center
National Taiwan University
10617 Taipei, Taiwan

[2]Department of Bio-Industrial Mechatronics Engineering
National Taiwan University
10617 Taipei, Taiwan
[*]jajiang@ntu.edu.tw

***Abstract*—Indoor localization is an important issue in wireless sensor network (WSN) studies. Sensed data may become meaningless, if the locations of sensors are not known. Traditional localization techniques do not meet the requirements of low-cost and energy-conservation while performing localization tasks. Recently, the received signal strength indicator (RSSI)-based range measurement technology is widely used in sensor networks due to its easy implementation. In typical indoor environments, RSSI is affected by dense multipath fading effects because people are moving around, or because furniture and equipment block transmission signals. Therefore, the overall accuracy of RSSI-based localization schemes remains low. In this paper, a new localization scheme which is based on a transmission power adjustment strategy is proposed. Firstly, power decay curves are created in a real indoor environment to accurately estimate the distances between an unknown node and anchor nodes. Secondly, the unknown node selects three nearest anchor nodes by using the minimum transmission power to limit the estimated location to a triangle area. And then, the centroid of the triangle is calculated and serves as the initial estimated point. Finally, based on the estimated distances of corresponding power curves determined by RSSI scores using different transmission power levels, the final estimated location falls in one of the three equally divided areas of the triangle. The experimental results demonstrate that the proposed method can provide a low-cost solution for indoor localization with high precision.**

Keywords-indoor localization; RSSI; WSN; transmission power;

I. INTRODUCTION

Wireless Sensor Networks (WSNs) is composed of numerous low-power nodes. Each node is designed to be a small computing unit that is equipped with various sensors and radio chips to monitor different targets and communicate with other nodes. These energy-efficient sensor nodes can be easily deployed to perform many tasks including ecological environment monitoring [1], building automation [2], remote homecare [3], and so on. To effectively complete these tasks, a number of issues have been raised, e.g., sensing coverage [4], media access control (MAC) [5], network security [6], network topology [7], object tracking [8]. Recently, a many methods have been proposed to solve localization problems, because more and more applications require sensor nodes not only to gather sensing information but also to provide information regarding its actual position.

Among traditional localization techniques, a common method is to use a global positioning system (GPS) receiver [9]. Unfortunately, GPS is not well suited for large-scale sensor networks, because of its high cost and energy requirement. Furthermore, due to the low penetrating satellite signals, GPS has its limitation in indoor applications. For indoor localization systems, radio frequency identification (RFID) [10], infrared [11], or ultrasound [12] are the other options to determine node positions with higher precision, but these options are not cheap. To avoid the drawbacks of using the above mentioned localization techniques, two types of localization techniques have been proposed, according to the precision requirement on distance: range-based and range-free schemes.

Popular algorithms that use range-free schemes are centroid, ad-hoc positioning system (APS) [13], DV-HOP [14], amorphous [15], and link state based annulus localization algorithm (LSBA) [16]. The centroid method is the simplest one to implement, which uses reference nodes (i.e., anchor nodes) that contain location information to estimate the position of an unknown node. In addition to geometry-based approaches, the DV-HOP is one of the famous hot-count based algorithms which calculate a position based on the received anchor locations, the hop-count from the corresponding anchor, and the average-distance per hop. However, its major drawback is that the positioning accuracy is low, because the distance of each hop is not identical. Although the localization accuracy of the range-free methods is lower than that of the range-based methods, and the former methods require numerous sensor nodes to collaborate to achieve a localization task, it is still considered as a cost-effective solution.

The range-based schemes realize that the distance between two sensors nodes relies on how to measure the distance. Several methods are proposed to measure the distance between nodes: angle of arrival (AOA), time of arrival (TOA), time difference of arrival (TDOA), received signal strength (RSS), and so on. In TOA methods, for example, the distance is calculated by measuring time shift

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between the sender and the receiver. TDOA, a method based on TOA, measures the signals of two different receivers at separate locations to build the cross-correlation function. The AOA measurement techniques use the amplitude response or phase response of a directional antenna to generate range information. The use of a set of carefully calibrated directional antennas has many disadvantages, include high costs and complex hardware design, but no time synchronization between measuring units is required while using the antennas.

In range-based schemes, the RSS-based techniques have been widely used, because the techniques are less expensive and simple to implement in hardware, and there is no need for additional hardware. RSS is defined as the voltage measured by a receiver's received signal strength indicator (RSSI) circuit. In fact, most of RF transceiver chips have a built-in RSS indicator, which provides RSS measurement without any additional cost. The strength of RSSI at a given transmission distance can be described as

$$RSSI(d) = PL(d_0) - 10\beta \log_{10}\left(\frac{d}{d_0}\right) + \omega \qquad (1)$$

where d is the transmission distance, d_0 is the reference distance, β is the rate at which the signal decays, ω is a zero-mean normally distributed random variable, $PL(d_0)$ is the received signal strength, RSSI(d) is the received signal strength from the sender. The RSSI can be estimated when the unknown nodes receive the RF signal from the anchor nodes, and the distance can be calculated via (1). Unfortunately, some studies showed large variability in RSS, because RSS is easily influenced by indoor environments.

Based on the advantages and disadvantages of the two types of localization methods, this paper proposed a highly precise RSSI-based indoor localization method using a transmission power adjustment strategy to acquire RSSI after reducing the effects of indoor environments. A variety of RSS patterns in the real indoor environment are also developed to increase the accuracy of the estimated distance between two nodes. The remainder of this paper is organized as follows. Section II presents the design and implementation of the indoor localization method using a transmission power adjustment strategy. The experimental schemes and results are shown in Section III. Finally, discussion and conclusion are given in the last section

II. PROPOSED SCHEME

A. Pre-configuration Phase

In indoor environments, RSS may degenerate because of reflection, shadowing, and fading after meeting various obstacles like walls, furniture, or equipment. The radio signal transmission model cannot be directly applied to real indoor environments. Thus, we used the transmission power strength to acquire the power decay curves in RSSI, which show the relationships between RSSIs and actual distances. The sensing platform used in our experimental setup was the Octopus II wireless sensor node [17], which is an open-source wireless node based on a MSP430 microprocessor produced by Texas Instruments and equipped with an IEEE 802.15.4-compliant CC2420 radio module. Two nodes were used in the experiment. One was a fixed node that served as the sender and was placed near the wall of a classroom, and the other was a mobile node that served as the receiver and was freely moving in the classroom. The furniture in the classroom was not removed, and the nodes were positioned at 1.5 m above the floor. The sender sent 100 packets to the receiver each round based on six levels of transmission power, including the maximum power, the minimum power, and four other power levels. In the beginning, the receiver and the sender was 10 cm apart. The distance between the sender and the receiver then increased by 10 cm each round, until the distance reached 4 m. The measurement results of the RSSIs and the distances between the sender and the receiver after varying the transmission power level are shown in Fig. 1.

In Fig. 1, the range of the Tx Power which is the output power level of CC2420 is from -45dBm to 0dBm, and R^2 represents the fraction of the total variance of RSSI that is explained by the variation of the actual distance. In this regression analysis, a high deviation is found when the distance between two nodes is high (over 200 cm), because of the higher probability of receiving the geometric noise including signal blocking and interference. However, R^2 declines when the Tx Power increases. This suggests that the regression lines cannot adjust to the actual distance. Therefore, using only one curve to fit all situations will produce larger errors in the distance estimation, if the distance between the nodes is larger and the transmission power is stronger. According to these results, we selected the Tx Power -45 dBm and the Tx Power -25 dBm to estimate the distance between the nodes if their distance fell between 0 cm and 100 cm and between 110 cm and 300 cm, respectively. The results are shown in Fig. 2.

B. Localization Phase

In the proposed localization scheme, the localization task includes several phases. These phases repeat during the localization process.

1) *Selection phase:* In this phase, the unknown node which need to be localized uses the minimum transmission power to broadcast the localization requests. Using the minimun Tx power ensures that only the anchor nodes which are near the unknown node can receive these requests, these anchor nodes will return acknowledgements (acks) to the unknown node. A RSSI table can be built by these acks, and the anchnor nodes with the top three RSSIs are selected to reduce the estimated area where the unknown node is located. If using the minimum Tx power cannot get at least three anchor nodes to answer with acks, the unknown node will use the higher Tx power until three anchor nodes are selected.The Fig. 3. show three different cases based on the acks received in the first round. Fig. 3(a) shows that only the anchor node B receives the requests from the unknown node in the first round (using the Tx Power -25 dBm). This node is used to localize the unknown node.

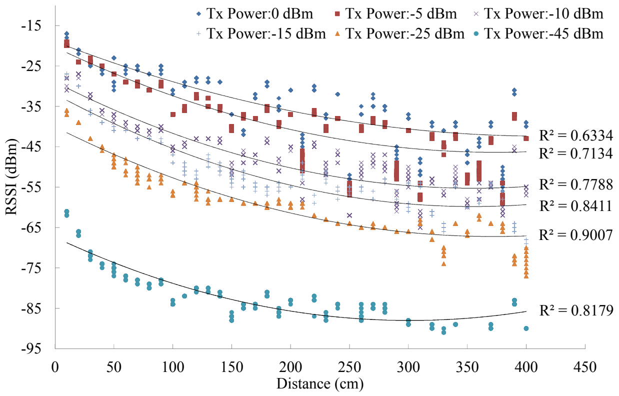

Figure 1. RSSI power decay curves.

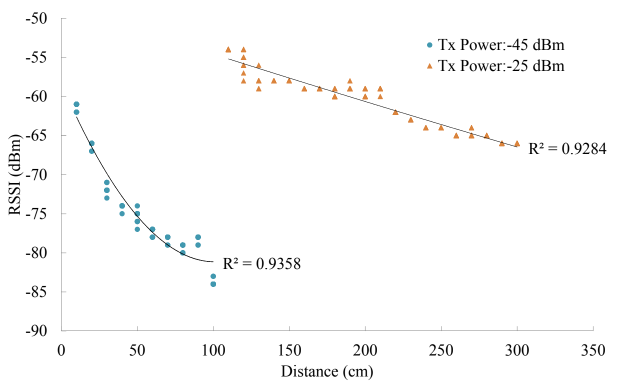

Figure 2. RSSI power decay curves.

The anchor nodes A and D receive the requests from the unknown node after increaing the transmission power and they will be used in the localizing process, along with the anchor node B. The Fig. 3(b) is the scenario of three anchor nodes A, B, and D receive the requests in the first round. Fig 3(c) shows that more three anchor nodes receive the requests in the first round show, and the three nodes with highest RSSI will be selected.

2) *Initial location phase*: We select the centroid of the triangle which is formed by the selected anchor nodes to be the initial estimated location of the unknown node, because the straight lines between the selected nodes and the centroid divide the triangle into three equal areas. Therefore, the probability of the unknown node being actually located in each area is the same. The centroid can be calculated by

$$(x_c, y_c) = \frac{\sum_{i=1}^{k}(x_i, y_i)}{k} \tag{2}$$

where (x_i, y_i) is the coordinates of the selected anchor nodes, and k is the number of the selected nodes.

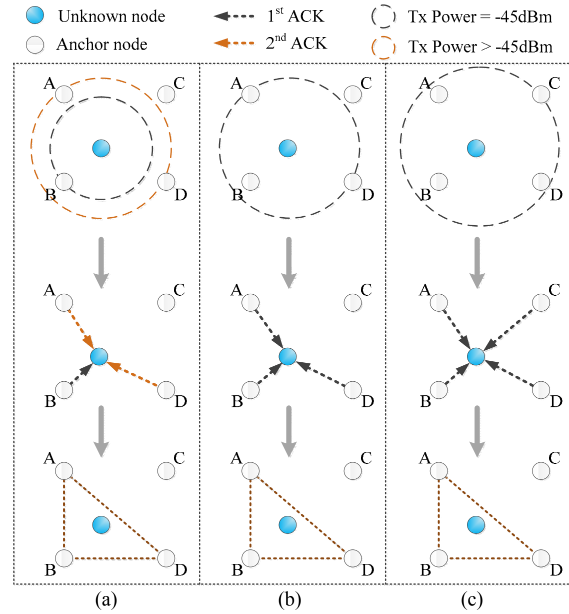

Figure 3. An example with three scenarios.

3) *Adjustment phase*: The unknown node individually asks the three selected anchor nodes to return acks again to reduce the inaccuracy in RSSI caused by packet collision. The anchor node which has the maximum RSSI among the selected nodes is the first one to be used to adjust the initial estimated location. This maximum RSSI can be transformed into the distance using the Tx Power –45 dBm curve. If the distance is greater than 100 cm, the unknown node asks the first selected anchor node to return acks again using the transmission power on –25 dBm. The newest RSSI can be also transformed into the distance by the Tx Power –45 dBm curve. We assume that the coordinates of the first selected anchor node and the centroid are (x_f, y_f) and (x_c, y_c), respectively. The first estimation location (x_e, y_e) can be described as.

$$(x_e, y_e) = (x_c, y_c) + (x_f - x_c, y_f - y_c) \times \frac{d_{frssi}}{d_{fc}} \tag{3}$$

where d_{fc} is the distance between the first anchor node and the centroid, and d_{frssi} is the distance transformed from the Tx Power curve. Thus, the first estimation location will fall on any two of the three equally divided areas. The anchor node which has the second largest RSSI is the second one used to adjust the first estimation location. If the distance which is transformed from the Tx Power –45 dBm curve is greater than 100 cm, the unknown node requests the second selected anchor node to return acks by using the transmission power on –25 dBm to transform the distance by the Tx Power –45 dBm curve. We assume that the coordinate of the second selected anchor node is (x_s, y_s). The final estimation location (x_r, y_r) can be calculated by (4).

$$(x_r, y_r) = (x_e, y_e) + (x_s - x_e, y_s - y_e) \times \frac{d_{srssi}}{d_{se}} \tag{4}$$

where d_{srssi} is the distance which is transformed from the Tx Power curve, and d_{se} is the distance between the second selected anchor node and the first estimation location.

III. EXPERIMENTAL RERULT

The proposed scheme is implemented in a classroom. The experimental deployment is depicted in Fig. 4. The 9 anchor nodes were placed in a 6 m x 6 m area and near the wall of a classroom. The equipment in the classroom is not removed in order to create a real indoor environment and the nodes were positioned at 1.5 m above the floor. The unknown node was located at 10 randomly selected positions, and these positions were used to analyze the performance of the localization system. In the experiment, each position was estimated 20 times. The root-mean-square error (RMSE) described by (5) is used to determine the distance error of the estimated position. The overall RMSE is also calculated to determine the system performance.

$$RMSE_{ai} = \sqrt{\frac{\sum_{ei=1}^{k}\left((x_{ei} - x_{act})^2 + (y_{ei} - y_{act})^2\right)}{k}} \tag{5}$$

and by the overall RMSE $= \frac{1}{k}\sum_{ai=1}^{k} RMSE_{ai}$

where k denotes how many times each random position are estimated, (x_{ei}, y_{ei}) is the coordinate of the estimated position, and (x_{act}, y_{act}) is the coordinate of the actual position. The RMSE results of each random position are shown in Table I, and the total estimated positions of each random position are drawn in Fig. 5. With two exceptions, the proposed localization scheme is able to produce accurate localization results.

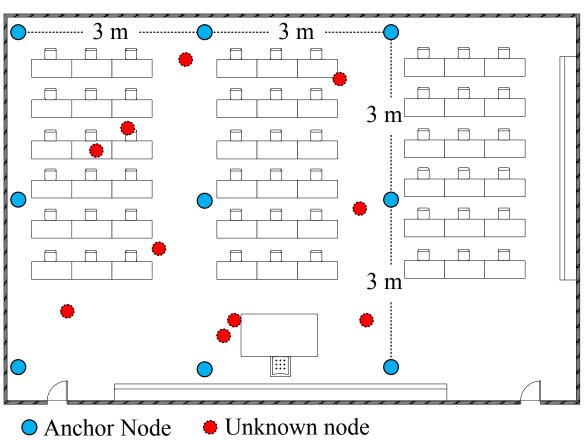

Figure 4. The experimental deployment.

TABLE I. THE COORDINATES OF THE ACTUAL POSITIONS AND RMSE OF THE ESTIMATED POSITIONS (THE OVERALL RMSE 40.4 CM)

(x_{act}, y_{act}) [cm]	RMSE [cm]
(325,100)	22.8
(100,140)	41.2
(550,314)	29.1
(160,412)	42.8
(227,206)	23.0
(572,113)	95.1
(522,560)	29.1
(274,572)	43.1
(122,385)	17.3
(330,120)	60.3

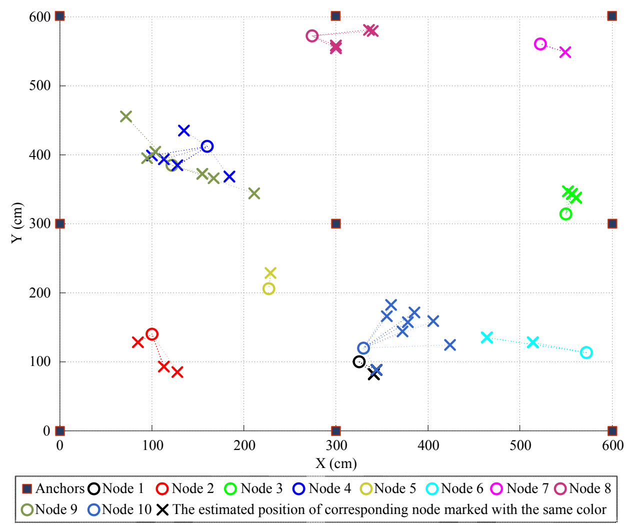

Figure 5. The estimated results for each random position.

IV. CONCLUSION

In this paper, the power decay curves in real environment are created to determine the accuracy transmission distance. The transmission power adjustment strategy is used to achieve high accuracy indoor localization due to the less reflection of obstacles. The proposed scheme uses external low-cost omnidirectional antennas and sensor nodes to perform localization tasks without the help of other accessories. The localization system is less complicated. The anchor nodes are simply required to return acks after receiving the requests from the unknown node, and the localization algorithm and the anchor node related information are solely known by the unknown nodes. This also means that the localization system is easy to maintain, update, and deploy. The proposed scheme is examined in a real-world environment, and the experimental results show that the lowest RMSE is 17.3 cm, and that the overall RMSE is 40.4 cm. The proposed localization scheme is able to provide precision localization results in indoor environment. The averaged estimation biases are also analyzed and reported.

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