

## Research Article

# Study of Hybrid Localization Noncooperative Scheme in Wireless Sensor Network

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In this paper, we evaluated the experiment and analysis measurement accuracy to determine object location based on wireless sensor network (WSN). The algorithm estimates the position of sensor nodes employing received signal strength (RSS) from scattered nodes in the environment, in particular for the indoor building. Besides that, we considered another algorithm based on weight centroid localization (WCL). In particular testbed, we combined both RSS and WCL as hybrid localization in case of noncooperative scheme with considering that source nodes directly communicate only with anchor nodes. Our experimental result shows localization accuracy of more than 90% and obtained the estimation error reduction to 4% compared to existing algorithms.

## 1. Introduction

Wireless sensor network (WSN) is a set of nodes that can communicate and interact with each other, with both transmission process or received process through source nodes (their locations still to be determined) and anchor node (their locations are known) via unwired network. WSN has the properties of sensing, data processing, and communicating that can be an application in various areas such as target tracking, intrusion detection, energy-efficient routing, wild animal monitoring, underground, deep water, and outer space explorations [1–9].

Localization is one of the essential fundamental techniques in WSN. Global Positioning System (GPS) is a modern localization system [10] but cannot be the solution to indoor localization because its signal is unreliable taking into account building infrastructure materials and absolutely installing GPS receiver in a large scale deployment would be very expensive. Various localization approaches include range-based ones such as received signal strength (RSS), Time of Arrival (TOA), Time Difference of Arrival (TDOA) [11], and Angle of Arrival (AOA) [12]. On the other hand, range-free approaches have been explored in recent years: mainly centroid, Distance Vector Hop (DV-Hop) [13], MDS-MAP [14], and Approximate Point-in-Triangulation

(APIT) [15]. High precision location information obtained in range-based schemes [8, 16–19] depends on expensive hardware devices to estimate distances or angles. In contrast, range-free approaches [15, 20, 21] provide a cost-effective way to determine a sensor's location with less accuracy. Since most of WSN applications involve very dynamic wireless environments, localization in range-free schemes can be easily affected [8].

The received signal strength (RSS) is considered an efficient ranging technique. It is because RSS estimates sensor position without using additional hardware. However, direct mapping of absolute RSS values to physical distances has many limitations [8]. In contrast, some prior studies showed the inaccuracy of RSS, due to channel impairments such as reflections, shadowing, fading, nonlinear of sight, and other sources of interference [7, 8, 22–28].

In addition to the characterization of adopted channel propagation model in RSS, we carry on analyzing the performance of a particular, low complexity, so-called weighted centroid localization (WCL) algorithm. It is not an entirely range-free approach because it requires additional information aside from RSS measurement [7, 29, 30].

In the range-based localization process, the primary concern is to accomplish good estimation accuracy from inaccurate position-bearing measurements collected inside

the network. It is necessary to enable node communication to get the information on the field of interest, which can be non-cooperative or cooperative. The noncooperative approach allows sources node to communicate only with the anchor nodes, whereas the cooperative approach allows source nodes to communicate with all nodes inside their communication range, whether they are anchor or source nodes [1, 2]. In this paper, we only focus on noncooperative approach according to our experiment.

Based on the previous analysis, we will show that combination of RSS and WCL noncooperative way can obtain high accurate location estimation and reduce the error measurement.

## 2. Related Work

Indoor localization using received signal strength (RSS) has drawn considerable research interest. Cheng et al. [10] proposed the method combining RSS and TDOA to reduce the big errors with active iterative, recursive weighted average filter and polynomial model to obtain the fitting of RSSI measurement. The experiment result shows that the approximate 0.5 m is sufficient for indoor location accuracy. Pagano et al. [31] presented an algorithm as known range algorithm in the nonclear line of sight according to two steps: firstly, the algorithm computes the ranging between anchor nodes and beacon node (in this paper called source node); in the second one, the algorithm estimates the beacon node localization. They achieved an average localization accuracy between 0.34 and 2.74 m with a density of 0.16 anchor/m<sup>2</sup>. In addition to used received signal strength through radio frequency (RF) or WiFi to locate the position of the sensor node, [32] proposed to use FM RSS signals for robust indoor fingerprint due to a lower frequency and also less susceptibility to human presence, multipath, and fading. The experimental results are outperformed when combined with additional information about the signal reception on the physical layer and the obtained localization is around 5.7 percent, more accurate than WiFi-based technique.

In the algorithm presented in [33], WCL is observed with improvement using cyclic autocorrelation (CAC) of received signal at cognitive receivers (CRs) through eliminating CRs in the vicinity of the interference from the localization process. The observed algorithm provided significantly lower error when there is a spectrally overlapped interference and promised to be robust against shadowing and multipath fading in the environment.

Paper [30] proposed the framework for WCL with considered node density, node placement, shadowing variance, correlation distance, and inaccuracy of sensor node positioning. The contribution is given guidelines in terms of some nodes, node placement required to achieve particular localization, variable node participant, and energy efficiency context which does not assume a fusion center that collects all RSS information from nodes.

Besides other factors in the indoor environment that affect the localization accuracy, in literature, there exist many studies to observe how the source node communicates with anchor nodes. In [34], researchers proposed an approach to

track multiple noncooperative targets by assuming that (1) there is only one target in the field; (2) signal from different cooperative targets can be differentiated, or (3) interferences caused by signals from other targets are negligible because of attenuation. Their methods use separated signal aggregation from the multiple identical targets by blind source node (BSS) algorithm. In [2], they addressed the RSS-based source localization problem in both noncooperative and cooperative schemes. In the case of the noncooperative scheme, they proposed the novel SOCP (Semi-Order Cone Programming) based approach which has an excellent tradeoff between performance and the computational complexity. The method provides not only a first estimation of the source positions but also a good estimation of  $P_T$  (transmitter power) both known and unknown. The simulation result shows that the gain of accuracy more than 15 is achieved.

Recently, some researchers have studied the hybrid localization with combining two methods or more to get the precise position of sensor nodes. Paper [22] used PSO-ANN algorithm implemented in MATLAB to improve the distance estimation accuracy. It achieved a mean absolute error of 0.022 and 0.208 m both outdoor and indoor, respectively. In [35], the authors proposed hybrid algorithm between RSS and Self-Organizing Maps (SOM). Firstly, the algorithm obtains RSS measurement values then fed it in learning step of SOM. Paper [35] proposed a novel filtering algorithm that has a mitigation effect of NLOS and recovered the PF from NLOS and caused failures with employing the hybrid particle finite impulse response (FIR) filter in TOA algorithm.

In the aforementioned, solving the issues of hybrid localization is done through the software simulation. In [36], the authors proposed design in antenna using hybrid passive UHF/UWB RFID for tag systems. The antenna is adequate for the low-cost mass production of hybrid passive tags.

Our contribution in this paper analyzes the precise source node's position in a real indoor environment that has obtained a low-level error of localization of both simulation and implementation. Other works take into account one side which is simulation or implementation only.

## 3. Experiment Setup

This section presents an experimental setup of WSN in an indoor environment. The real-time experiments were conducted to determine the received strength signal of WSN in the experimental testbed area. The research aims to obtain the RSS values between anchor nodes and the source node. The testbed environment is the office of the laboratory in The School of Computer and Software, Nanjing University of Information Science and Technology (NUIST), Jiangsu, China. The development kit used in the experiment is the Crossbow TelosB sensor node from Berkeley University as shown in Figure 1 which uses CC2420 transceiver with an IEEE 802.15.4 standard communication with a built-in 2.4 GHz omnidirectional antenna.

The testbed consisted of five TelosB nodes provided by TinyOS, with the operating system used in those sensor nodes. The configuration of TelosB in the experiment is shown in Figure 2. The adopted interface for acquiring



FIGURE 1: TelosB sensor node.

the data and displaying the node identification and the transmitted power level is written in Java programming, and then processing analysis of the entire result was made using MATLAB. The nodes are programmed to send data in the real time. The data collected over an extended period were averaged and used for computing mean values and variances for each RSS measurement. One of the sensor nodes was connected to a laptop via USB cable and was used as the source node as shown in Figure 3.

The remaining four sensor nodes that act as anchor nodes were placed at  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$ , and  $270^\circ$  from the source node at the same distance while taking the measurements. The first setup had all anchor nodes at the same level distance of 1 meter. The sensor node acting as source node started consecutive reading of the packet recorded during 2 minutes given a total of 500 packets for every distance. The RSS measurement between the sensor nodes was done every meter from 1 to 5 meters as shown in Figure 4.

## 4. Indoor Adaptive Localization Algorithm

**4.1. RSS Based on Wireless Propagation Channel.** Typically, the radio propagation is used to signal transmissions, such as the free space propagation model, log-distance path loss model, and log-normal distribution model. The observed model utilized in this study is log-normal shadowing model which considers the fact that the surrounding environmental cluster may be vastly different at two different locations having the same transmitter and receiver separation; in reality, the relationship between distance and received power can be expressed according to the following formula:

$$P_i = P_0 - 10\phi \log_{10} \left( \frac{\|S - A_i\|}{d_0} \right) + G_i; \quad i = 1, \dots, N. \quad (1)$$

In this model,  $P_i$  represent the path loss at a separation distance given in dB relatively to 1 mW.  $P_0$  is path loss for the reference distance.  $d_0$  is the reference distance which equals 1 meter, the distance of source node is denoted by  $S$ , distance of the anchor nodes is denoted by  $A_i$  ( $A_1, A_2, \dots, A_n$ ) in meter, and  $G_i$  is a zero mean Gaussian distributed random variable with variance  $\sigma_i^2$ , that is,  $G_i \sim \mathcal{N}(0, \sigma_i^2)$ . These values represent the changed strength signal received within certain distance; the value of  $\phi$  depends on the specific propagation

environment as path loss exponent (PLE). For instance, in free space environment,  $\phi$  is equal to 2, and when obstructions are present,  $\phi$  will have a large value.

Practically, the variables described in (1) are fitting to develop mapping the curve, which converted  $P_i$  to internode  $\|S - A_i\|$ .

In terms of RSS, we first rewrite and calibrate (1) to obtain the curve that reflects the characteristic of the environment.

We removed the dependency from reference distance  $d_0$  and simplified the formula changing the parameters  $P_0$  and  $\|S - A_i\|$  with  $\mathcal{R}$  and  $d_i$ . Therefore, the distance measurement equation based on the RSS value used within practical is given by

$$\text{RSS} = \mathcal{R} - 10\phi \log_{10} d_i + G_i. \quad (2)$$

The estimation distance between anchor nodes and a source node is shown:

$$d_i = 10^{((\mathcal{R} - \text{RSS})/10\phi)}, \quad (3)$$

where  $d_i$  represent the distance from each anchor to source node in meter.  $\mathcal{R}$  is strength signal received within distance of 1 meter in dBm.

**4.2. Weight Centroid Localization (WCL).** The development of WCL has improved the low accuracy of a location estimation of centroid localization. WCL introduced the quantification of the anchor nodes depending on their distance towards the source node. The aims are to give more influence to those anchor nodes which are closer to the source node. As the RSS also increases with a decreasing distance, it is selected as an appropriate quantifier.

WCL uses weight to ensure an improved localization comparing with the centroid method where arithmetic centroid is calculated as object's location. Weights are a measure of anchor attraction to object. The biggest value of weight is closer to the source node.

The following formula is used to compute the weight:

$$w_i = d_i^{-g}, \quad (4)$$

where  $w_i$  represents weight of anchor node and  $g$  is degree which determines the contribution of each anchor node. An appropriate value for  $g$  was found equal to 1 since WCL with a degree of zero is similar to centroid localization. Thus, estimation of target's position is further calculated by the following formula:

$$\begin{aligned} X_{\text{est}} &= \frac{\sum_{i=1}^m (W_i \times x_i)}{\sum_{i=1}^m W_i}; \\ Y_{\text{est}} &= \frac{\sum_{i=1}^m (W_i \times y_i)}{\sum_{i=1}^m W_i}. \end{aligned} \quad (5)$$

**4.3. Hybrid Localization Algorithm.** In this subsection, we proposed an algorithm which combines the RSS and WCL as hybrid localization algorithm. According to the free space



FIGURE 2: Configuration of TelosB in office room.

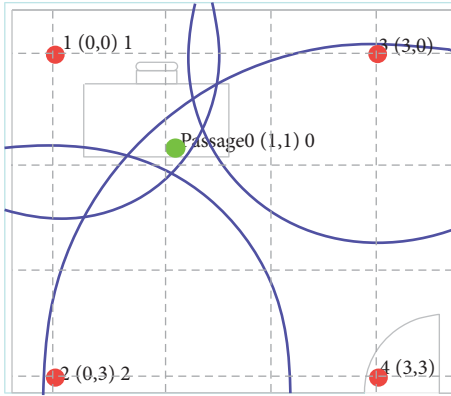


FIGURE 3: The anchor nodes position by 3 m x 3 m in GUI Java.

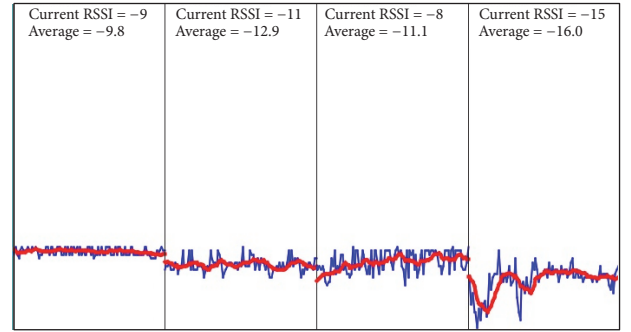


FIGURE 4: RSS and average of RSS.

propagation in an indoor environment [37], the received strength signal is expressed as

$$\begin{aligned}
 P_{Rxi} &= A_e S_r = \frac{\lambda^2}{4\pi} G_{Rx} \cdot \frac{G_{Tx} P_{Tx}}{4\pi d_{ij}^2} \\
 &= P_{Tx} \cdot G_{Tx} \cdot G_{Rx} \times \left( \frac{\lambda}{4\pi d_{ij}} \right)^2,
 \end{aligned} \quad (6)$$

where  $P_{Rxi}$  is the remaining power of wave at the receiver from the  $i$ th anchor node;  $P_{Tx}$  is the transmission power of sender.  $G_{Tx}$  represents the gain of transmitter antenna.  $G_{Rx}$  is the gain of the receiver antenna.  $\lambda$  is the wavelength.  $d_{ij}$  is the distance between anchor node  $j$  and a source node  $i$ .  $A_e$  is effective area of the receiving antenna and  $S_r$  represents the power density of the signal at the site of the receiving antenna.

From (6) we can obtain the relation between  $P_{Rxi}$  and  $d_i$ .

In an embedded system, the received signal strength is converted to  $RSS_i$ .  $RSS_i$  can be expressed as

$$RSS_i = 10 \log \left( \frac{P_{Rxi}}{P_{Ref}} \right), \quad (7)$$

where  $P_{Rxi}$  represents the received signal strength from the  $i$ th anchor node;  $P_{Ref}$  is the reference power. So we can also know the relation between RSS and  $P_{Rxi}$ .

Derived from (6), we can modify the formula:

$$d_{ij} = \lambda \times \sqrt{\frac{P_{Tx} \times G_{Tx} \times G_{Rx}}{(4\pi)^2 P_{Rxi}}}. \quad (8)$$

Based on (7),  $P_{Rxi}$  can be expressed as

$$P_{Rxi} = P_{Ref} \times 10^{RSS_i/10}. \quad (9)$$



Substituting formula (8) into (4), the weight of anchor node can be expressed as

$$w_i = d_{ij}^{-g} = \left( \lambda \times \sqrt{\frac{P_{Tx} \times G_{Tx} \times G_{Rx}}{(4\pi)^2 P_{Rxi}}} \right)^{-g}. \quad (10)$$

Substituting (9) into (10), the weight of anchor node can be expressed as

$$w_i = \left( \lambda \times \sqrt{\frac{P_{Tx} \times G_{Tx} \times G_{Rx}}{(4\pi)^2 \times P_{Ref} \times 10^{RSS_i/10}}} \right)^{-g}. \quad (11)$$

After  $w_i$  normalization, weight can be expressed by

$$W_i = \frac{w_i}{\sum_{j=1}^m w_j} = \frac{\sqrt{(10^{RSS_i/10})^g}}{\sum_{j=1}^m \sqrt{(10^{RSS_j/10})^g}}. \quad (12)$$

Furthermore, the estimation position of target node can be expressed as follows:

$$\begin{aligned} X_{est} &= \sum_{i=1}^m (W_i \times x_i); \\ Y_{est} &= \sum_{i=1}^m (W_i \times y_i), \end{aligned} \quad (13)$$

where  $W_i$  is the weight of anchor node and  $(x_i, y_i)$  represent the coordinates location of anchor node.

In particular, from (12) and (13), it can be seen that we can obtain the estimated position of a target node by just knowing the RSS values and the coordinates of anchor nodes. Moreover, a source node does not need to compute the path loss exponent and obtain other information parameters. Also, the proposed localization algorithm has the advantage of lower complexity and hence correction of accuracy.

## 5. Distributed Implementation of Hybrid Localization

Based on the theoretical analysis, both RSS and WCL require a significant number of nodes to obtain a higher level of accuracy. The algorithm considered the transmit power consumption, and the amount of information are overhead when implemented in centralized localization. We present RSS and WCL in a practical distributed localization implementation.

**5.1. RSS Algorithm Description.** As signal attenuation may be caused by many effects, that is, multipath, fading, shadowing, and timely variation in the environment, RSS is gained from anchor nodes at uncertain moments.

The algorithm of RSS is shown as Algorithm 1.

**5.2. WCL Algorithm Description.** The relative coordinate position among four anchor nodes must be determined first when plotting the proposed method. Let four anchor nodes be  $A_1, A_2, A_3$ , and  $A_4$ , whose send signal range is ideal circles with radius  $R$ , since the anchor cannot be in the same line.

Localizing sensor node requires at least three anchor nodes as trilateration or more as multilateration, whereas WCL method consists of three steps: (i) The anchor nodes send their information in the positioning area. (ii) The source node received anchor node information to estimate its position. (iii) The undetermined source node in the previous phase sends a request to its anchor and utilizes the coordinate of them to estimate its position.

The algorithm of WCL with four anchor nodes is shown as Algorithm 2.

**5.3. The Proposed Algorithm Implementation.** Because RSS has inconsistent values considering the numerous obstacles in the environment, meanwhile, WCL has constant values when  $g = 1$  and it is impractical in nature. So we join those algorithms to reduce estimation error measurement and improve estimation accuracy distance of source node. We proposed the algorithm be as shown in Algorithm 3.

## 6. Analysis Results

This section presents a set of analyses to compare the experiment results with the general cause noncooperative scheme of both RSS and WCL, along with new approach combination between RSS and WCL.

We employed four anchors and one source node. The positions of the anchor nodes and source node have the similar latitude and antenna orientations putting on  $0^\circ$  for whole sensor nodes whether anchor nodes or source node. The further is analyzed as follows.

**6.1. Analysis of RSS Algorithm.** The indoor radio channel is adjusted from the conventional mobile radio channel in two aspect: the distance covers are much smaller, and the variability of the environment is much greater for a much smaller range of receiver and transmitter separation distance. The source node and all anchor nodes are placed on the line of sight assuming the signal attenuation would be impacted significantly by a person or object surrounding the environment. Then, the next step is to change the position of source node away from anchor nodes to obtain path loss exponent with minimizing estimated root mean square error (RMSE) for all anchor nodes.

RMSE is defined as

$$RMSE = \sqrt{\frac{\sum_{i=1}^k \|S - \hat{S}\|^2}{k}}, \quad (14)$$

where  $S$  is the actual source node position,  $\hat{S}$  denotes the estimation source node position, and  $k$  is the number of the anchor nodes.

Figure 5 illustrates RSS against distance for four anchor nodes. Anchor- $i$ ex refers to experiment result of RSS recorded from  $i$ th anchor nodes, whereas anchor- $i$ th relates to the theoretical result of RSS acquisition from (2). As we can see in that figure, for indoor environment, although we put the anchor nodes in the same level distance in the real world, each anchor node has to meet different RSS values

```

Input: [RSSij]
i = 1 ··· nAN; //number of anchor nodes
j = 1 ··· nTN; //number of source nodes
//values of RSS measured nTN times from target to each anchor at time t.
Output: {RSS' : i = 1 ··· nAN}
//values of RSS
Process:
For i = 1 to nAN
    d ← Set of RSS measured from target to nANi at time t.
    Calculate  $\mu(\mathbf{d})$  as path loss exponent
    Calculate Pi as power node ith
    For each RSS ∈ d
        If  $|\mu(\mathbf{d}) - \text{RSS}| > 2\delta(\mathbf{d})$ 
            d ← d/RSS
    Calculate  $\mu'_i \leftarrow \mu(\mathbf{d})$ 

```

ALGORITHM 1: RSS.

```

Procedure Anchor(A)
Repeat
    Move to a new position for each d = 1 to 5
    transmission a packet including its ID, coordinate at the time;
Until finish
End procedure
procedure SourceNode(S)
repeat
    Receive information from Anchor (Ai);
    Calculate di according to (3);
until finish
Sort the anchor information at time;
for all the information IN at the same time
    if |IN| == 4 or |IN| == 3
        Estimate position according to (5);
    else
        Discard IN;
end for
Use average of all estimated positions as the final value;
end procedure

```

ALGORITHM 2: WCL with four anchor nodes.

due to change for every signal wavelength as wall, door, and furniture affected the received signal strength.

In that figure it is also shown that the chart comparison values of RSS based on the experiment and the RSS calculation, in theory, have increased distance related to decreased RSS. As we see in that value, the calculation theoretically has a value that is constant against to distance, as calculation neglects the other factors in the environment. On the other hand, the experiment shows that the generated RSS values from emitted received signal through each anchor nodes always fluctuated.

Figure 6 shows that, based on our experiment result, the measurement error of RSS increases relatively with actual distance increase. The performance of anchor node regarding RSS value within calibration with actual distance can be

conducted with calculating the RMSE for entire anchor nodes. The small value of RMSE shows that anchor node works properly to detect distance between anchor nodes and the source node.

Figure 6 also illustrates that the chart of actual distance in the environment is readable by anchor nodes with a low-level error. Through the RMSE, it generates an average of around 30% for the entire distance at all anchor nodes.

**6.2. Analysis of WCL Algorithm.** In WCL algorithm, the experiment has been done according to the location of each anchor node. The experiment result produced estimated distance corresponding to (4). Due to the use of only the weight of anchor nodes without considering another condition, estimated distance is fully similar to actual distance. In

```

Procedure n Anchor nodes( $An$ )
  Repeat
    Each  $An$  sends their information, including ID's, Position Coordinates and Level RSS
  Until finish
End procedure
procedure SourceNode( $S$ )
  repeat
     $S$  receive broadcast information (IB)
  until finish
  if  $A_{i+1} \neq A_i; i = 1, 2, \dots, n$ 
     $S$  record IB for whole  $An$ 
    if (IB  $\geq$  threshold packet); packets = 500
      Calculate average of RSS and  $\mu(d)$  as PLE
    else
      Discard IB;
    end if
  else
    Discard record;
  end if
procedure weight( $w$ )
  repeat
    compute the  $w$  according to (12);
  until finish
procedure EstimationPosition (EP)
  repeat
    compute the EP according to (13);
  until finish
end procedure

```

ALGORITHM 3: Hybrid algorithm.

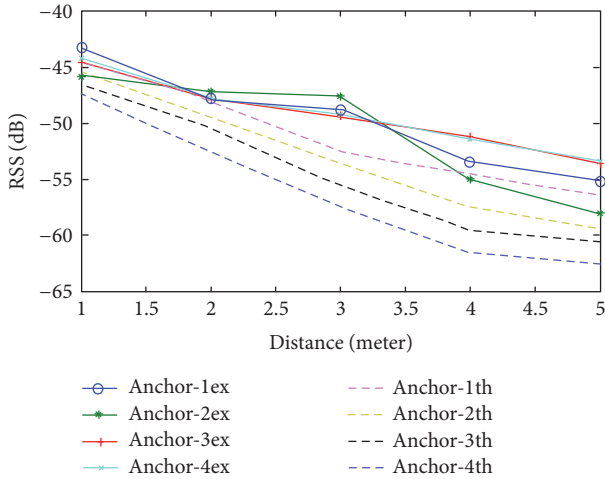


FIGURE 5: Estimated against actual position in anchor nodes.

other words, that error level is irrational. As we see in Figure 7, estimate value calculated by weight for four anchors with level distance from 1 to 5 m produced the equal value of both actual and estimated distance. In terms of practice localization, it means that it is impossible to implement in the field of interest

due to many significant factors such as signal strength and the position of anchor node.

According to [7], distance error measurement for four anchors with  $g = 1.8$  is about 13.7%, lower than RSS algorithm. The range of attraction field will reduce that caused by increasing the value of  $g$  on the source node; thus, the relative weight of the closest anchor node increases.

These algorithms come with limitation between RSS and WCL; we proposed to combine those algorithms for improving the high accuracy, particularly in the indoor localization. The further proposed algorithm is explained as shown in Figure 7.

**6.3. Analysis of Proposed Algorithm.** In the proposed algorithm, we consider to use previous data achieved still in RSS algorithm with utilizing the weight of WCL when degree contribution of the anchor node is 1.

Regarding the experiment at the indoor building, distance setting among four anchors to source anchor keep ranging in 1 to 5 m, respectively. The yield can be seen in Figure 8. In that figure, error comparison among RSS, WCL, and proposed algorithm is shown. Our proposed algorithm outperformed the existing algorithm. When the distance increases, RSS algorithm has localization error of 30%, whereas WCL algorithm has localization error of 13.7%, and our algorithm has localization error of 4% according to

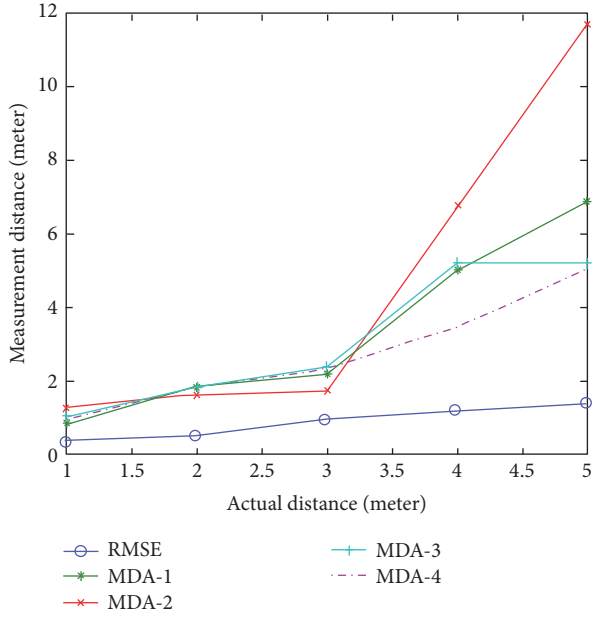


FIGURE 6: The actual distance versus the measurement distance versus RMSE.

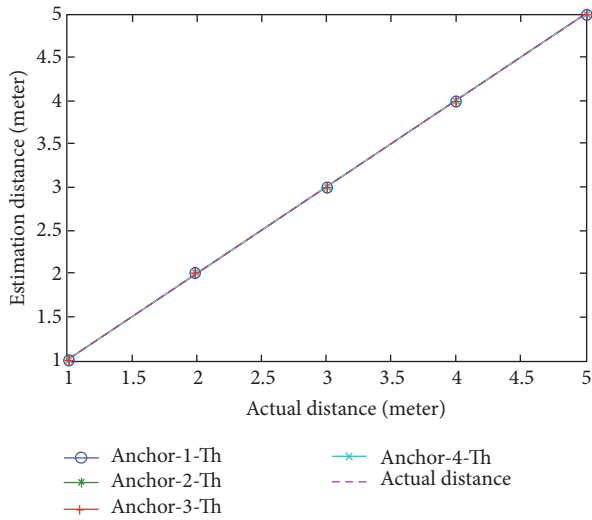


FIGURE 7: WCL analysis derived by simulation.

RMSE. It means if an error has small values, then accuracy will be close to actual distance and produce better localization result. The proposed algorithm achieved improvement in accuracy compared to the existing algorithm.

## 7. Conclusion

This study has presented a localization algorithm which combined RSS and WCL as hybrid localization. Comparing this existing RSS algorithm and WCL, our algorithm shows that the accurate location of the source node is more precise, lightweight, and less complex, due to getting the estimated position of the source node by just merely knowing the RSS values and the coordinates of anchor nodes. The proposed

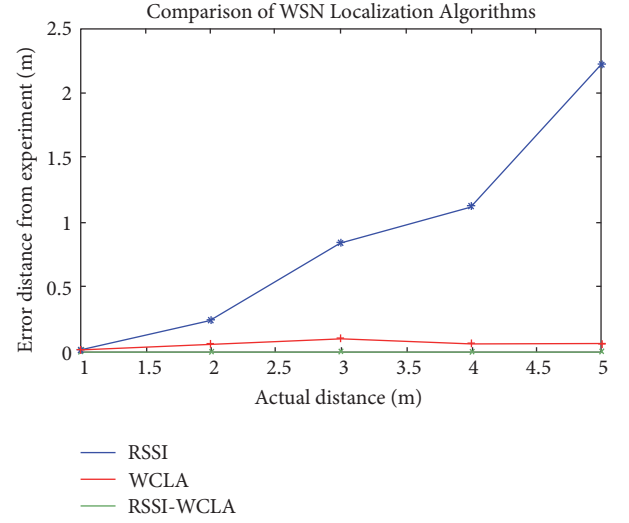


FIGURE 8: Three kinds of localization algorithm result upon distance according to RMSE.

algorithm obtains the mean distance error 4%, whereas the mean distance error in RSS algorithm is 30% which influences only used received strength signal, while WCL has an error of around 13.8%. It means that our proposed algorithm is still better than RSS and WCL algorithms to derive accuracy improvement.

## Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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