



WEIGHTED HYBRID LOCALIZATION SCHEME FOR IMPROVED NODE POSITIONING IN WIRELESS SENSOR NETWORKS

Prima Kristalina, Wirawan, Gamantyo Hendrantoro

Department of Electrical Engineering

Institut Teknologi Sepuluh Nopember

Surabaya, Indonesia

Emails: prima@eepis-its.edu; wirawan@its.ac.id; gamantyo@ee.its.ac.id

Submitted: July 12, 2013

Accepted: Nov. 1, 2013

Published: Dec. 16, 2013

Abstract- Localization schemes have a significant role in wireless sensor networks. During random deployment in an untouched area, the nodes have to be capable of self-management to determine their position. Received Signal Strength (RSS) and DV-Hop, are two different schemes that each have environment or hop dependency problem. Hybrid localization scheme, called H-Loc, is a combination of RSS and DV-Hop method. This scheme is proposed to make the selection of distance determination process based on the proximity of nodes position. The weighted least square is proposed as a refining of DV-Hop scheme's position calculated process. Simulation results show that the proposed scheme has the capability of improving the accuracy of node positioning up to 3.4 %.

Index terms: DV-Hop, H-Loc Scheme, localization, weighted least square

I. INTRODUCTION

Localization technique is required to determine the position of nodes in wireless sensor networks. This technique is needed for the sensor nodes that have the capability on distributed self-configuration [1]. Each node has to be able to send and receive information from the other nodes, and estimate its position relative to the vicinity nodes [2]. A node position can determine the location of phenomena observed.

Location scheme in wireless sensor networks relies on determination of distance among nodes. The distance can be obtained by measuring the signal (range-based) or without any measurement (range-free). The range-based scheme is usually taken by the strength of the signal received (RSS), time of arrival (TOA) and time difference of arrival (TDOA) which can be retrieved from the propagation of radio, acoustic, seismic, infrared and also sonic waves [3]. Meanwhile, the range-free scheme that does not use range measurement is done by considering the proximity of the node with its references, such as averaging of the closest node reference (centroid) or rendering a node position around a triangle formed by the reference nodes around (Approximate Point In Triangle/(APIT), or by calculating the number of hops, as proposed in DV-Hop [4]. Range based schemes have a high accuracy in determining the distance, but have an extravagant cost. Whereas the range-free can only retrieve a coarse estimated distance, but are cost-efficient. Weighted Least Square Method could be used to minimize the estimated node position error in localization. There are two different approaches to implementing this method: first, it can be used to minimize the difference between the estimated and the actual distance [5] and second, it is to minimize the error position of nodes estimated by the various kinds of calculation position schemes [6], [7].

In the real application, nodes are deployed randomly. The random deployment is yielding a variety of nodes position. Some nodes are close each other and the other is far away. This means that using only one kind of distance measurement is not an efficient way. Motivated from this condition, we propose a combination of range-based and range-free method to obtain the estimated distance from a pair of nodes. The refinement process to obtain the accuracy of estimated distance is proposed as the second algorithm.

Our first proposed scheme, called a Hybrid Localization scheme (H-Loc) has been proposed in the previous work [8] as the combination of DV-Hop and RSS-based method. The aim of this scheme is to make the selection between them for distance determination process. As we know, RSS-based technique only determines the distance depend on the signal received directly from transmitting node. This technique has a dependency with reference node's power transmit. On the other side DV-Hop technique determines the distance between two involved nodes by calculating hop count between them. This technique is suitable done on multi hop connection. Thus, by combining these schemes yield a flexible method in the distance determination process. The selection is run by sensor node as follows: when the transmitted signal from the reference could be achieved directly by the node, the Received Signal Strength (RSS) scheme is employed, otherwise, DV-Hop is chosen.

The second proposed scheme is exploiting the least squares of error between the estimated and expected distance. The variance of errors will be used as a weighted factor in the least square solution. The weighted least square method using minimization of error variances is applied to the DV-Hop method in order to enhance the accuracy level of estimated node position. Although there are many researchers have been working to do the weighting for DV-Hop algorithm to obtain the accuracy on estimated distance, but only few of them apply the weighted least squares on it. The second proposed scheme is a solution to refine the estimated distance determined by H-Loc algorithm. After refining process, sensor node calculates its position using multilateration scheme. The whole process, start from distance determination to calculation process are developed in each sensor node. Therefore, this system implies a distributed processing system.

The contribution of this paper is combining two schemes of distance measurement in distributed sensor nodes to make the flexibility in determining the estimated distance between reference nodes and them. Weighted least square is subjected to the estimated distance in order to reach the closest form of the actual one.

The rest of the paper is organized as follows: section II reviews the related works on distance measurement schemes and weighted least square method, section III describes the proposed algorithms, section IV explains the performance and evaluation of the proposed algorithms by simulation and experimental results and section V draws the conclusion.

II. RELATED WORKS

There have been many localization algorithms for wireless sensor networks proposed by some previous researchers. The papers of them are distinguished into two schemes of distance measurements. Received Signal Strength represented a range-based scheme, which is based on the signal receiving by the sensor node as the distance parameter to the other particular node. The environmental condition was the biggest issue found within the researchers in this field, [9], [10]. Those papers applied the Maximum Likelihood, log normal or the weighted least square to minimize the effect of environmental condition, so the accurate distance between nodes could be obtained.

In the range free scheme, some researchers focused on DV-Hop algorithm. This algorithm was firstly announced by [11], to estimate the sensor node position based on its reference node position coordinate and hop information between the node mentioned and its reference node. The weighted factors in the hop size calculation from the reference nodes were proposed by [12], [13], [14], [15] to obtain the optimal distance between nodes. The weighting scheme for proximity, irregularity signal sending degree, the parameter of correction from the empiric data, the asymmetric factor of node position in distributing process, were briefly discussed to obtain an optimal distance. Some version of research employed hybrid localization scheme [12], [13], [14], [15]. They combined RSSI-AOA, Bounding Box-DV-Hop, DV-Distance-Centroid and RSS-RTT. The combination used the same measuring scheme, either the same range based scheme or the same range free scheme. The main purpose of these combinations was improving the estimated distance obtained by the available measuring scheme. The weighted least square scheme was suggested by [7], [16]. In the first paper, the standard hyperbolic and circular positioning was refined using weighted least squares in linear form, whereas the second paper proposed weighted nonlinear least squares. Both papers aforementioned employed the weighted least square scheme for RSS-based node positioning system. In this paper, we explore the variance error between distance obtained by range-free scheme - represented by DV-Hop algorithm, and actual distance. The variance, hereinafter, is applied as a weighted factor in determining the accuracy of estimated distance

III. PROPOSED ALGORITHM

In this part, we are going to explain the proposed schemes, called the hybrid localization (H-Loc) scheme for the selection of distance determination process on the side of sensor node, and the weighted least square scheme in DV-Hop algorithm (DV-WLS) to refine the accuracy of estimated distance.

A. Hybrid Localization Scheme (H-Loc)

A couple of nodes in a network are said to be connected if both of them are able to communicate each other using a particular link. In wireless sensor networks, connectivity between sensor nodes is seen as the relation between a vertex and edge. The node is considered to be the vertex and the communication link between nodes is the edge. Thus, the connected network implies the presence of connectivity in a graph between a couple of nodes that able to have a link of single or multi-hop communication line in the graph system [17]. Connectivity scheme between nodes usually has a strong relation to the coverage area of the node itself. A node is able to communicate with the other nodes, or it could be connected to other nodes, if the coverage area of this node could reach the other nodes. The coverage area is closely related to energy consumption. In wireless sensor networks, energy consumption problem becomes a really important problem to be noted, taking into account that sensor nodes could only obtain a limited amount of power supply from the battery [18]. The behavior of a node in communicating with the other nodes becomes a consideration in determining the distance between them. The easier the node is connected to another node, the smaller the distance and the bigger the coverage area between them. On the other hand, degree of connectivity is inversely proportional with coverage area and distance. A hop, i.e. the number of jumps of an information packet are propagated from sending node to the receiving node. A node is said to be easily connected and has a large degree of connectivity if it only needs one hop to reach the destination node. This is called a single hop connection. Meanwhile, the node has a small degree of connectivity with other node if it needs multiple hops to go to other nodes, this is called a multi hop connection. Hybrid localization scheme (H-Loc) that we suggested [8] accommodates the reasons above, taking advantage of coverage area that is reachable by the sensor nodes. This scheme presents the choice as follows: the reference nodes broadcast two kinds of information. The first is the signal strength and the other is information packet. If the coverage area of reference node cannot reach the sensor node,

then the range-free scheme will be selected by the sensor nodes, otherwise, they will select RSS-based scheme. These schemes work on the distance determining phase, which is the first phase of localization scheme that aims to get the estimated distance between sensor nodes and its reference nodes. In the H-Loc scheme, every sensor node has the ability to receive signal strength and hop amount, i.e. hop count and hop size, which is transmitted by each reference node.

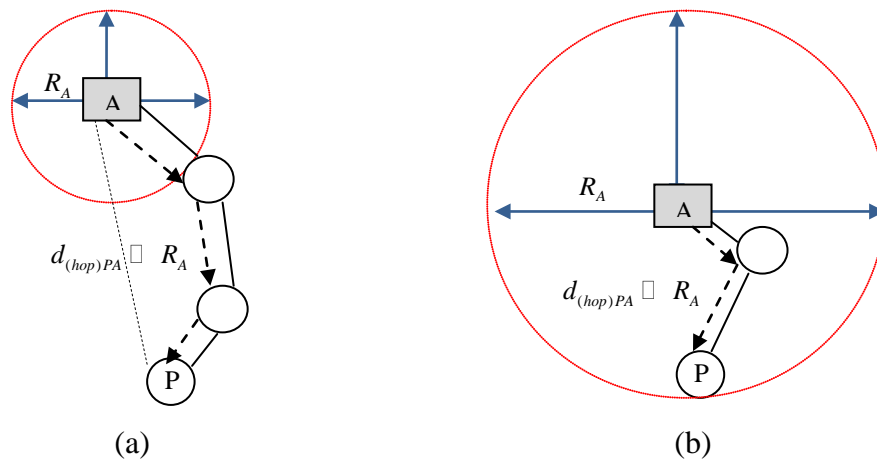


Figure 1. The concept of H-Loc Scheme Application

- a. DV-Hop Selection for Range-Free Scheme (P is outside of A's coverage) b. RSS Selection for Range-Based Scheme (P is inside of A's coverage)

In a sensor node, the received signal strength data are stored in a certain database. The other data, i.e. hop that counted by transit node, and attached to the packet which is flooding from reference to the sensor node, will be kept in another database.

Assume there are $m+n$ nodes deployed in the observation area, where m reference nodes with the known position coordinates $\{(x_1, y_1), (x_2, y_2), \dots, (x_m, y_m)\}$, and n sensor nodes which their position $\{(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)\}$ will be estimated. Let $P(x_p, y_p)$ is the sensor node and $A(x_A, y_A)$ is the reference node. Using the proposed algorithm, there are two possibilities of P in estimating its range to the reference node A , as shown in Figure 1. First, if P is outside the coverage area of A (R_A), then P will apply the DV-Hop algorithm to calculate the distance from A and utilizes the path of the other nodes, as shown in Figure 1a. On the contrary, if P is inside the coverage area of A , P will pick up the RSS information from A directly, pursuing the RSS method, as shown in

Figure 1b. The H-Loc algorithm starts while all reference nodes broadcast the packets which contain their position to the surrounding nodes in the observation area. Each node which receives the packet will store the packet information, updates the hop count information and forwards the updating packet to the other nodes. Obviously, every node will be flooded with some packets come from the other nodes. These packets can have the same content or not. Moreover, the node is also receiving the RSS information while it is in the coverage area of reference nodes. The node with the three kinds of information (number of hops and position of reference in a packet and RSS) will make the selection process. If the estimated distance produced by DV-Hop Algorithm is lower than the estimated distance by the RSS method, the node will take into account this value for calculating process, and vice versa. The hybrid algorithm for each sensor node is shown in Figure 2.

```

1. Deploy  $m$  references and  $n$  sensor nodes in square area
2. FOR each reference node,  $A_i, i \in \{1, 2, \dots, m\}$ 
3.   Broadcasts RSS information to the neighbor node
   Broadcasts information packet contains ID, position and initial hop
   count = 0 to the other reference node
4.   Do Equation (4)
5.   Return Hopsizes(i)
6.   Broadcasts information packet contains ID, position and hopsizes to
   the sensor nodes
7. END
8. FOR each sensor node,  $P_i, i \in \{1, 2, \dots, n\}$ 
9.   Increase hop count, and obtain the minimum hop from reference nodes
10.  DO H-Loc Algorithm:
11.  IF  $P_{R_i}(d) = 0$  ; distance from reference is unreachable
      Apply DV-Hop Algorithm, obtain estimated distance as equation (5)
    ELSE
      Apply RSS Method, obtain estimated distance as equation (3)
    END
12.  Get 3 nearest reference nodes  $\{(x_A, y_A), (x_B, y_B), (x_C, y_C)\}$  with
       $\{d_{iA}, d_{iB}, d_{iC}\}$  as obtained by the proposed algorithm.
13.  Apply trilateration method to calculate the estimated position  $(\hat{x}_i, \hat{y}_i)$ 
14. END
15. Send the estimated position, ID node and sensing values to the server.

```

Figure 2. H-Loc Algorithm for distance determination selection

The proportion of received signal power by node i , P_{Ri} at d distance from the transmitter j in a free space environment, to the received signal power, P_{R0i} at d_0 reference distance is expressed as [10]:

$$P_{Ri} = P_{R0i} \left(\frac{d_{ij}}{d_{0i}} \right)^{-n} \tag{1}$$

or
$$P_{Ri} (dBm) = P_{R0i} (dBm) - 10n_p \log \frac{d_{ij}}{d_{0i}} \tag{2}$$

where n_p is a path loss coefficient, from 2 to 4, depend on the urban environment. The estimated distance, \hat{d}_{ij} from a pair of sensor node i , and reference node j found at equation (2) can be solved as:

$$\hat{d}_{ij} = d_{0i} 10^{\frac{[P_{Ri} - P_{R}(d_0)]}{10n_p}} \tag{3}$$

Sometimes, a sensor node fails to detect the presence of reference nodes. In this case, the sensor node is able to use hop value which stored in the second database. In this case, the sensor nodes will use DV-Hop scheme. The concept of this scheme is based on the multiplication of hops between reference nodes and sensor nodes, and the hop size of the reference nodes involved. Hop size is calculated from the physical distance between two reference nodes toward the hop amount between them. In this algorithm, each reference node broadcasts its position information in the packet form. The sensor nodes which receive the packet will update the shortest path based on the hop size of each reference node. This shortest path will be used as an estimated distance among each other. Furthermore, the estimated distances will be incorporated together with the reference coordinates in order to calculate the estimated position of the sensor node.

There are three steps on estimating the node position using DV-Hop algorithm [19]. First, calculate the hop size of each reference node. The hop size is calculated from the sum of physical distance of the other reference nodes divided by the hop count between them.

The hop size of each reference node is stated as

$$H_j = \frac{\sum_{j \neq k} \sqrt{(x_j - x_k)^2 + (y_j - y_k)^2}}{\sum h_{jk}} \tag{4}$$

where (x_j, y_j) and (x_k, y_k) are the reference node's coordinates and h_{jk} is the hop amount from reference node j to reference node node k .

The second step is to calculate the distance between sensor node P with each reference node, where the distance is stated as the multiply of reference node's hopsize destination and hop amount from sensor node toward the reference node.

$$d_{ij} = H_j \cdot h_{ij} \quad (5)$$

B. Least Square Solution for Distance Estimation

Distance accuracy is very crucial in determining the precision of estimated node position. Therefore, some efforts are required to get an optimal distance value. The optimization of distance means to make an approach between the estimated distance obtained from the DV Hop scheme and the expected distance, using the linear solution. The variance of the difference between expected and measured distance is used as the weighted from linear expression to get the new estimated distance. Assume the expected distance, y_i , where i state an index of certain point from the set of data N , and \hat{y}_i is a measured distance. The square of residue from the difference between expected and estimated distance is expressed as:

$$e = \sum_{i=1}^n \|\mathbf{v}_i\|^2 = \mathbf{v}'\mathbf{v} = \sum_{i=1}^n v_i^2 \quad (6)$$

with

$$v = (y - \hat{y}) = (y - \beta X) \quad \text{or} \quad v = y - (\beta_0 + \beta_1 X) \quad (7)$$

If the independent variable y represents distance response, i.e an expected distance between sensor nodes and their references, and dependent variable X represents the distance which obtained by DV-Hop scheme, then y can be approximated linearly by X in β times. β is an estimated parameter, i.e the parameter that could be used to fit the dependent variable to independent variable. The DV-Hop's estimated distance can be stated as a linear form as:

$$\hat{y} = \beta X \quad (8)$$

Ordinary Least Square (OLS)

Equation (8) is a linear form that contains some kind of estimated parameter, depends on the kind of its dependent variable. In the distance determining case, there's just one kind of dependent

variable, called the measured distance. Thus, there are two estimated parameters: β_0 and β_1 .

Equation (8) can be rewritten as:

$$\hat{y}_i = \beta_0 + \beta_1 X_i \tag{9}$$

For N observation data, linear approach between measured distance and expectation distance can be written as a matrix form as follows:

$$\begin{bmatrix} \hat{y}_1 \\ \cdot \\ \cdot \\ \hat{y}_N \end{bmatrix} = \begin{bmatrix} X_1 & 1 \\ \cdot & 1 \\ \cdot & 1 \\ X_N & 1 \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \end{bmatrix}$$

$$\boldsymbol{\beta} = (\mathbf{X}^T \mathbf{X})^{-1} \mathbf{y} \quad \text{and} \quad \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \end{bmatrix} \tag{10}$$

with p numbers of dependent variable type, where $p < N$, we will obtain p of β . Assume that all dependent variables X are 1.

The value of β_0 and β_1 can be obtained by minimizing residue by decreasing v at equation (7) toward each β , so we have:

$$\frac{\partial v}{\partial \beta_0} = \frac{\partial}{\partial \beta_0} \sum_{i=1}^n (y_i - (\beta_0 + \beta_1 X_i))^2 = 0 \quad \text{then} \quad \beta_0 = \frac{\sum_{i=1}^n y_i \sum_{i=1}^n X_i^2 - \sum_{i=1}^n X_i \sum_{i=1}^n X_i y_i}{n \sum_{i=1}^n X_i^2 - \left(\sum_{i=1}^n X_i \right)^2}$$

and (11)

$$\frac{\partial v}{\partial \beta_1} = \frac{\partial}{\partial \beta_1} \sum_{i=1}^n (y_i - (\beta_0 + \beta_1 X_i))^2 = 0 \quad \text{then} \quad \beta_1 = \frac{n \sum_{i=1}^n X_i y_i - \sum_{i=1}^n y_i \sum_{i=1}^n X_i}{n \sum_{i=1}^n X_i^2 - \left(\sum_{i=1}^n X_i \right)^2}$$

The new estimated distance can be found by multiplying each estimated distance data with obtaining estimated parameter, as shown in equation (9).

Weighted Least Square (WLS)

The WLS scheme is used to improve the estimated result that has been taken by least squares. WLS criteria, as proposed by [7] is used to minimize residue between estimated distances and model distance. The enhancing form of equation (7) becomes:

$$\boldsymbol{\varepsilon} = \mathbf{v}^T \mathbf{W}^{-1} \mathbf{v} \quad (12)$$

where \mathbf{W} is a matrix covariant of random error vector $\mathbf{v} = (v_1, v_2, \dots, v_N)^T$ which is the difference between estimated distance with model distance. If we assume that the error of measured distance among nodes, e_i is independent, then W represents a diagonal element from error matrix, with $W_{ii} = \text{var}(v_i)$. Residue can be minimized with:

$$\boldsymbol{\varepsilon} = \mathbf{v}^T \mathbf{W}^{-1} \mathbf{v} = \sum \frac{v_i^2}{\text{var}(v_i)} = \sum_{i=1}^N \left(\frac{1}{\text{var}(v_i)} (y - (\beta_0 + \beta_1 X))^2 \right) \quad (13)$$

The matrix form of W is as follows:

$$W = \begin{bmatrix} \text{var}(v_{11}) & \text{cov}(v_{12}) & \cdot & \cdot & \text{cov}(v_{1N}) \\ \text{cov}(v_{21}) & & & & \cdot \\ \cdot & & \cdot & & \cdot \\ \cdot & & & \cdot & \cdot \\ \text{cov}(v_{N1}) & & & \cdot & \text{var}(v_{NN}) \end{bmatrix} \quad (14)$$

The aim of the position calculation is to obtain the estimated position of sensor nodes. The accuracy of estimated position is to be expected, or having a minimum residue toward the actual position as stated in:

$$\boldsymbol{\varepsilon} = \sum_{i=1}^n \left(\sqrt{(x_i - x)^2 + (y_i - y)^2} - \tilde{d}_i \right) \quad (15)$$

The least square solution in matrix form is expressed as:

$$\begin{bmatrix} x_i \\ y_i \end{bmatrix} = \begin{bmatrix} \hat{x}_i \\ \hat{y}_i \end{bmatrix} + \boldsymbol{\varepsilon}_i$$

To minimize $\boldsymbol{\varepsilon}$ by differentiating it into x and y and equating the differential to zero,

$\frac{\partial \boldsymbol{\varepsilon}}{\partial x}$ and $\frac{\partial \boldsymbol{\varepsilon}}{\partial y} = 0$ for each nodes, we obtain the linear solution of closest distances of reference

nodes:

$$\begin{aligned}
 \tilde{d}_1^2 &= (x_1 - x)^2 + (y_1 - y)^2 \\
 \tilde{d}_2^2 &= (x_2 - x)^2 + (y_2 - y)^2 \\
 \tilde{d}_3^2 &= (x_3 - x)^2 + (y_3 - y)^2 \\
 &\vdots \\
 \tilde{d}_N^2 &= (x_N - x)^2 + (y_N - y)^2
 \end{aligned} \tag{16}$$

where $\{(x_1, y_1), (x_2, y_2), (x_3, y_3), \dots, (x_N, y_N), \tilde{d}_1, \tilde{d}_2, \tilde{d}_3, \dots, \tilde{d}_N\}$ are the coordinates and estimated distance of reference nodes. Hence, by substituting each estimated distance to the reference distance, for instance, we use \tilde{d}_1 as the reference distance, then the form of equation (16) could be expressed as:

$$\tilde{d}_i^2 - \tilde{d}_1^2 = x_i^2 - 2x_i x_1 + y_i^2 - 2y_i y_1 \tag{17}$$

In matrix form, it could be written as:

$$\begin{bmatrix} 2x_2 & 2y_2 \\ 2x_3 & 2y_3 \\ \vdots & \vdots \\ 2x_N & 2y_N \end{bmatrix} \begin{bmatrix} x_i \\ y_i \end{bmatrix} = \begin{bmatrix} x_2^2 + y_2^2 - \tilde{d}_2^2 + \tilde{d}_1^2 \\ x_3^2 + y_3^2 - \tilde{d}_3^2 + \tilde{d}_1^2 \\ \vdots \\ x_N^2 + y_N^2 - \tilde{d}_N^2 + \tilde{d}_1^2 \end{bmatrix} \tag{18}$$

Or $\mathbf{Ax} = \mathbf{B}$

where

$$\mathbf{A} = \begin{bmatrix} 2x_2 & 2y_2 \\ 2x_3 & 2y_3 \\ \vdots & \vdots \\ 2x_N & 2y_N \end{bmatrix}, \quad \mathbf{x} = \begin{bmatrix} x_i \\ y_i \end{bmatrix}, \quad \mathbf{B} = \begin{bmatrix} x_2^2 + y_2^2 - \tilde{d}_2^2 + \tilde{d}_1^2 \\ x_3^2 + y_3^2 - \tilde{d}_3^2 + \tilde{d}_1^2 \\ \vdots \\ x_N^2 + y_N^2 - \tilde{d}_N^2 + \tilde{d}_1^2 \end{bmatrix}$$

The estimated position can be obtained as follows:

$$\hat{\mathbf{x}} = (\mathbf{A}^T \mathbf{A})^{-1} \mathbf{A}^T \mathbf{B} \tag{19}$$

IV. PERFORMANCE ANALYSIS AND EVALUATION

In this section, we will analyze and evaluate the performance of the system. This evaluation is distinguished into simulation scheme and experimental work. The performance of proposed algorithm is examined using Matlab in simulation scheme, whereas the environmental characteristic is measured in experimental work in order to obtain the variation of signal strength received by nodes. This work is implemented using Imote2. The diagram of the relationship between simulation and experimental work is illustrated in figure 3. In this figure, RSS values are obtained by measuring the received signal from reference nodes. Furthermore, the RSS values are converted to the distance, as described in the next section, and evaluated as input of the H - Loc algorithm. WLS scheme refines the estimated distance issued by H-Loc algorithm, after the evaluation is completed, this scheme is developed in each sensor node.

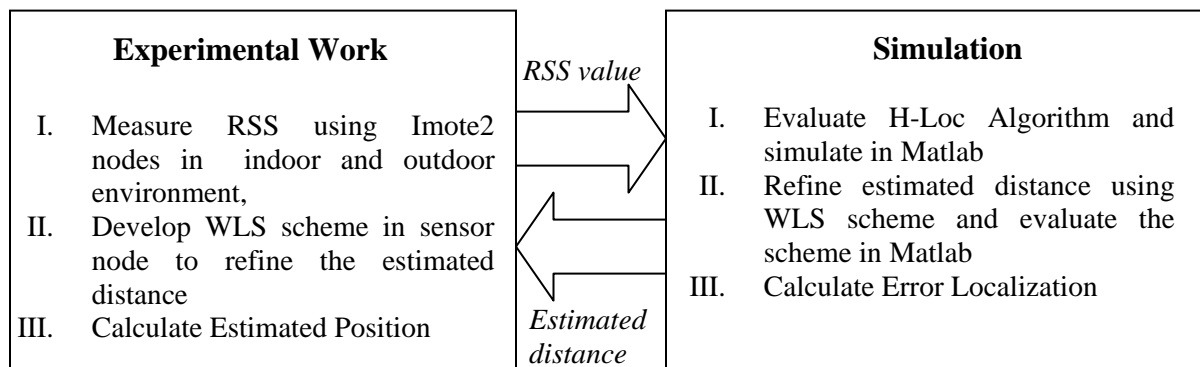


Figure 3. The relationship between simulation and experimental work

A. Simulation scheme

The simulation parameter as listed in Table 1, consists of the maximum number of nodes, observation area, communication range of each node, path loss coefficient of the observed environment, and power received by sensor node, P_{R_0} at a reference distance, d_0 . The deployed nodes are classified into reference nodes and sensor nodes, where each node has common communication range. The maximum communication range is set equal to the maximum length of the observation area. This area is simulated as a squared form. The RSS method is applied based on the measurement results from the outdoor environment with a certain path loss coefficient. The communication mechanism is Line of Sight (LOS). Node deployment is

illustrated as in figure 4, where sensor nodes are configured as C-shape and reference nodes is in a random normal distribution.

Table 1. Simulation Parameter

Parameter	Value
Number of nodes max.	200 pcs
Observation area	100mx100 m
Communication range	40-100 m
Path loss coefficient	1.6 – 2.2
Reference Power Received	102 dB
Reference distance (d0)	1 m

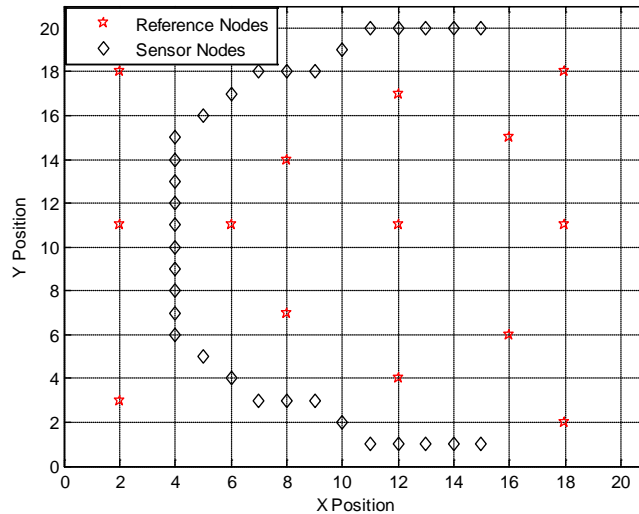


Figure 4. The Scenario of Node Deployment

1. Performance Evaluation of Algorithm 1: H-Loc Scheme

The performance of proposed algorithm will be evaluated by comparing it with the original DV-Hop and RSS method. The average error localization is evaluated based on the ratio of reference nodes and number of sensor nodes, adjusting the communication range and the density of the system (number of nodes per squared area). Figure 5 implies that the original DV-Hop results the worst accuracy, followed by the RSSI method. The proposed algorithm could enhance the accuracy up to 88 % better than the original DV-Hop. This algorithm also reduces the average error position to 66% lower than the RSS method.

In the adjustment of communication range, the algorithms are simulated to evaluate the average error position of the system when the communication range ratio is increased. The simulation result shown in Figure 6 describes the convergence of algorithm in solving the average error position occurs in 60% of communication range ratio. The proposed H-Loc algorithm offers a better performance than the others.

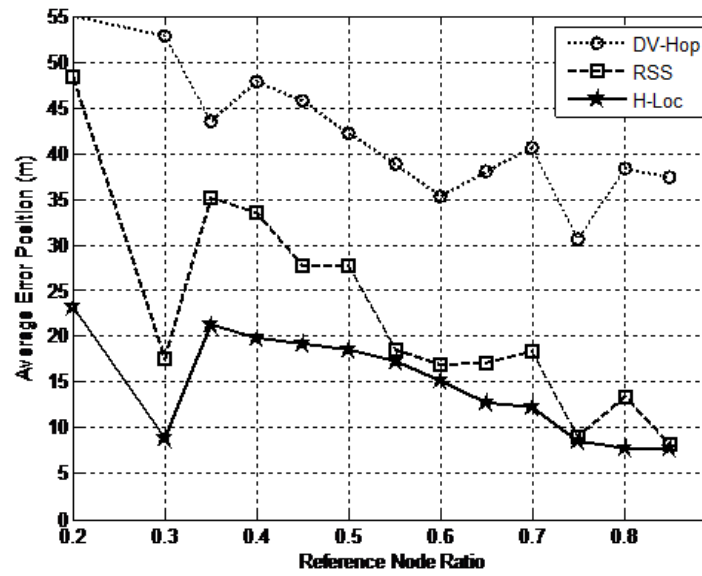


Figure 5. Average Position Error vs Reference Node ratio

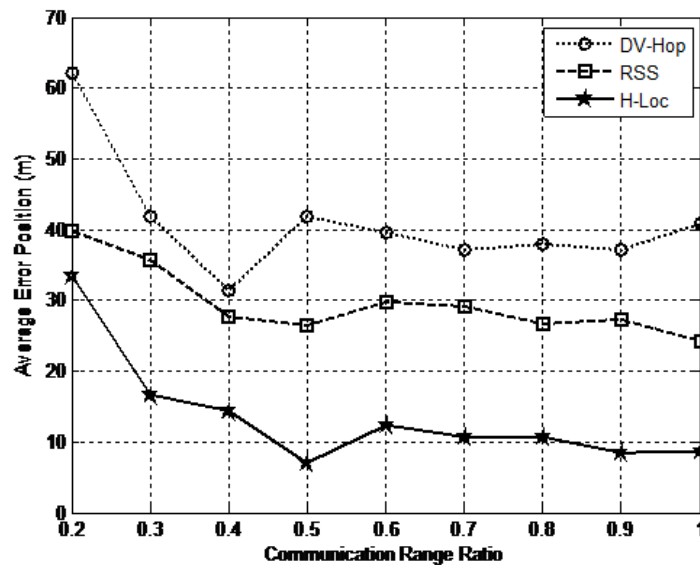


Figure 6. Average Position Error vs Communication Range Ratio

The proposed algorithm is specifically examined based on the adjusting observation area and communication range of reference nodes. The result shows, as in Figure 7, the wider the communication range adjusted (40,60 and 80 m respectively) in an increased observation area (from $40 \times 40 \text{ m}^2$ to 200 m^2), the higher the average error position obtained. In the simulation, a fixed number of nodes are deployed (50 nodes and 5 reference nodes) and the area is increased from $10 \times 10 \text{ m}^2$ to $200 \times 200 \text{ m}^2$. As we know, enlarging the area will increase the range between nodes. The H - loc algorithm will select adaptively whether selected reference nodes could be reached in one hop or not.

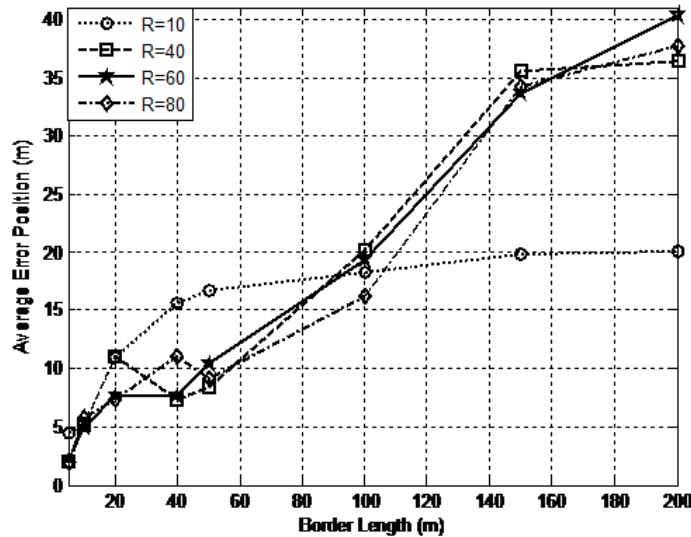


Figure 7. Average error vs Border Length for H-Loc Algorithm

2. Performance Evaluation of Algorithm 2: DV-WLS Scheme

The other scheme proposed in this paper is for refining the performance of the DV-Hop scheme. Actually, DV-Hop scheme has dependencies in hop count between nodes. The nodes which have the same reference nodes and the same hop count will have the same estimated coordinate position, even though the actual position is rather different. Using a weighted factor of least squared error position, it can be proven that the accuracy of the estimated position is increased, as illustrated in figure 8. DV-WLS scheme has the capability in reducing the average position error when the node is increased, up to 3.611 % comparing with standard DV-Hop. Meanwhile, DV-LS just reduces 0.1 %. The H - Loc scheme could reduce up to 0.572431 %.

The influence of communication range changes is examined in our proposed scheme. The simulation result shows the wider the communication range increase, the bigger the error position

occurs in the system. The phenomenon is shown by DV-Hop scheme and its improved schemes, as drawn in figure 9. The reason of this phenomenon can be explained as follows: increasing the communication range of each node yields the overlapping area.. This overlapping area yields some errors in selecting references for each node. The accumulated error due to overlapping area yields accumulating error position estimation. The performance of system could be reached by DV-WLS and DV-LS scheme as 3.33 % and 0.875 % better than standard DV-Hop scheme.

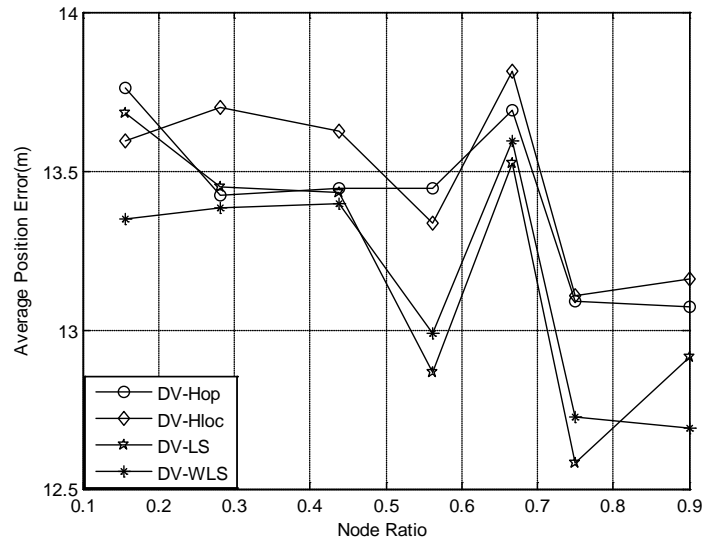


Figure 8. Average Position Error vs Node Ratio for DV-Hop scheme and its improved schemes

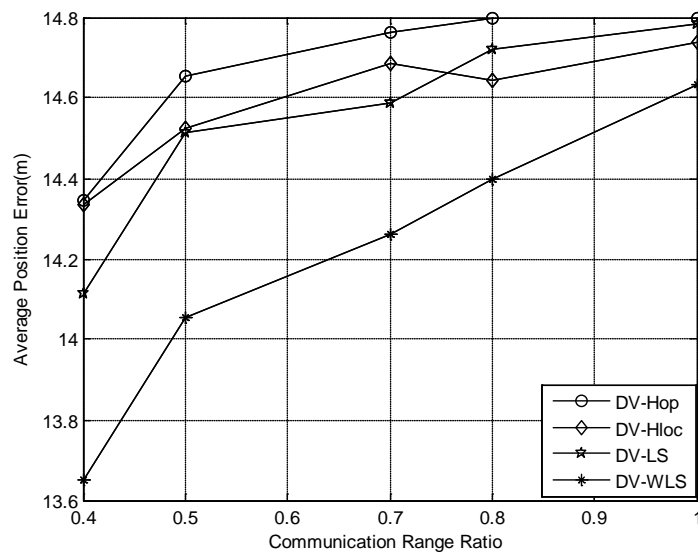


Figure 9. Average Position Error vs Communication Range Ratio for DV-Hop scheme and its improved schemes

We evaluate the average distance error for a set of sensor nodes towards a certain reference node. In our case, the distance comes from sensor node 1,2,3,4,5,6,7,8 towards the reference node 1. The average distance error of them is shown as in figure 10. The average distance error of RSS scheme is 4.740261m, or 23 % of the length of the observation area, followed by the average distance error of DV-WLS scheme (4.9711m or 24.8 % of ratio with the length of observation area). The worst is using DV-Hop scheme, which shows 46.75 % of the length of the observation area.

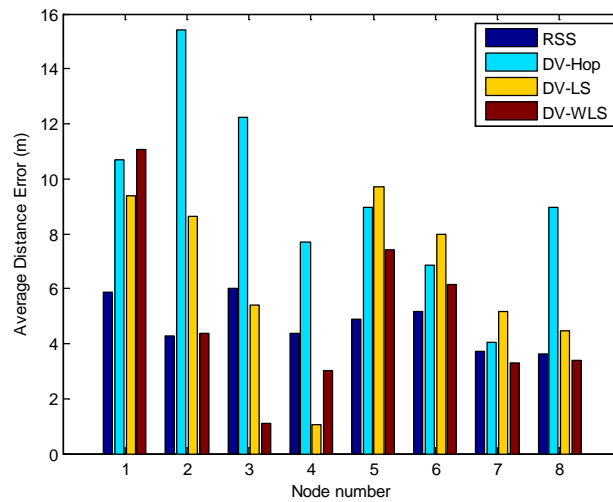


Figure 10. Average Distance Error for each sensor node

Finally, the accuracy of position concerns the capability of the proposed scheme to achieve the actual position of the node [20]. The scheme is running in n iteration to solve a certain position of node. We apply a particular node with the coordinate (8,3) as an actual node, and the algorithm is iterated n times until the convergence is obtained. The closest value of estimated position obtained by DV-WLS scheme is (10.24032,10.42694), and obtained by DV-LS scheme is (8.333,3.3363). The DV-LS scheme seems to be better than the DV-WLS scheme, but shows instability, as shown in figure 11c and d.

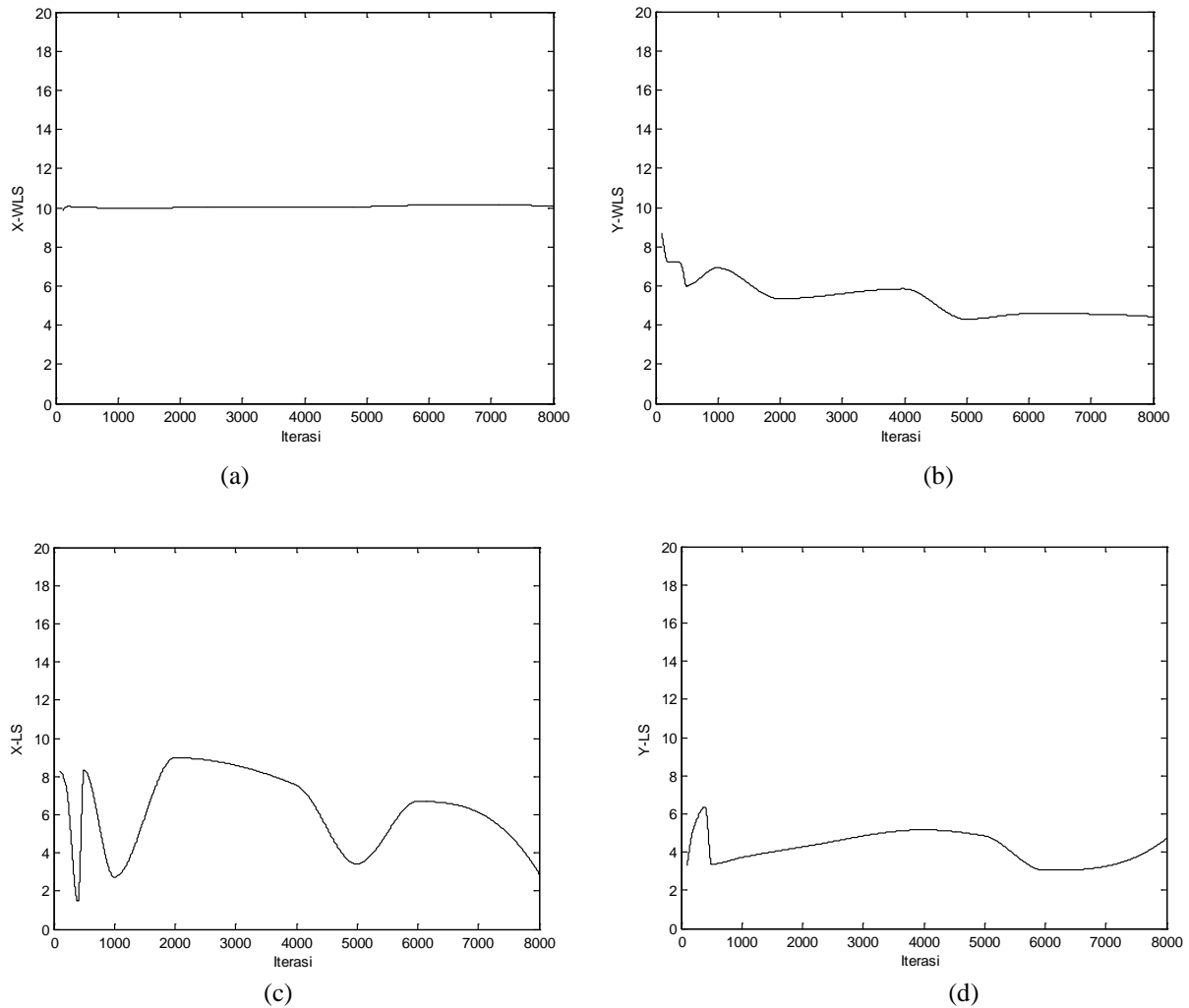


Figure 11. The convergence of the proposed scheme to the particular node with coordinate (8,3).

B. Experimental Work

In this work, we concern on LOS observation area, both in indoor and outdoor environment. The aim of measurement is to observe path loss coefficient which represents signal characterization received by wireless device in certain area. Multipurpose building at Politeknik Elektronika Negeri Surabaya, Indonesia is selected to represent indoor environment, meanwhile the soccer field around campus area is represented as the outdoor environment. The photograph of the measurement in the two areas is shown in figure 12. A pair of nodes is attached in the observation area. Imote2 applies 802.15.4 series 1 with 1 mW of power transmit for the communication system among nodes. The first node acts as a reference node, which broadcast the information packet and RF signal to the second node. The aforementioned node will receive the packet, measures RSS level signal and converts it to the estimated distance, based on the

modeling of path loss as described in (2). This node is shifted away from the reference node with 2 meters spacing. The height of each node is 0.45 m. In the same distance, the received signal strength is measured 12 times by the 30° difference angle of receiving antenna. The scenario of measurement procedure is shown in figure 13.



Figure 12. Observation area for Signal Strength Measurement

a. Indoor LOS

b. Outdoor LOS

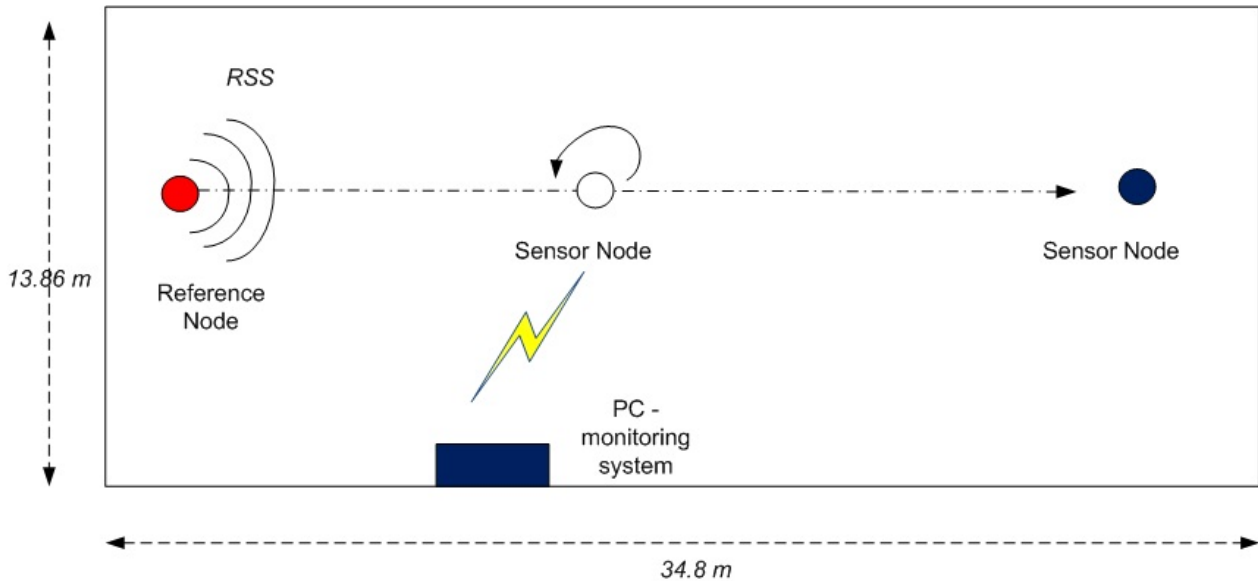


Figure 13. The scenario of RSSI measurement procedure

1. Performance evaluation of Environmental Characteristic

Distance measurement among nodes is fully dependent on the environment where the nodes are deployed. In the measurement process, 12 samples of signal strength data were taken by the receiving node in the same distance, with 30° angle difference for between them. The experimental results of Outdoor LOS environment show that the range of power received is -37.8571 to -77.0714 dBm and the results of Indoor LOS have the range between -52.9167 to -74.2500 dBm. Using path loss modeling as (2), the path loss coefficient, n of outdoor LOS was obtained as 2.2040, and in indoor LOS was obtained as 1,6027. The experimental results were approached by polynomial modeling order 2. The derivation of this modeling and experimental data yield the values as follows: mean, variance and deviation standard of data error on indoor LOS are 1.4807, 56.37945 and 7.5086 respectively, whereas in outdoor LOS these values are 2.0345, 156.0797 and 12.4932. The variance of receiving power in an outdoor environment, as shown in figure 14b, is larger than the variance in indoor, and the path loss coefficient is larger too. These values indicate that indoor measurement yields poor quality of signal caused by reflection and attenuation of the building.

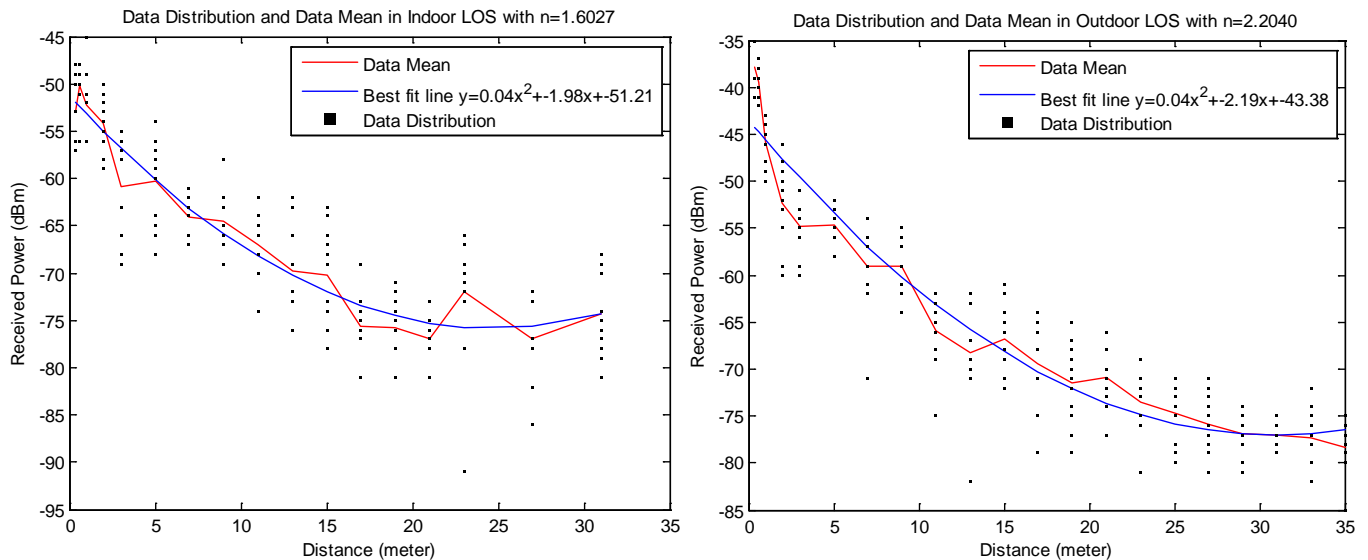


Figure 14. The measurement received power towards the distance

a. Indoor LOS

b. Outdoor LOS

2. Performance evaluation of Estimated Distance

The variation of received signal strength indicates the unique pattern of the observation area. This pattern is represented by a path loss coefficient, which implies the category of the observation area, whether indoor, outdoor, Line of sight (LOS) or Non line of Sight (NLOS). Using the path loss coefficient, estimated distance is calculated as equation (4). The estimated distance obtained by path loss modeling are compared with actual distance. From the various distance measurement in an indoor environment, the average of the difference between estimated and actual distance or mean square error (MSE) of distance is 4.6959 m. The variance and standard deviation are 20.6903m and 4.5486m, respectively. The comparison of estimated and actual distance is illustrated in figure 15a. Meanwhile, the MSE, variance and standard deviation of distance in outdoor LOS are 4.153, 23.2539m and 4.8222m, and the comparison of the data is shown at Figure 16a. Cumulative distribution function (cdf) of error between estimated and actual distance for indoor and outdoor LOS is shown in figure 15b and 16b. In indoor LOS, cdf shows that the error estimated distance is spread evenly throughout the measurement, meanwhile, in outdoor LOS, the spreading tend to narrow in certain measurement. This indicates that the data error will be occurred easily in indoor area caused by the reflection or obstacle around observed area.

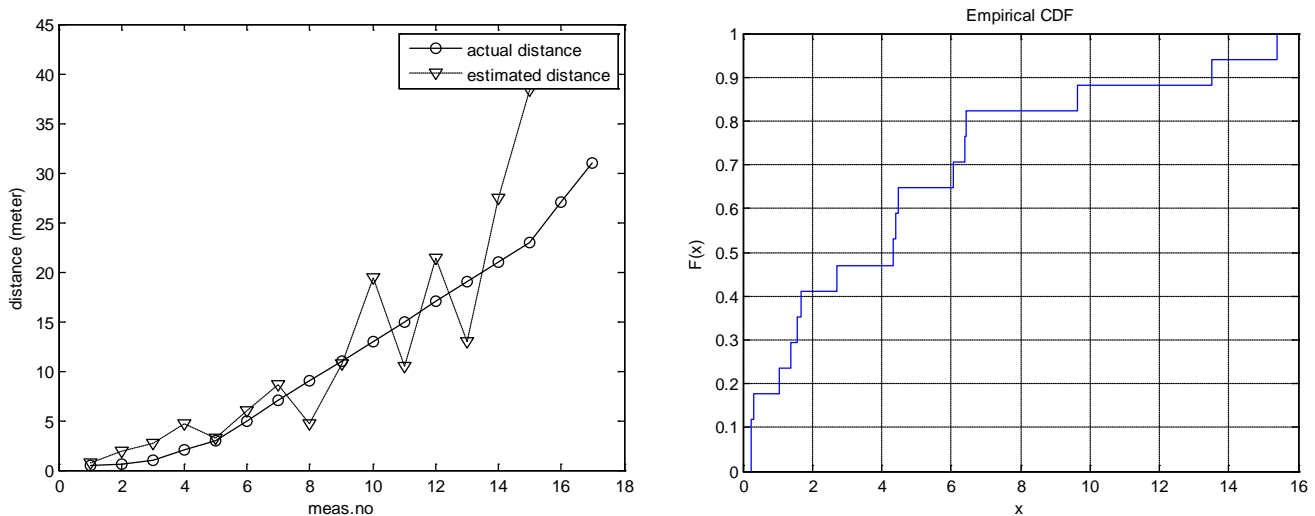


Figure 15. Evaluation of Estimated Distance in Indoor LOS

- a. Comparison of estimated and actual distance
- b. cdf form of least square error

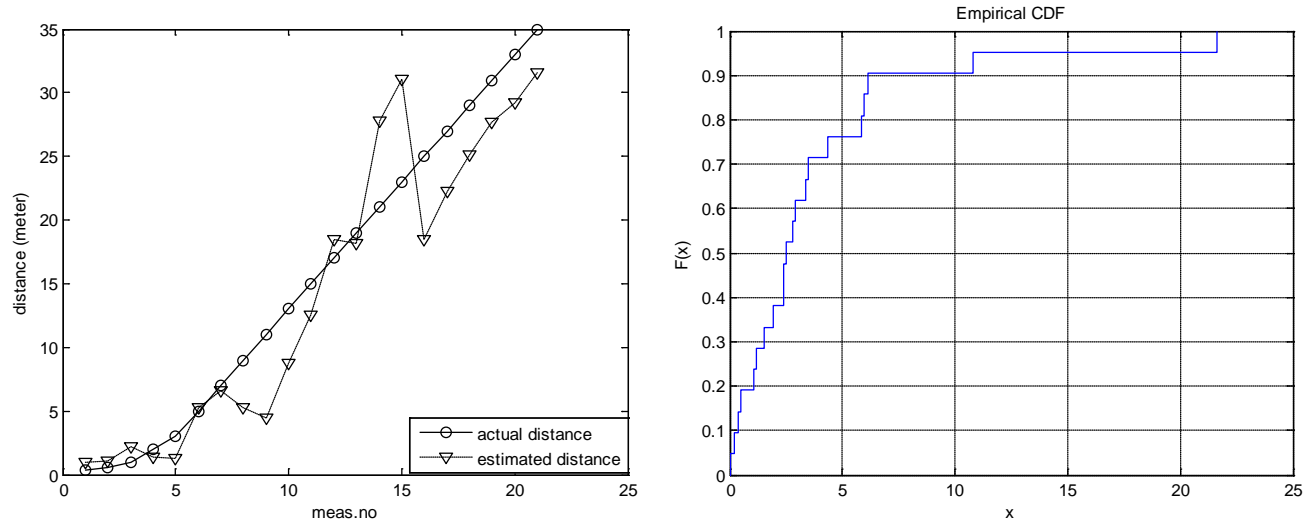


Figure 16. Evaluation of Estimated Distance in Outdoor LOS

- a. Comparison of estimated and actual distance b. cdf form of least square error

V. CONCLUSIONS AND FUTURE WORK

The robust localization scheme has been proposed by combining DV-Hop scheme and RSS scheme. The combination scheme, called H-Loc performs better than standard DV-Hop for arbitrary nodes amount and communication range. An improvement on distance accuracy has been solved by weighting the variance of a distance error by the least square method. The proposed algorithm provides critical benefit on node positioning accuracy. In the future we will apply the weighted least square scheme to estimate indoor movable node position by considering environmental characteristic and calculation rate for self-localization in wireless sensor networks.

ACKNOWLEDGEMENTS

The research work in this paper is supported by Directorate General of Higher Education of Indonesia under Grant No. 062.12/PL14/PG.1/2013.

REFERENCES

- [1] S. Indu, V. Kesam, S. . Chaudury, and A. Bhattacharya, “Self Organizing Sensor Network to Enhance Event Coverage,” *J. on Smart Sensing and Intelligent System*, vol. 4, no. 1, pp. 53 – 74, Mar. 2011.
- [2] N. Patwari, I. Hero, A.O., M. Perkins, N. S. Correal, and R. J. O’Dea, “Relative location estimation in wireless sensor networks,” *IEEE Transactions on Signal Processing*, vol. 51, no. 8, pp. 2137 – 2148, Aug. 2003.
- [3] G. Mao and B. Fidan, *Localization Algorithms and Strategies for Wireless Sensor Networks*, 1st ed. Information Science Reference, 2009.
- [4] Y. Liu and Z. Yang, *Location, Localization, and Localizability: Location-awareness Technology for Wireless Networks*. Springer, 2011.
- [5] F. Reichenbach, A. Born, D. Timmermann, and R. Bill, “A distributed linear least squares method for precise localization with low complexity in wireless sensor networks,” in *Proceedings of the Second IEEE international conference on Distributed Computing in Sensor Systems*, Berlin, Heidelberg, 2006, pp. 514–528.
- [6] J. Wan, N. Yu, R. Feng, Y. Wu, and C. Su, “Localization refinement for wireless sensor networks,” *Computer Communications*, vol. 32, no. 13–14, pp. 1515–1524, Aug. 2009.
- [7] P. Tarrío, A. M. Bernardos, and J. R. Casar, “Weighted Least Squares Techniques for Improved Received Signal Strength Based Localization,” *Sensors*, vol. 11, no. 12, pp. 8569–8592, Sep. 2011.
- [8] P. Kristalina, W. Wirawan, and G. Hendrantoro, “The enhancement of node positioning accuracy using hybrid localization method for wireless sensor networks,” in *2012 International Conference on Advanced Computer Science and Information Systems (ICACSIS)*, 2012, pp. 65–69.
- [9] G. Zanca, F. Zorzi, A. Zanella, and M. Zorzi, “Experimental comparison of RSSI-based localization algorithms for indoor wireless sensor networks,” in *Proceedings of the workshop on Real-world wireless sensor networks*, New York, NY, USA, 2008, pp. 1–5.
- [10] J. Xu, “Distance Measurement Model Based on RSSI in WSN,” *Wireless Sensor Network*, vol. 02, no. 08, pp. 606–611, 2010.

- [11] D. Niculescu and B. Nath, "Ad hoc positioning system (APS)," in *IEEE Global Telecommunications Conference, 2001. GLOBECOM '01*, 2001, vol. 5, pp. 2926–2931 vol.5.
- [12] F. Dai, Y. Liu, and L. Chen, "A Hybrid Localization Algorithm for Improving Accuracy Based on RSSI/AOA in Wireless Network," in *2012 International Conference on Computer Science Service System (CSSS)*, 2012, pp. 631–634.
- [13] L. Liu, Y. Wei, and G. Xiu, "An Adaptive Hybrid Localization Algorithm for Wireless Sensor Network," in *2012 Second International Conference on Instrumentation, Measurement, Computer, Communication and Control (IMCCC)*, 2012, pp. 1579–1582.
- [14] J. Zhao and H. Jia, "A hybrid localization algorithm based on DV-Distance and the twice-weighted centroid for WSN," in *2010 3rd IEEE International Conference on Computer Science and Information Technology (ICCSIT)*, 2010, vol. 7, pp. 590–594.
- [15] A. Bahillo, S. Mazuelas, R. M. Lorenzo, P. Fernández, J. Prieto, R. J. Durán, and E. J. Abril, "Hybrid RSS-RTT Localization Scheme for Indoor Wireless Networks," *EURASIP Journal on Advances in Signal Processing*, vol. 2010, no. 1, p. 126082, Apr. 2010.
- [16] F. Xiao, M. Wu, H. Huang, R. Wang, and S. Wang, "Novel Node Localization Algorithm Based on Nonlinear Weighting Least Square for Wireless Sensor Networks," *International Journal of Distributed Sensor Networks*, vol. 2012, Nov. 2012.
- [17] A. Ghosh and S. K. Das, "Coverage and connectivity issues in wireless sensor networks: A survey," *Pervasive Mob. Comput.*, vol. 4, no. 3, pp. 303–334, Jun. 2008.
- [18] C. Zhu, C. Zheng, L. Shu, and G. Han, "A survey on coverage and connectivity issues in wireless sensor networks," *Journal of Network and Computer Applications*, vol. 35, no. 2, pp. 619–632, Mar. 2012.
- [19] Hongbeom Ahn and Jinpyo Hong, "DV-hop localization algorithm with multi-power beacons under noisy environment," 2011, pp. 7–12.
- [20] L. Haiyan, H. Yun-an, and Z. Min, "Adaptive Estimation and PI Learning Spring-Relaxation Technique for Location Estimation in Wireless Sensor Networks," *International Journal of Smart Sensing and Intelligent System*, vol. 6, no. 1, pp. 317 – 332, Feb. 2013.