KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS VOL. 4, NO. 1, February 2010

An RSS-Based Localization Scheme Using Direction Calibration and Reliability Factor Information for Wireless Sensor Networks

Cong Tran-Xuan[1] **and Insoo Koo**[2]
[1] Ericsson Vietnam Company Ltd
Ho Chi Minh City, Vietnam
[e-mail: txuancong@yahoo.com]
[2]School of Electrical Engineering, University of Ulsan
680-749 San 29, Muger 2-dong, Ulsan, Republic of Korea
[e-mail: iskoo@ulsan.ac.kr]
*Corresponding author: Insoo Koo

Received October 12, 2009; revised January 14, 2010; accepted January 27, 2010; published February 27, 2010

Abstract

In the communication channel, the received signal is affected by many factors that can cause errors. These effects mean that received signal strength (RSS) based methods incur more errors in measuring distance and consequently result in low precision in the location detection process. As one of the approaches to overcome these problems, we propose using *direction calibration* to improve the performance of the RSS-based method for distance measurement, and sequentially a weighted least squares (WLS) method using *reliability* factors in conjunction with a conventional RSS weighting matrix is proposed to solve an over-determined localization process. The proposed scheme focuses on the features of the RSS method to improve the performance, and these effects are proved by the simulation results.

Keywords: Localization, received signal strength, multi-lateration, direction calibration, reliability factors, weighted least squares, path loss exponent

---

This work was supported in part by the Ministry of Commerce, Industry, and Energy and in part by Ulsan Metropolitan City through the Network-based Automation Research Center at the University of Ulsan. This paper was presented in part at the 2009 International Conference on Advanced Communication Technology.

DOI: 10.3837/tiis.2010.01.003

1. Introduction

Wireless sensor networking has been attracting considerable research interest. In many circumstances, it is necessary for a sensor node in a WSN to be aware of its physical location with absolute or relative position. In some applications, such as tracking or event-detection, it is vital that sensor nodes can provide sensed data or information along with place. To provide location information, the locations of nodes have to be known. The locations of nodes can be set manually but this is infeasible for large scale WSNs. Similarly, equipping every sensor node with a global positioning system (GPS) is also impossible because of cost and deployment limitations; GPS cannot work indoors and consumes excessive energy, while sensor nodes have to work under energy constraints. Moreover, the position of nodes can be used in location-based routing, queuing inquiry, inventory management, etc.. Thus, self-localization is a crucial function in WSN operation.

Localization protocols can be divided into two categories according to the mechanisms used for estimating location: range-based and range-free methods. Range-free methods do not use ranging techniques for estimating the location but replace those by the number of hops or probabilities. Representative of this type are methods such as Centroid [1], DV-Hop [2], APIT [3], etc. While range-based methods use ranging techniques for localization. There are four main ranging techniques that can be used for ranging: time of arrival (TOA) [4], time difference of arrival (TDOA) [5], angle of arrival (AOA) [6] and received signal strength (RSS) [7][10][11][12][13]14]. The TOA technique requires strict time synchronization of the whole sensor network, which is very difficult to implement between beacon and unknown nodes. This approach is therefore costly and difficult to deploy in real systems. Because TDOA uses differing times of arrival at sensor nodes to calculate the distances, it reduces time synchronization, but it also uses a time method that requires synchronization. It is moderately costly and complex to implement in real systems but it produces good performance in terms of distance measurements. There is a clear trade-off between range error and complexity and cost. In the AOA method, sensor nodes have to be equipped with an array to define the angle from which the signal arrives. This technique is expensive, the hardware requirement is large, and it has high power consumption requirements. In contrast, RSS is one of the simplest methods of distance measurement and can be easily implemented in real systems. This technique is based on a standard feature found in most wireless devices, a received signal strength indicator (RSSI). It is attractive because it requires no additional hardware, and is unlikely to significantly impact local power consumption, sensor size and cost.

The signal in the communication channel, regardless of whether the environment is outdoor or indoor, is affected by many factors that can cause errors. In papers [8] and [9], the outdoor experimental measurements record different values of path loss power surrounding a transmitter for the same distance. If we use the same value of path loss exponent in the path loss model, it causes considerable error in distance measurements, and further, it limits the precision of the RSS method. An indoor communication channel was set up for the experiment in paper [10]. The experimental results prove that the path loss values change according to direction around the transmitter. Although the real distance is the same for many receivers deployed in various directions, if the same path loss exponent for the log-distance path loss model is used, the estimated distances are different. It is only for the case of RSS-based ranging that the parameters in the model are fitted with the environment.

Because wireless sensor networks have different characteristics compared with other wireless networks, and they possess some unique characteristics such as small size, cost for deployment, power consumption, low communication range, etc, it is complicated to design a localization technique. Thus, with the simple hardware for measuring signal strength, the RSS-based ranging technique has attracted more research for localization in wireless sensor networks [11][12][13][14][16]. In these works, the authors showed RSS-based localization algorithms with a simple ranging technique.

In paper [14], Cong et al. also used this simple ranging technique for wireless sensor networks, and presented a localization scheme using calibration, but the process requires more steps and consumes more energy during localization. This limits the applicability of the localization scheme for implementation in WSNs. In this paper, we suggest a new simple localization scheme that uses a better calibration method called *direction calibration*. Subsequently, the best fit value of the path-loss exponent can be obtained at the nodes. Moreover, we also set up a parameter called the *reliability* factor that depends on the *temporary* location of unknown nodes in the sector. The proposed localization process saves more energy in WSNs than the process proposed in [14] due to the reduced calibration steps. Finally, the measuring distances in the path-loss equation can be computed more precisely by the calibration process. In addition, we propose the use of a weighted least squares method (WLS) with *reliability* factors, and an RSS weighting matrix to solve an over-determined problem in the location detection process, and this further improves the resolution of localization.

The rest of this paper is presented as follows. Section 2 describes the path-loss model and Section 3 explains the network model. In section 4 the proposed localization scheme is presented. The simulation results are provided in section 5. Finally the conclusion is given in section 6.

2. The Communication Model

Wireless waveforms propagating through free space are subject to a distance-dependent loss of power and this relation is described by the Friis equation:

$$P_r(d) = P_t.G_t.G_r.\left(\frac{c}{4\pi fd}\right)^2 \tag{1}$$

where P_t is the transmitted power, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, c is the propagation speed of the radio frequency signal and f is the frequency of the signal.

The signal propagation in other environments is affected by reflection, diffraction and scattering, which alter the distance-dependent power relation in a manner unlike the simple one described in free space. Especially in an indoor communication channel, these factors make the path loss power distance relation change by a parameter called the path loss exponent. From the statistically averaged received signal power, regardless of whether the radio channels are indoor or outdoor, the received signal strength decreases logarithmically with distance [15][16],

$$P_r(d) = P_t.\left(\frac{c}{4\pi f}\right)^2.\frac{1}{d^\gamma} \tag{2}$$

where γ is the path-loss exponent. The path-loss exponent differs by environment [15], and **Table 1** lists some path loss exponents obtained in various radio environments.

The relation between the averaged received signal strength and distance, expressed by Eqn.(2), doesn't account for the instant received signal strength, which is much different from the averaged value. Moreover, to empirically express the instant received signal strength and distance at any value of d, the log normal shadowing path loss model is used:

$$PL(d)[dB] = PL(d_0)[dB] + 10\gamma \log_{10} \cdot \left(\frac{d}{d_0} \right) + \chi[dB], \tag{3}$$

where $PL(d)[dB] = Pt[dBm] - Pr[dBm]$ is the path loss at distance d from the sender and all values of antenna gains of transmitter and receiver and offset levels for compensation are included in $PL(d)$. $PL(d_0)$ is the path loss at a standardized distance d_0. It is a fixed quantity and can be found using the free space model with $\gamma = 2$ and $d_0 = 1$m; γ is the path loss exponent, which has a normalized distribution function with mean value γ_m and variance σ_γ^2. The values of γ within adjacent areas are correlated; χ is a random variable with a zero-mean Gaussian distribution and variance of σ_χ^2 on a dB scale, and χ is called the shadow fading variable.

In this paper, we use the log normal shadowing path loss model for wireless sensor communication to range distances between sensor nodes. We assume that all sensor nodes have the same configuration to ensure that no other factors of its configuration are affecting the path loss.

Table 1. Path loss exponents for different environments [15]

Environment		γ
Outdoor	Free Space	2
	Shadowed urban area	2.7 to 5
In building	Line-of-sight	1.6 to 1.8
	Obstructed	4 to 6
In factories	Obstructed	2 to 3

Using the log normal path loss model expressed by Eqn.(3), we describe the linearly proportional relationship between the path loss value and the log distance between the sender and receiver as

$$PL[dB] = 10\gamma \log_{10} d, \tag{4}$$

where PL is the path loss value, which is equal to $PL(d) - PL_0$ and d is the distance between two nodes. We can see that in Eqn. (4), PL is proportional to the log scale of distance d, and is not directly proportional to distance d. This noting point is useful for the WLS method. We set D to be the value of the log scale of distance d, called the log-scale distance. From Eqn.(4) we have

$$PL[dB] = \gamma D \tag{5}$$

Based on the path loss value and location from the informing process and Eqn. (4), the path loss exponent γ can be obtained.

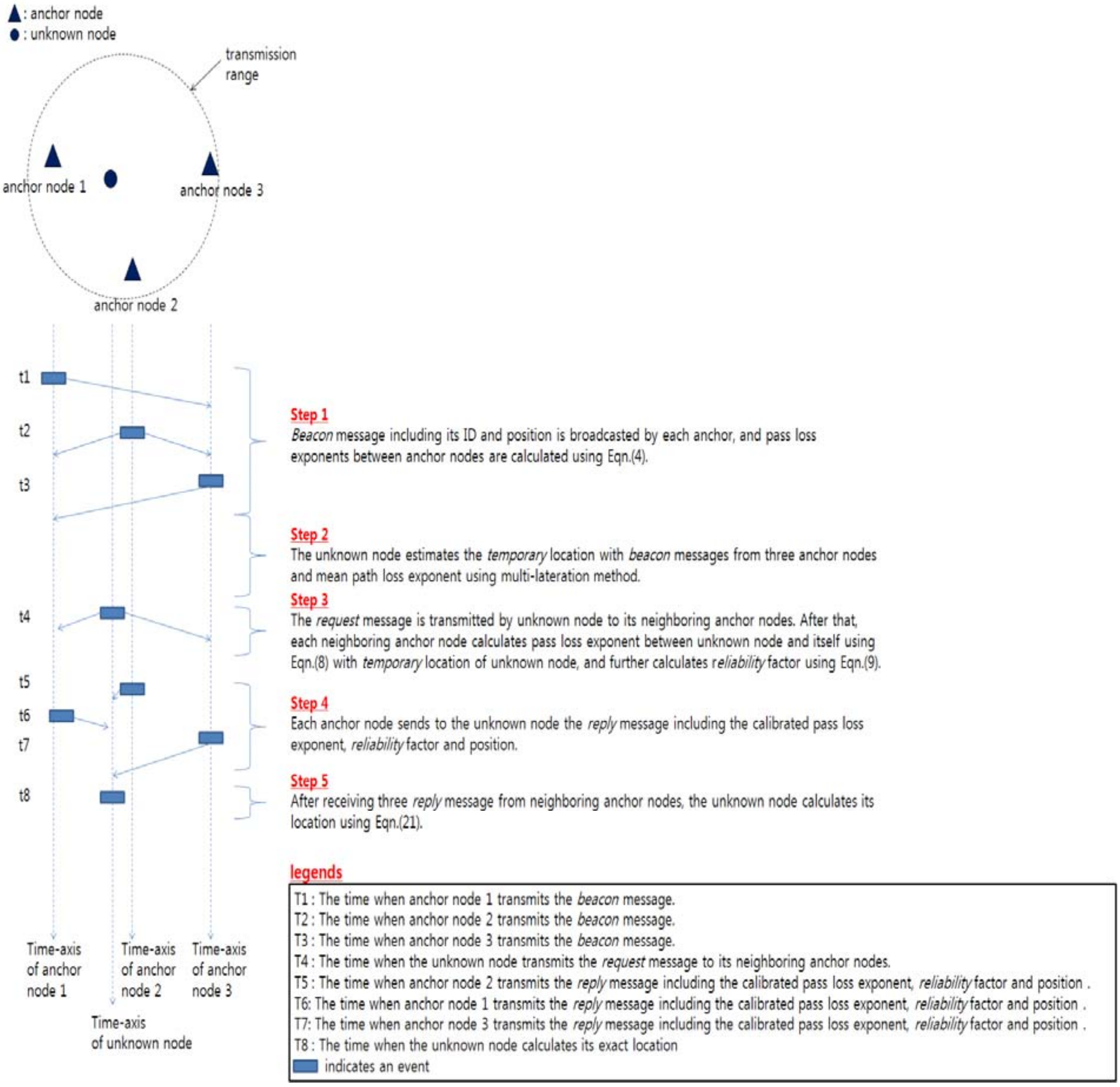
3. The Network Model

For a simple scenario, we suppose the network is on a two-dimensional planar area, so we only need to localize the location of unknown nodes in two-dimensional coordinates. We also assume that there are some anchors that know their locations because they are equipped with GPS or are deployed at known positions. There are also many unknown nodes or sensor nodes which need to be localized. Each node has the ability to acquire RSS. We also assume that the network comprises of N anchors (x_i,y_i) with i from 1 to N, and M unknown nodes requiring us to localize the locations (x_j,y_j) with j from 1 to M.

The proposed scheme is designed to be used in a one-hop localization system where the number of anchor nodes has to satisfy the requirements of the multi-lateration method. That is, there should be more than three anchor nodes in the transmission range of any unknown nodes. When the transmission range of the unknown nodes is given, the minimum density of the anchor nodes will be $3/\pi r_{transs}^2$ where r_{transs} is the transmission radius of the unknown nodes. This is mainly due to the fact that the proposed scheme is based on the multi-lateration method. The concept of the proposed scheme is how to improve the precision in measuring distance and using weighting matrix specified for the RSS method to improve the location detection. Because the path loss model depends on the power law of the path loss exponent, a small error in the path loss exponent will produce a significant error in distance measuring. Moreover, the path loss exponent depends on the space and time in which the localization process is realized. To combat these undesired characteristics, we propose a localization scheme that is capable of adapting to changes of the path loss exponent in wireless communication. This scheme uses a calibration technique to find the best temporal and spatial match for the path loss exponent around a node in order to measure distance during the localization process instead of using an average value that may result in considerable error. After a node has enough information from anchors including distances and locations, the multi-lateration method is applied to obtain the position. To resolve the problem of the multi-lateration method in order to minimize error and get the best location estimation, we suggest using the WLS method with the proposed weighting matrix. A detailed explanation of the proposed algorithm is presented in the next sections

4. The Proposed Scheme

In this section, we describe the steps of the proposed algorithm. As shown in **Fig. 1**, the proposed algorithm can be divided into five steps: In the first step, anchors periodically broadcast *beacon* messages containing their IDs and positions; ‘broadcast’ means on-hop broadcasting. That is, the *beacon* message of an anchor node will be sent to all nodes in its transmission range. When an anchor receives the *beacon* messages, it records the RSS values in order to calculate the path loss of the power values, and extracts the locations. Using the path loss value and the distance between any pair of anchors, the path loss exponent for that link can be found. The details of this step will be explained in subsection 4.1. In step 2, the unknown nodes also receive these *beacon* messages from anchors in their transmission range. In this step, an unknown node uses the path loss of the power values from the anchors and the mean path loss exponent to define distances and compute its *temporary* location, but this is imprecise. The details of this step will be explained in subsection 4.2. In step 3, to improve the precision of this location, an unknown node sends to the neighboring anchors a *request* message including its *temporary* location and ID. In step 4, once the anchor nodes receive the *request* message, they calculate the calibrated path loss exponent based on the *temporary* location of the unknown node and the path loss exponents between neighboring anchor nodes, and then they reply to the sensor node with the calibrated path loss exponent. The details of this step will be explained in subsection 4.3. In step 5, the unknown node calculates its location after receiving three *reply* message from the neighboring anchor nodes. The details of this step will be explained in subsection 4.4.



Step 1
Beacon message including its ID and position is broadcasted by each anchor, and pass loss exponents between anchor nodes are calculated using Eqn.(4).

Step 2
The unknown node estimates the *temporary* location with *beacon* messages from three anchor nodes and mean path loss exponent using multi-lateration method.

Step 3
The *request* message is transmitted by unknown node to its neighboring anchor nodes. After that, each neighboring anchor node calculates pass loss exponent between unknown node and itself using Eqn.(8) with *temporary* location of unknown node, and further calculates *reliability* factor using Eqn.(9).

Step 4
Each anchor node sends to the unknown node the *reply* message including the calibrated pass loss exponent, *reliability* factor and position.

Step 5
After receiving three *reply* message from neighboring anchor nodes, the unknown node calculates its location using Eqn.(21).

T1 : The time when anchor node 1 transmits the *beacon* message.
T2 : The time when anchor node 2 transmits the *beacon* message.
T3 : The time when anchor node 3 transmits the *beacon* message.
T4 : The time when the unknown node transmits the *request* message to its neighboring anchor nodes.
T5 : The time when anchor node 2 transmits the *reply* message including the calibrated pass loss exponent, *reliability* factor and position .
T6: The time when anchor node 1 transmits the *reply* message including the calibrated pass loss exponent, *reliability* factor and position .
T7: The time when anchor node 3 transmits the *reply* message including the calibrated pass loss exponent, *reliability* factor and position .
T8 : The time when the unknown node calculates its exact location
▬ indicates an event

Fig. 1. Steps of the proposed scheme

4.1. Angle and path loss exponent calculation between anchor nodes

Using simple geometric theory, we can determine the direction from sender to receiver based on their locations. In this method, we assume that the direction is implicitly oriented toward the x axis. Suppose the sender location and receiver location are (x_1,y_1) and (x_2,y_2) respectively.

At the receiver, the direction can be obtained by

$$\Phi = \begin{cases} \tan^{-1}\left(\dfrac{y_1 - y_2}{x_1 - x_2}\right)(mod\,2\pi), & x_1 \geq x_2 \\ \pi + \tan^{-1}\left(\dfrac{y_1 - y_2}{x_1 - x_2}\right), & x_1 < x_2 \end{cases} \tag{6}$$

where *Φ* is the direction formed by the sender sensor node to the receiver sensor node. Similarly, while anchors periodically broadcast *beacon* messages containing its ID and position, the directions from other anchors help the *central* anchor to divide its surrounding space into sectors where the *central anchor* denotes an anchor node which calculates the path loss exponents of the links between the unknown nodes, and any anchor node can play this role during calibration of the path loss exponent. As shown in **Fig. 2**, let us assume that anchor node 0 receives *beacon* messages from its neighboring anchor nodes, which means that anchor node 0 is in the transmission ranges of anchor node 1 to anchor node 5. Then, anchor node 0 can calculate the angle of arrival of its neighboring anchor nodes by using Eqn.(6) and the received *beacon* messages, and further calculate the path loss exponent of that direction using Eqn.(5), since it knows the log-scale distance and the path loss value between its neighboring anchors.

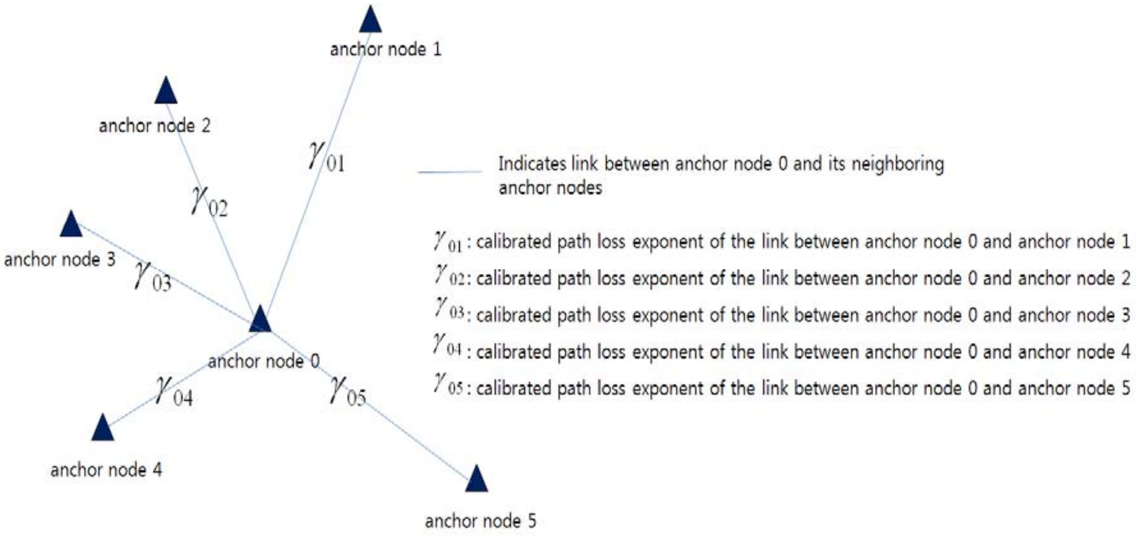


Fig. 2. Calculating the angles and path loss exponents between anchor nodes when anchor node 0 receives *beacon* messages from anchor node 1 to anchor node 5

4.2 Temporary location calculation by unknown nodes

While anchor nodes exchange *beacon* messages periodically, the unknown nodes also receive these *beacon* messages from anchors in their receiving range. In the case that an unknown node receives more than three *beacon* messages from its neighboring anchor nodes, it can calculate its *temporary* location using the multi-lateration method. However, the *temporary* location is imprecise, since the *mean* path loss exponent rather than the calibrated one is used to define the distances between the unknown node and its neighboring anchor nodes.

4.3 Request messages and path loss exponent calibration

After obtaining the *temporary* location, the unknown node sends to the anchors the *request message* including its *temporary* location and ID, in order to improve the precision of the location. Once an anchor receives a request message from an unknown node, it checks the direction by using the *temporary* location of the unknown node and Eqn.(6). After that, the best fitted path loss exponent or calibrated path loss exponent is found by direction cooperation with the path loss values and the distances of the pair of anchors forming the sector. This concept is called *direction calibration*. **Fig. 3** shows an example of *direction calibration.* As showed in **Fig. 3 (a)**, we initially consider the case that an unknown node is in the sector formed by anchor nodes 0, 1 and 5. That is, the anchor node 0 has received a *request message* from the unknown node and has checked the direction by using the *temporary* location of the unknown node and Eqn.(6). In order to obtain the calibrated path loss of the link to the unknown node, in this case the anchor node 0 utilizes two points (PL_{01},D_{01}) and (PL_{05},D_{05}) which represent the data from the two anchor nodes 1 and 5, where PL_{01} and D_{01} are the path loss and the log-scale distance of the link between anchor node 0 and anchor node 1 respectively, and PL_{05} and D_{05} are the path loss and the log-scale distance of the link between anchor node 0 and anchor node 5, respectively. From these points, we have two straight lines with slopes γ_{01} and γ_{05}. Now we need to find a straight line with slope γ according to the direction from the unknown node, based on the condition that the deviation of the sum of squares from the measured path loss points about this line is minimized. The desired value of the path loss exponent for the unknown node, γ_{0U} is calculated by,

$$\gamma_{0U} = \frac{PL_{01}D_{01}\phi_{U5} + PL_{05}D_{05}\phi_{U1}}{D_{01}{}^{2}\phi_{U5} + D_{05}{}^{2}\phi_{U1}} \tag{7}$$

where ϕ_{U1} and ϕ_{U5} are the angles from the unknown node's direction to anchor node 0 and anchor node 5 that form the section.

However, it is noteworthy that any anchor node can be a central node, for example anchor node 0.

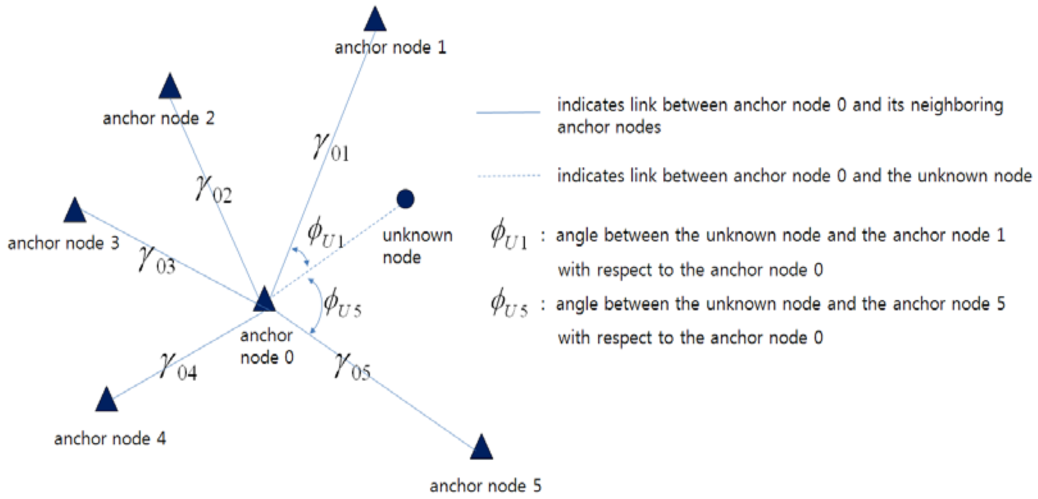


Fig. 3 (a). Calibrating the path loss exponent of an unknown node at anchor node 0 when the unknown node is not extremely near to any neighboring node

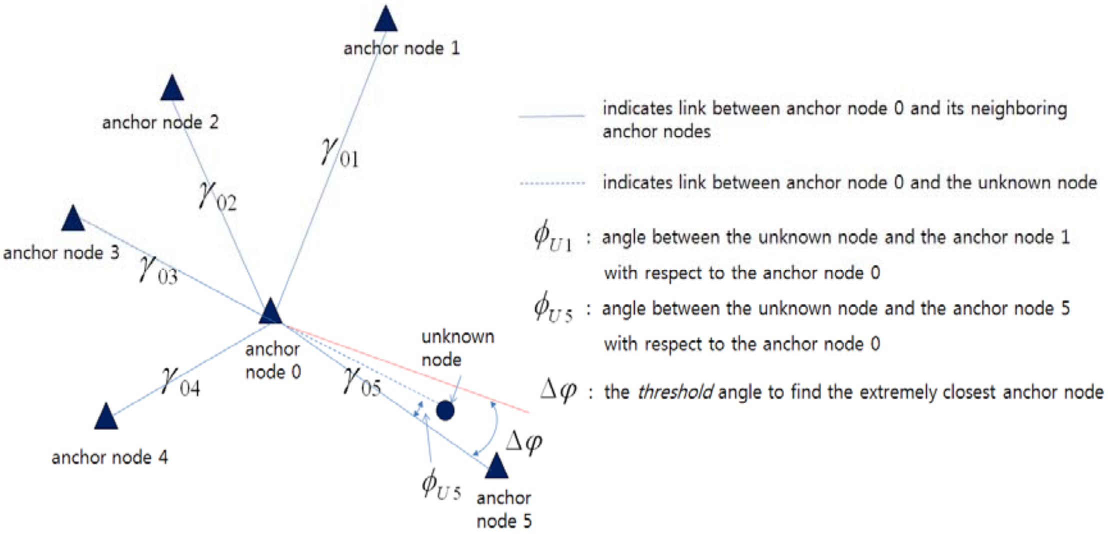


Fig. 3 (b). Calibrating the path loss exponent of an unknown node at anchor node 0 when the unknown node is extremely near to neighboring anchor node 5

Secondly, let us consider the case that an unknown node's direction is very near to an anchor node. In this case, the best calibrated parameter for this unknown node will be the path loss exponent from the anchor. To define an extremely close anchor node, in this paper we introduce the parameter $\Delta\varphi$, *the threshold angle*, which is decided by the system operator. When the angle between an unknown node and the closest anchor is less than $\Delta\varphi$, the calibrated path loss exponent of the unknown node will be that of the closest anchor. **Fig. 3 (b)** shows an example of calibrating the path loss exponent of an unknown node at anchor node 0 when the unknown node is extremely near to a neighboring node. In this case, the best calibrated path loss exponent for the unknown node will be ϕ_{U5}. The relationship between the parameter $\Delta\varphi$ and the localization and measuring distance error in our simulation model will be shown in **Fig. 4 (b)**.

In summary, the calibrated path loss exponent of an unknown node at any anchor node is given as following the function:

$$\gamma_u = \begin{cases} \gamma_\alpha & \beta < \Delta\varphi \\ \dfrac{PL_1 D_1 \phi_1 + PL_2 D_2 \phi_2}{\left(D_1^2 \phi_1 + D_2^2 \phi_2\right)} & \beta \geq \Delta\varphi \end{cases} \tag{8}$$

where β is the angle between the unknown node and the closest anchor and γ_α is the path loss exponent of the closest anchor. The two points (PL_1,D_1) and (PL_2,D_2) represent the data from a pair of anchor nodes forming a sector, and ϕ_1 and ϕ_2 are the angles between the unknown node and anchor nodes forming a sector.

Although we have used *direction calibration* for the path loss exponent, it is not very precise when just a few anchors surround a central anchor. Subsequently, large sectors in which the values of the path loss exponent change considerably do exist. These path loss exponent values are very different from the values obtained when two anchors form the sector. For this reason, we also set up a parameter called the *reliability* factor to indicate the reliability level of the calibrated path loss exponent that anchors transmit to the unknown nodes. Given the *temporary* location of an unknown node, the anchor node can easily find the path loss exponent by considering this unknown node as a *temporary* anchor and using Eqn.(5). This path loss exponent is called a *temporary exponent* γ_t, and then the *reliability* factor is defined as given by

$$w = |\gamma_u - \gamma_t| \tag{9}$$

The calibrated path loss exponent will help the unknown nodes to measure distances to anchor nodes, and the corresponding *reliability* factor indicates the reliability level of these distances. The *reliability* factor contributes to the location detection process when it is used in the WLS method described in the next sub-section.

Lastly, anchor nodes which received a *request* message will send a *reply* message including the calibrated path loss exponent and *reliability* factor to an unknown node.

4. 4 Location calculation with reliability factors

When an unknown node receives at least three *reply* messages including the calibrated path loss exponent and *reliability* factor from neighboring anchor nodes, finally it can calculate the precise location based on multi-lateration with WLS. Before discussing our application of multi-lateration with the WLS method to find the location of an unknown node, we review some criteria that are important for location detection. Numerous methods [17][18][19][20] for solving an over-determined problem exist in multi-lateration. In our proposed algorithm, distributed computing is implemented at each unknown node. We have to consider the complexity, precision and convergence of each method and the tradeoff between the criteria to ensure the capability of distributed implementation at the sensor node under real-time working conditions and the energy constraints in WSNs.

Suppose that there are $n \geq 3$ anchor nodes with known locations (x_i,y_i) for $i=1,\ldots,n$ in the transmission ranges of an unknown node aiming to locate its location, and that the exact location of the unknown node is (x,y). The Euclidean distance from the unknown node to a given anchor node is expressed as

$$d_i = \sqrt{(x-x_i)^2 + (y-y_i)^2}, \tag{10}$$

During the measuring distance phase, we obtained the estimated distance r_i, and this value can also be modeled as

$$r_i = d_i + \varepsilon, \tag{11}$$

where ε is the range error, which arises in the distance measuring phase.
If the range error ε of the Euclidean distance is not accounted for, Eqn.(11) becomes

$$r_i = d_i = \sqrt{(x-x_i)^2 + (y-y_i)^2}, \tag{12}$$

Squaring both sides of Eqn.(12) yields

$$r_i^2 = x_i^2 + y_i^2 - 2x_i x - 2y_i y + x^2 + y^2, \tag{13}$$

Set $\Psi_i = x_i^2 + y_i^2$, and $\Upsilon = x^2 + y^2$, and Eqn. (13) becomes,

$$2x_i x + 2y_i y - \Upsilon = \Psi_i - r_i^2, \tag{14}$$

Eqn. (14) is expressed in matrix form as

$$K\theta = \mathrm{P}, \tag{15}$$

where

$$\mathrm{K} = \begin{bmatrix} 2x_1 & 2y_1 & -1 \\ & \cdots & \\ 2x_n & 2y_n & -1 \end{bmatrix}, \mathrm{P} = \begin{bmatrix} \Psi_1 - r_1^2 \\ \cdots \\ \Psi_n - r_n^2 \end{bmatrix}, \quad \theta = \begin{bmatrix} x & y & \Upsilon \end{bmatrix}^{\mathrm{T}},$$

For a given range error ε, we can express Eqn. (15) as

$$\xi = \mathrm{P} - \mathrm{K}\theta, \tag{16}$$

The least squares (LS) estimation method is used to minimize the object function:

$$\Lambda = \xi^{\mathrm{T}}\xi = (\mathrm{P} - \mathrm{K}\theta)^{\mathrm{T}}(\mathrm{P} - \mathrm{K}\theta), \tag{17}$$

The solution $\hat{\theta}_{LS}$ satisfying Eqn.(17) is

$$\hat{\theta}_{LS} = \left(\mathrm{K}^{\mathrm{T}}\mathrm{K}\right)^{-1}\mathrm{K}^{\mathrm{T}}\mathrm{P}, \tag{18}$$

To improve performance, we can add a weighting matrix ***H*** to the object function expressed by Eqn. (17) and it becomes

$$\Lambda = \xi^{\mathrm{T}}\xi = (\mathrm{P} - \mathrm{K}\theta)^{\mathrm{T}}\mathrm{H}(\mathrm{P} - \mathrm{K}\theta), \tag{20}$$

The solution to minimize Eqn. (20) is

$$\hat{\theta}_{WLS} = \left(\mathrm{K}^{\mathrm{T}}\mathrm{HK}\right)^{-1}\mathrm{K}^{\mathrm{T}}\mathrm{HP}, \tag{21}$$

where ***H*** is an n×n symmetric and nonsingular weighting matrix.

In the RSS-based method, when an anchor node is far away from an unknown node, the estimated distance is less reliable, because the path loss value and the distance are related by an exponential relationship and the larger path loss value results in a larger distance error than the smaller path loss value. Moreover, the i^{th} equation according to estimated distance r_i containing a large distance is less trustworthy and results in considerable error in estimating θ. To minimize this problem, the RSS weighting matrix ***H*** is conventionally chosen as $\mathrm{H} = \mathrm{B}\Delta\mathrm{B}$ [7], where $\mathrm{B} = \mathrm{diag}\,(1/r_1,\ldots,1/r_n)$, $\Delta = \mathrm{diag}\,(1/\sigma_1^2,\ldots,1/\sigma_n^2)$ and $\boldsymbol{\sigma_i^2}$ is the variance of errors in measuring distance process $\boldsymbol{r_i}$ for $i=1,\ldots,n$.

The contribution of our scheme is using WLS with the new proposed weighting matrix for which the elements are determined via Eqn.(9) in subsection 4.3. The *reliability* factors express the reliable level of distances and subsequently they represent the error level in equation i with estimated distance $\boldsymbol{r_i}$. Now we use this parameter in cooperation with the RSS weighting matrix to find the solution. The WLS now has the form

$$\hat{\theta}_{WLS} = \left(\mathrm{K}^{\mathrm{T}}\mathrm{MK}\right)^{-1}\mathrm{K}^{\mathrm{T}}\mathrm{MP}, \tag{22}$$

and

$$\mathbf{M} = \mathbf{H}.\mathbf{W}, \tag{23}$$

where ***W*** is a diagonal matrix of *reliability* factors, that is $\boldsymbol{W} = \mathrm{diag}\,(1/w_1,1/w_2,\ldots,1/w_n)$, and w_i is the *reliability* factor of the i^{th} anchor node.

Using an RSS weighting matrix and *reliability* factors in *direction calibration*, the WLS method focuses on the sensitivity in estimating distance to obtain the location of a sensor node. The proposed weighting matrix is much improved in terms of the precision in the multi-lateration method for finding the location. It is also simple and easy to implement in WSNs under operating constraints.

5. Simulation Results

A computer simulation has been conducted to evaluate the performance of the proposed algorithm. We utilize *Matlab* to simulate the network scenario and determine the localization results. We also have set up a simulation model in which the value path loss exponent is changed around each sensor node. To emulate a real environment, we have partitioned the nodes' surroundings into six unequal sections with angles ranging from 30^0 to 90^0. The path loss exponent value of each section is randomly created with a maximum deviation called the *delta.* This means that the values of the path loss exponent belong to section [*mean–delta*: *mean+delta*] where the *mean* represents the mean value. The path loss exponent also changes according to the environment in which the network is setup; in this simulation, we used an example case with a mean equal to 4. We deployed a network comprising 25 anchors and 50 unknown nodes distributed in a 100 x 100 meter square, as shown in **Fig. 4 (a)**. To ensure that each unknown node is able to localize its position at a one-hop distance, the minimum transmission range in this network is set to *30.23m* so that in every case there are at least three anchor nodes around an unknown node. In most simulation cases, the variance of the Gaussian white noise process is 1dB; the transmission range and *delta* are set to 32 and 0.3, respectively; the number of samples is 20 and each simulation result is implemented with 100 independent run times.

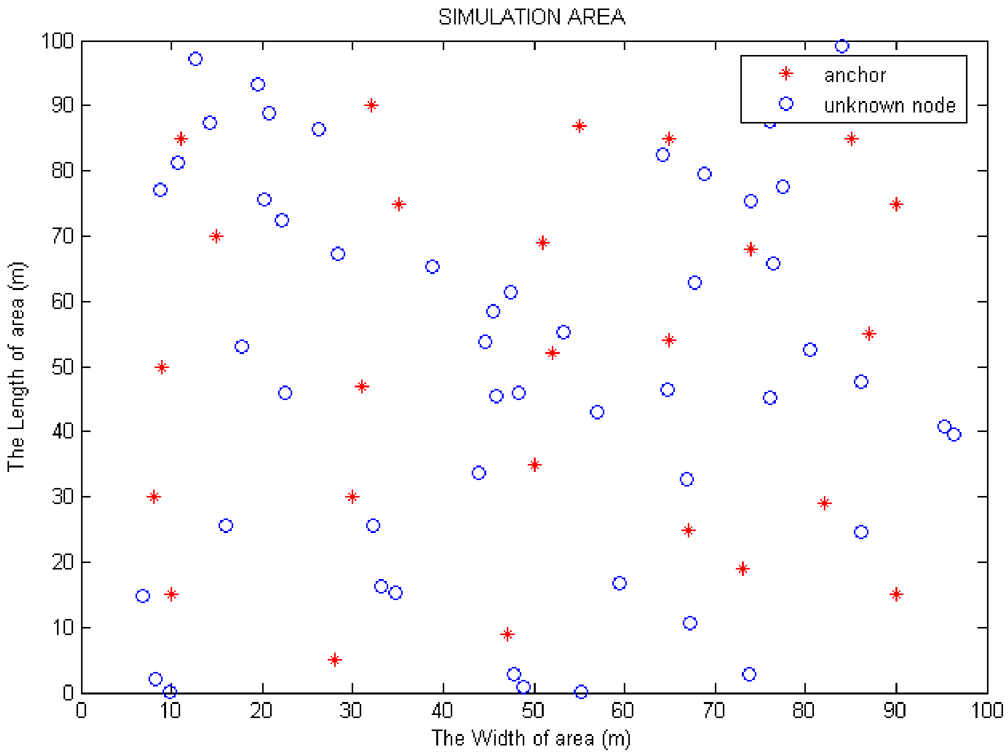


Fig. 4 (a). The simulation area

To demonstrate the performance of our scheme with respect to precision in localization, we have compared our proposed scheme, *direction calibration and WLS with reliability* factors *and RSS weighting matrix,* with the following other schemes:

- Maximum likelihood (ML) calibration; Uses all path loss exponents from in-range anchors.
- The mean (MEAN) calibration; the mean value is 4.
- The proposed *direction calibration* method without the *reliability* factors (No-RF).

- The calibration scheme presented in [14] characterizes every sector by only one path loss exponent (SECTOR).

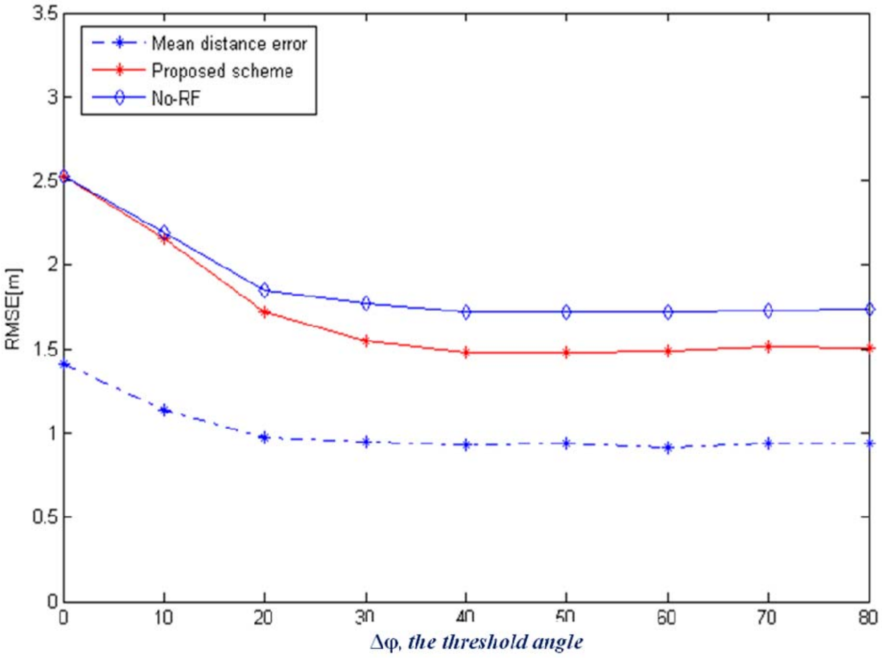


Fig. 4 (b). The localization errors according to Δφ, *the threshold angle*

In **Fig. 4 (b)**, the dot-dash line shows the mean distance errors, while the other lines show the localization errors of the proposed scheme and No-RF according to changes of Δφ, *the threshold angle*. When angle Δφ is more than 20^0, the error does not change much. Subsequently, we have chosen Δφ to be 40^0, because the proposed scheme gains the least error at this value, and we also set this value in other simulation cases for *direction calibration*.

Fig. 5 (a) shows the error in measuring distances with changes of *delta*, the maximum deviation of the path loss exponent. The *direction calibration* method proves its performance compared with other methods, especially compared with the SECTOR calibration method proposed in [14]. Moreover, in **Fig. 5 (b)**, we can see that when the *reliability* factors and RSS weighting matrix are used in WLS, the proposed scheme much improves the precision compared with the SECTOR calibration method and the other schemes. At high values of *delta* such as 0.4 and 0.5, the proposed scheme has fewest errors at 2.03 m and 2.58 m, respectively, whilst the SECTOR calibration scheme had worse values, namely 3.23m and 4.05m, respectively.

The Gaussian white noise process characterizes thermal noise in the received signal strength while *delta* represents obstructions and terrain where the WSN works. In our model, the main cause of error is *delta* and Gaussian noise has less effect if a higher sampling method is applied. **Fig. 6 (a)** proves that Gaussian noise has little impact on our model. Even when the variance of Gaussian noise changes significantly, the variation in location error is slight. When we increase the transmission range, the unknown nodes can connect to more anchors, which may improve localization performance. **Fig. 6 (b)** shows the mean localization error as a function of the increase in transmission range. We have tested a simulation with transmission ranging from 31 m to 38 m. **Fig. 6 (b)** shows that the localization error decreases as the transmission range increases. That is, performance of the proposed scheme improves as the number of anchor nodes in the transmission range of the unknown nodes increases. It is also observed that *direction calibration* with *reliability* factors provides the best performance among the other schemes considered.

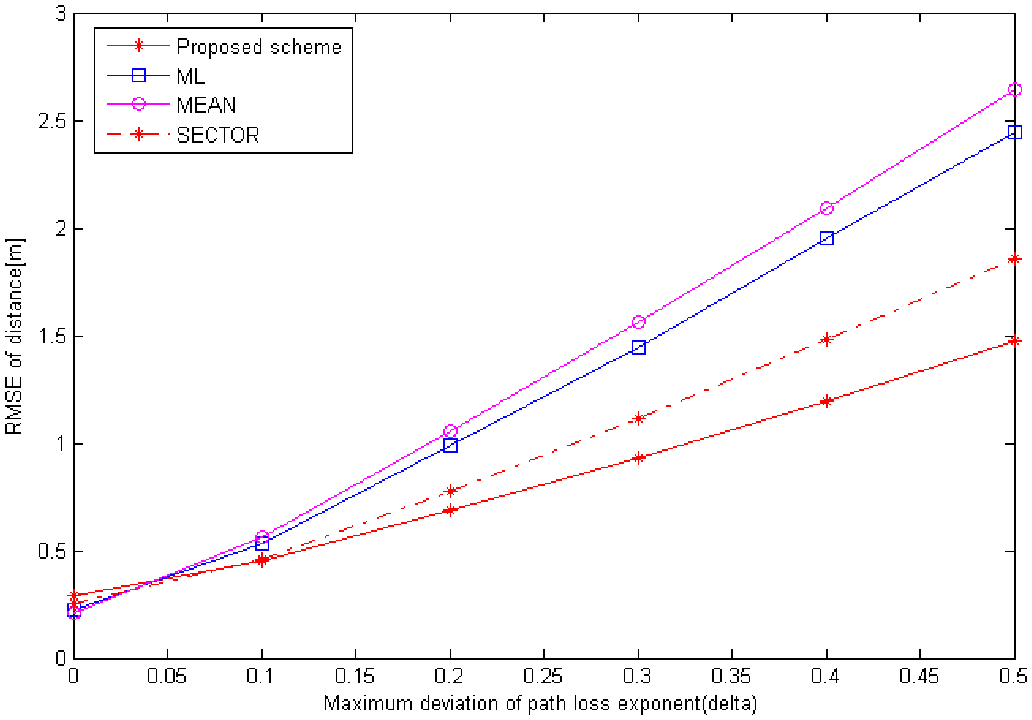


Fig. 5 (a). The distance errors according to values of *delta*

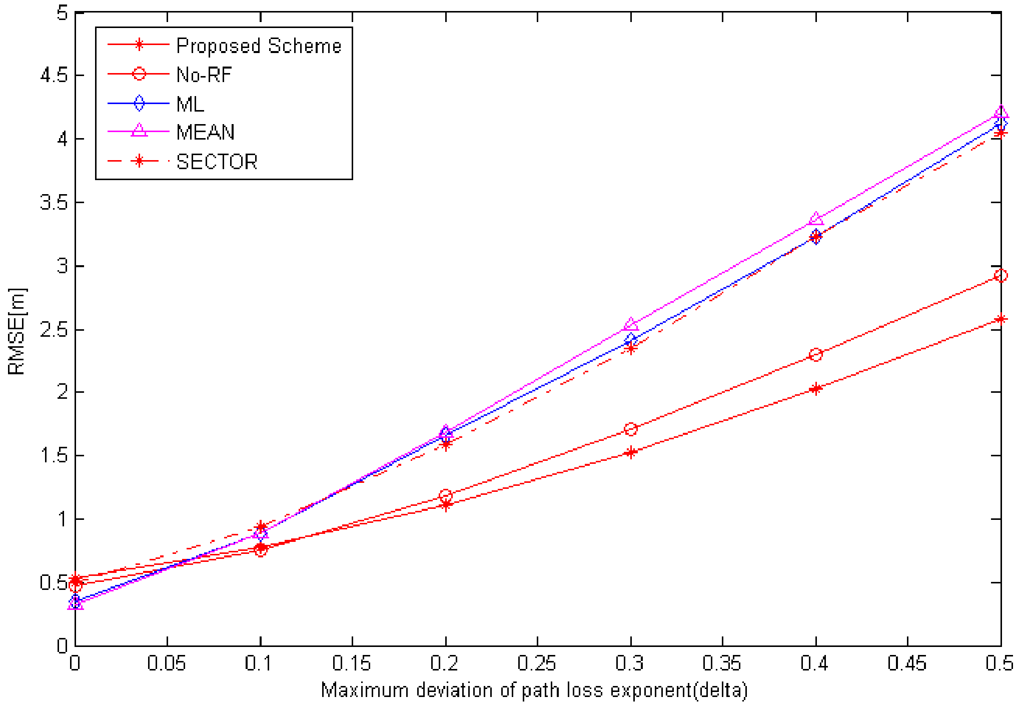
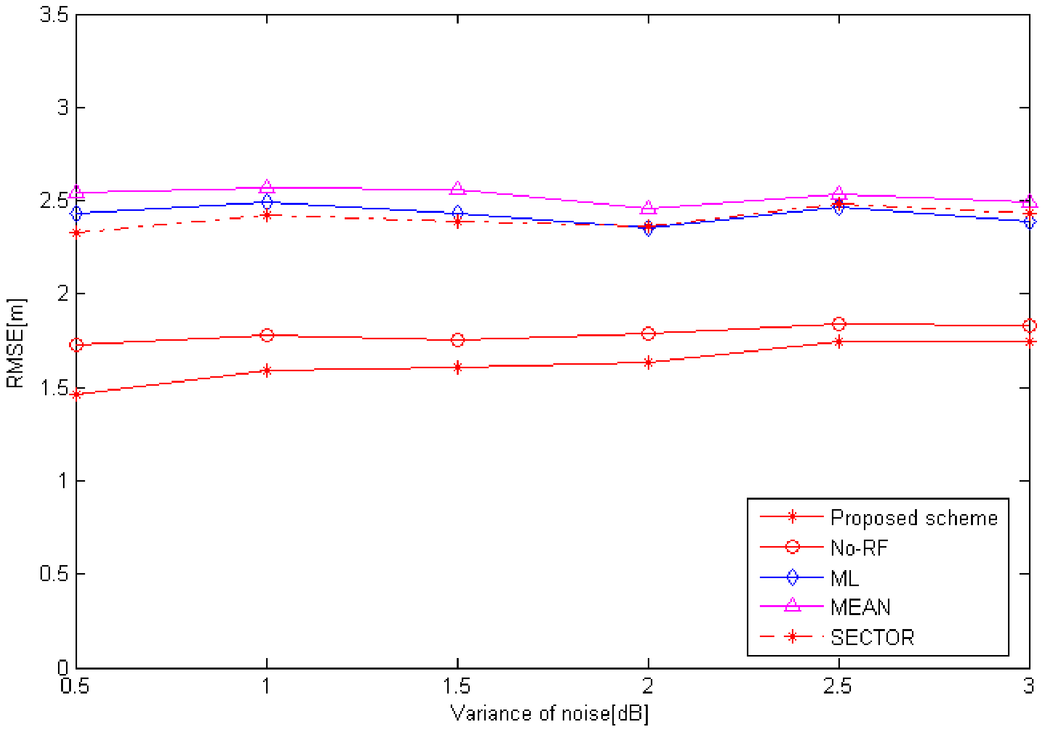


Fig. 5 (b). The localization errors according to values of *delta*



.

Fig. 6 (a). Localization errors according to variance in Gaussian noise

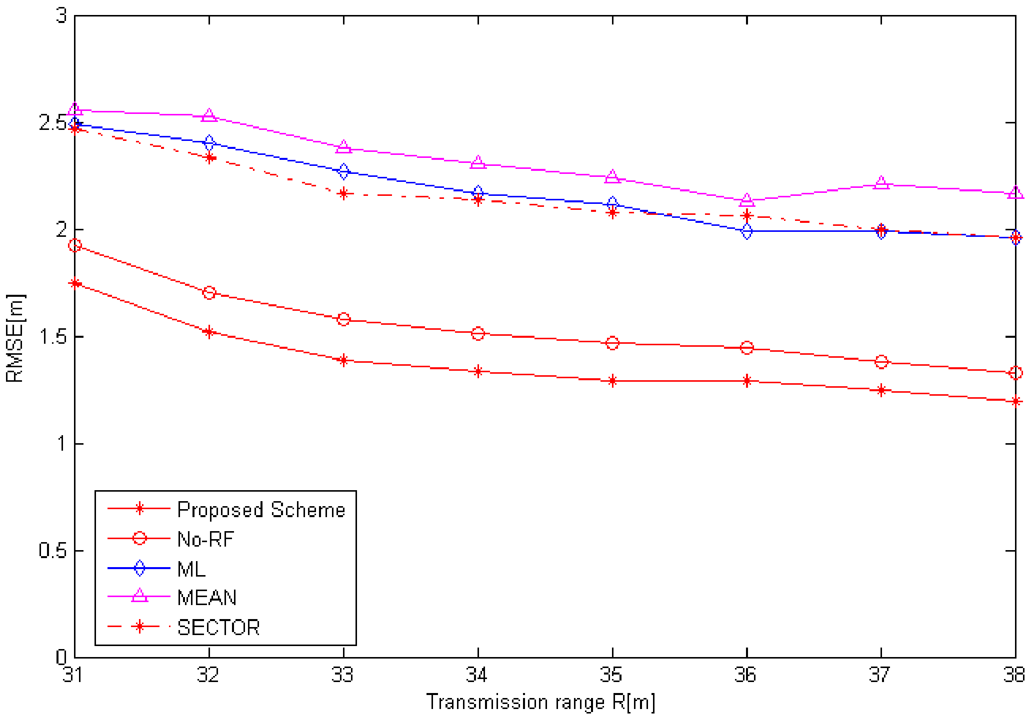


Fig. 6 (b). The relation between localization error and transmission range

6. Conclusions

Wireless sensor networks have numerous applications, and a localization function is one of the base functions of WSNs applications. One of the simplest methods to measure distance is the RSS method. RSS can be implemented easily in WSNs under operating constraints, but it can result in imprecise measurements because of environmental effects. *Direction calibration* was proposed to solve this problem, making the RSS method more suitable for localization in WSNs. Besides, the WLS method is not only simple, but also gives high precision in solving an over-determined problem. We proposed a localization scheme using two methods, and the simulation results proved the performance of this scheme.

References

[1] J. Blumenthal, R. Grossmann, F. Golatowski, D. Timmermann, “Weighted Centroid Localization in Zigbee-based Sensor Networks,” in *Proc. WISP 2007*, pp.1-6, Oct 2007.

[2] D. Niculescu, B. Nath, “DV Based Postitioning in Ad Hoc Networks,” *Telecom. Syst.* 2003, vol. *22*, pp. 267-280, 2003.

[3] T. He, C. Huang, B. M. Blum J. A. Stankovic, T. F. Abdelzaher, “Range-Free Localization Schemes in Large-Scale Sensor Networks,” in *Proc. MOBICOM*, San Diego, CA, USA, pp.81-95, Sep 2003.

[4] A. C. Chang, C. M. Chung, “Covariance Shaping Least-Squares Location Estimation Using TOA Measurements,” *IEICE Trans. Fundamentals of Electronics, Communications and Computer Sciences*, E90-A, pp.691-693, 2007.

[5] H. C. So, S. P. Hui, “Constrained Location Algorithm Using TDOA Measurements,” *IEICE Trans. Fundamentals of Electronics, Communications and Computer Sciences*, E86-A, pp.3291-3293, 2003.

[6] P. Rong, M. L. Sichitiu, “Angle of Arrival Localization for Wireless Sensor Networks,” in *Proc. SECON ‘06*, pp. 374-382, Sept 2006.

[7] K. W. Cheung, H. C. So, W.-K. Ma, Y. T. Chan, “Received Signal Strength based Mobile Positioning via Constrained Weighted Least Squares,” In *Proc. ICASSP '03*, pp. 137-140, Apr 2003.

[8] V. Erceg, L. J. Greenstein, S. Y. Tjandra, S. R. Parkoff, A. Gupta, B. Kulic, A. A. Julius, R. Bianchi, “An Empirically based Path Loss Model for Wireless Channels in Suburban Environments” *IEEE Journal on Selected Areas in Communications,* vol. 17, pp.1205-1211, 1997.

[9] D. De-Luca, F. Fiano, F. Mazzenga, C. Monti, S. Ridolfi, F. Vallone, “Outdoor Path Loss Models for IEEE 802.16 in Suburban and Campus-Like Environments,” in *Proc. ICC ’07,* pp. 4902-4906, Jun 2007.

[10] D. Lymberopoulos, Q. Lindsey, and A. Savvides, “An Empirical Characterization of Radio Signal Strength Variability in 3-D IEEE 802.15.4 Networks Using Monopole Antennas,” in *Proc. EWSN 2006, LNCS vol. 3868,* pp.326-341, 2006.

[11] X. Li, “Collaborative Localization with Received-Signal Strength in Wireless Sensor Networks,” *IEEE Trans. on Vehicular Technology*, vol. 56, pp.3807-3817, 2007.

[12] H. Shi, X. Li, Y. Shang, D. Ma, “Cramer-Rao Bound Analysis of Quantized RSSI Based Localization in Wireless Sensor Networks,” in *Proc. 11th International Conference on Parallel and Distributed Systems,* pp. 32-36, 2005.

[13] J. Kang, D. Kim, Y. Kim, “RSS Self-calibration Protocol for WSN Localization,” in *Proc. ISWPC '07*, pp.181-184*,* 2007.

[14] C. Tran-Xuan, E.-C. Kim I. Koo, “RSS Based Localization Scheme Using Angle-Referred Calibration in Wireless Sensor Networks,” in *Proc. ICIC’08*, pp. 1222-1233, 2008.

[15] T. Rappaport, “Wireless Communication: Principles and Practice,” 2nd Ed; Prentice-Hall 2002.

[16] M. Srbinovska, C. Gavrovski, V. Dimcev, “Localization Estimation System Using Measurement

of RSSI Based on Zigbee Standard," in *Proc. of the Conference on Electronics 2008,* pp. 45-50, 2008.

[17] K. W. Cheung, H. C. So W.-K. Ma, Y. T. Chan, "A Constrained Least Squares Approach to Mobile Positioning: Algorithms and Optimality," *EURASIP Journal on Applied Signal Processing* 2006, pp.1-23, 2006.

[18] W. Chan, H.C. So, "Accurate Sequential Weighted Least Squares Algorithm for Wireless Sensor Network Localization," in *Proc. 2006 European Signal Processing Conference,* Sept 2006.

[19] Y. C. Eldar, A. V. Oppenheim, "Covariance Shaping Least-Squares Estimation," *IEEE Trans. on Signal Processing*, vol. 51, pp.686-697, 2003.

[20] S. Zhang, L. Ren, J. Xiao, J. Tan, "A High Precision Localization Algorithm in Wireless Sensor Network," in *Proc. ICARCV'06*, Dec 2006.

Cong Tran-Xuan received the B.E. degree from Electrical Engineering, Ho Chi Minh City University of Technology in 2007 and the M.S. degree from the school of Electrical Engineering, University of Ulsan, South Korea in 2009, respectively. His research interests include data communication, telecommunication systems and wireless sensor networks. Now he is working for Ericsson as a transmission designer in Vietnam.

Insoo Koo received the B.E. degree from the Kon-Kuk University, Seoul, South Korea, in 1996, and received the M.S. and Ph.D. degrees from the Gwangju Institute of Science and Technology (GIST), Gwangju, South Korea, in 1998 and 2002, respectively. From 2002 to 2004, he was with Ultrafast Fiber-Optic Networks (UFON) research center in GIST, as a research professor. For one year from September 2003, he was a visiting scholar at Royal Institute of Science and Technology, Sweden. In 2005, he joined University of Ulsan, South Korea where he is now associate professor. His research interests include next generation wireless communication systems and wireless sensor networks.