International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 15 (2015) pp 35264-35271

A novel range-free localization algorithm based on optimal anchor placement and reliable anchor selection in wireless sensor network

Priya Dev Anand [1] **, Hyunjae Woo** [2] **and Chaewoo Lee** [3]
Department of Electrical and Computer Engineering, Ajou University
206 World cup ro Yeongtonggu Suwon Gyeonggido, 443-749, South Korea
priyadev@ajou.ac.kr [1] woo@ajou.ac.kr [2] cwlee@ajou.ac.kr [3]
Corresponding author: Chaewoo Lee (cwlee@ajou.ac.kr)

Abstract- In wireless sensor networks, an unknown node estimates the distance to the anchors, and then utilizes the estimated distance to compute its position by multilateration. The localization accuracy by multilateration depends on the distance estimation accuracy and the relative positions of anchors. Since the range-free scheme is based on the connectivity information such as hop count, the distance can always be estimated with error. Actually the unknown nodes can estimate its position accurately even with three reliable anchors. However when selecting the reliable anchors, each unknown node should also consider the relative positions. Hence we study the relationship between the localization accuracy by considering the distance estimation and relative positions of anchors. From the study we find that there are two conditions need to be satisfied to improve the localization accuracy. To increase the possibility of all unknown nodes to select the reliable anchors based on the two conditions, anchor node placement needs to be considered. Hence, we propose an optimal anchor placement algorithm and reliable anchor selection scheme to improve the localization accuracy. Simulation results show that the proposed method improves the localization performance better than the existing methods.

Keywords- Range-free localization, Optimal anchor placement algorithm, Reliable anchor selection scheme.

1. Introduction

Wireless sensor network is broadly used in the field of military surveillance, area monitoring, health care monitoring, forest fire detection etc. Identifying the location of the nodes in a WSN [1] is of great importance. Localization scheme mainly consists of two categories namely range-based scheme and range-free scheme [2]. Range-based scheme measures the distance between two nodes by considering the range or angle information such as time of arrival (ToA) [3], TDoA etc., but it requires additional hardware devices. Range-free scheme on the other hand utilizes the connectivity information (hop count between the nodes) to estimate the position of a node. It is cheaper and simpler than the range-based scheme because it does not require any additional hardware devices.

In range-free scheme, unknown node estimates its position by utilizing the anchor nodes which knows its position. Generally, most of the algorithms utilize the position of anchor, the hop count between the anchors, and the hop count between the unknown and the anchor node. In order to compute the location, each unknown node estimates its distance to the anchors and then utilizes the estimated distance to find its position by multilateration technique [4]. Hence, the localization accuracy by multilateration is affected by the distance estimation accuracy.

DV-Hop [5] is one of the well-known range-free localization algorithms, in which each unknown node estimates its distance to anchor nodes by multiplying the average hop size and the hop count. Here, the average hop size is calculated by utilizing all the anchors in the network. It may have a distance estimation error when an unknown node estimates the distance to the specific anchor node. Since the distance is obtained by multiplying the average hop size and the hop count, the distance estimation error increases in proportion to the hop count. Especially the distance estimation error becomes worse when the anchors are far from the unknown nodes or when the network irregularity is high.

DV-Hop exploits all anchors to estimate an unknown node's position. In this case, the localization error becomes large even if few incorrect estimated distances are used in localization by multilateration. In fact, the location of an unknown node can be computed accurately even with three reliable anchors. Generally, the localization accuracy can be improved, if the unknown node selects the three anchors which can give a well estimated distance and a good relative position. The localization error can be increased, if the unknown node improves the distance estimation accurately without considering the relative positions of anchors. For example, the unknown node may select the anchors which can improve the distance estimation but if the selected anchors are deployed together at one point, then the localization accuracy will be decreased. The localization error can be decreased if the unknown node selects the reliable anchors by considering the distance estimation accuracy and the relative positions of anchors.

Many algorithms [6] [7] [8] have been proposed, where each unknown node focus on selecting the reliable anchors by considering the distance estimation accuracy between the anchor and the unknown node. In [6], unknown node selects the anchors which are located nearby, such that the smaller the number of hops the more the distance estimation accuracy. In [7] [8], the unknown node selects the anchors whose shortest path is close to a straight line. If the unknown node selects the anchors by considering only the distance estimation accuracy, then the localization accuracy can be decreased. Therefore some authors [9] have proposed a method to select the anchors by considering the relative positions. In [9], each unknown node selects the reliable anchors which form a large triangle. In some study [10], each unknown node selects the reliable anchors by considering both the distance estimation and relative positions. In [10], each unknown node selects the nearby anchors only if it is inside the triangle formed by three anchors.

Hence, to improve the localization accuracy by allowing all unknown node to select the reliable anchors, the anchor node placement need to be considered. There have been many range-based algorithms regarding the placement of anchor nodes. In [11] [12], by assuming the distance estimation error between anchor and unknown node to have a Gaussian noise, they prove that the regular placement of anchors can minimize the variance of error. However, it is difficult to apply the anchor placement algorithm in range-free scheme because the distance between the unknown node and the anchor node can be multi-hop but in range-based scheme the distance between the unknown node and the anchor node is always 1-hop distant. Because of this reason, it is difficult to deal with the placement of anchor nodes like [11] [12] in range-free scheme.

In this paper, we study the relationship between the localization accuracy obtained by considering the distance estimation and relative positions of anchors. As a result, we find two conditions that can minimize the localization error by multilateration. In order to improve the localization accuracy of the entire network, all unknown nodes should select the reliable anchors based on the two conditions. Hence the anchor node placement needs to be studied in the range-free scheme. Because if the anchor node placement is random, then either it is spread throughout the network or deployed at one point. In that case the number of unknown nodes selecting the reliable anchors based on the conditions will be less. In order to avoid this, we place anchor nodes optimally, such that the number of unknown nodes which can select the reliable anchors based on the distance estimation and the relative positions will be high. Hence we propose an optimal anchor placement algorithm and a reliable anchor selection scheme.

The rest of this paper is organized as follows. Section 2 presents a survey of related works, Section 3 presents the optimal anchor placement algorithm and the reliable anchor selection scheme, and Section 4 presents the simulation results. Finally a conclusion is drawn in Section 5.

2. Related Work

Here, we discuss some terms to understand further sections. The two categories of sensor nodes are: U unknown nodes and A anchors. Let $\mathbf{l}_i = [x_i, y_i]^T$ be the real location of sensor node i, and $\hat{\mathbf{l}}_i$ be the estimated location of the sensor node i. $d_{ij} = \|\mathbf{l}_i - \mathbf{l}_j\|$ is the original distance between the sensor nodes i and j, $\hat{d}_{ij}$ be the estimated value of d_{ij}, and $\|\cdot\|$ is the 2D Euclidean norm. The minimum hop count between the sensor nodes i and j is h_{ij} and Ω_A denotes the set of all anchors in network.

In this section, we discuss some of the related works in detail. In DV-Hop, initially all sensor nodes obtain its minimum hop count information from all the anchors through flooding [5]. Then, each anchor calculates and broadcasts its average hop size by utilizing the known distance between all the anchor nodes in the network with its hop count. The average per hop size of anchor i is calculated by,

$$s_i = \frac{\sum_{j \neq i, j \Omega_A} d_{ij}}{\sum_{j \neq i, j \Omega_A} h_{ij}} \quad (1)$$

Then, each unknown node estimates the distance to every anchor by multiplying the average hop size with the corresponding hop count. For example, the unknown node u estimates the distance to the anchor i by,

$$\hat{d}_{ui} = s_i \times h_{ui} \quad (2)$$

Finally, unknown node calculates its position by multilateration. The main drawback in DV-Hop method is, each unknown node estimates its distance to all the anchors in the network which is then used to estimate the position by multilateration. Basically, it is difficult to estimate the distance accurately to all anchors in the range-free scheme. Thus the localization error can be increased, if the unknown node computes the position with incorrect estimated distance.

Actually the location of an unknown node can be estimated even with help of three reliable anchors. The localization accuracy is affected by the distance estimation and relative positions of anchors. Recently, many algorithms [7] [8] focus on selecting the reliable anchors by considering the distance estimation accuracy. In [7] [8], each unknown node selects the reliable anchors whose shortest path is not curved.

In [7], each unknown node selects the reliable anchors that have an undistorted shortest path with the help of ratio between the hop count and distance estimation error. Initially the unknown node selects one nearest anchor which has minimum hop count from itself. Then the nearest anchor selects the set of anchors which gives smaller distance estimation error from itself. The shortest path from the unknown node to the set of anchors selected by the nearest anchors may be curved. To avoid this, the unknown node selects the set of reliable anchors whose shortest path is not curved based on the maximum number of hops. Finally unknown node estimates the distance only to the reliable anchors to estimate its position by multilateration. If the unknown node selects the nearest anchor which has large hop count, then the set of anchors selected by the nearest anchors to the unknown node will be large, which may result in curved shortest path.

In [8], each unknown node selects the reliable anchors that have an undistorted shortest path with the help of average hop size information. Basically, the shortest path will be close to a straight line if the average hop size is large compared to the curved path. The anchor pair estimates its average hop size with unknown node in its shortest hop path. Then the unknown node selects the anchor pair which has larger average hop size to utilize the less detoured shortest path. The unknown node should be in the intersection area of anchor pair with estimated distance as radius. Then the distance error from the curved path can be reduced by assuming the unknown node to be in a line where the points of intersection of two circles meet. In this method, unknown nodes cannot select the reliable anchor subset when the node density is low. In that case the unknown node should select the anchor pair which has small average hop size to estimate the position.

Some study discuss about selecting the reliable anchors by considering the relative positions of anchors. In [9], each unknown node selects the three reliable anchors with help of beacons received from anchors at different power levels. The anchors nodes transmit its beacon signal at different power levels and the unknown node which listen the beacon signals determines in which annular ring it is located. The unknown node which receives the beacon signal from the anchors records its position information, its power level and the estimated distance that the signal can travel. Based on the beacon signals from different power level, unknown node determines in which ring it is located within each anchor. The position of an unknown node can be estimated in the centre of intersection of the annular rings of each anchor. The unknown node selects the three farthest anchors that form a largest triangle to reduce the intersection area. This method completely depends on the number of anchor nodes deployed in the network. It shows large localization error even if the anchor deployment is low and if the transmission range is large. Because by increasing the transmission range, the intersection area where the unknown node can be located will be large which results in large localization error.

The algorithm [10], selects the reliable anchors by considering both the distance estimation and the relative positions. In [10], each unknown node selects the reliable anchor combination by checking whether it is inside a triangle formed by three anchor nodes. If there are many three anchor node combination satisfying this condition, then the unknown node selects the one combination which provides the minimum area. This method improves the localization accuracy by selecting the anchors which has short distance from itself and also by considering the relative positions of anchors. But it is not possible for all unknown nodes to select the reliable anchors based on the above conditions.

To allow all unknown nodes to select the reliable anchors which improve the localization accuracy, anchor node placement needs to be considered. There are many studies [13] [14] [15] [16] [17] [18] which deliberate the various shapes of anchor node placement in range-based localization scheme. In [13], uniform anchor node placement, in [17] [18], equilateral triangle placement of anchor nodes has been discussed.

Authors of [13] have proposed to place the anchor nodes in uniform (grid) pattern to track the mobile unknown nodes in the network. The mobile unknown node first sends it hello message when it tries to enter the network to know which anchor it should attach and communicate. The anchor node which receives message from unknown nodes selects top four largest RSSI value to estimate the location. Then by converting the RSSI to distance each unknown node estimates its position using maximum likelihood.

In [14][15][16] various anchor placement patterns are discussed in terms of coverage and connectivity and shows that the triangular pattern is reliable compared to other patterns. Based on this, authors in [17] have proposed an iterative multilateral localization algorithm with an optimal anchor placement scheme. In this method the anchors are grouped in an equilateral triangle shape and placed in the sensing field, the unknown node which can communicate directly with these grouped anchors will estimate its position and sends the estimated position to other neighbouring nodes until all unknown node estimate its position in the network.

Some studies have made the three mobile anchor nodes to move in an equilateral triangle pattern to improve the localization accuracy. In [18], the mobile anchor nodes are allowed to move in a sensing area by placing the anchors in an equilateral triangle shape. Then the mobile anchor node is allowed to move until it covers the whole network in an equilateral triangle pattern. The unknown node utilizes the mobile anchors message to find its position by trilateration method. Thus many anchor placement algorithm had been discussed only in range-based localization scheme. Because anchor placement in range-based scheme is not so difficult, the unknown node and the anchor nodes can communicate directly but the direct communication is not always possible in range-free scheme.

Thus in this paper, we study the relationship between the localization accuracy by taking distance estimation and relative positions into account. From the study we find that, to minimize the localization error, there are two conditions need to be satisfied. To allow all unknown nodes to select the reliable anchors based on the above two conditions, anchor node placement needs to be considered. Hence we propose an optimal anchor node placement algorithm and reliable anchor selection scheme in range-free scheme.

3. Proposed Algorithm

3.1. Relationship between the localization accuracy by considering the distance estimation and relative positions

Fig.1 shows the difference in the localization accuracy by varying the relative positions of anchors. As shown Fig.1, we assume that the three anchor nodes have an identical transmission range R and are located 1 hop from the unknown node. In this case, the real position of an unknown node should be located within the intersection area of anchors transmission range. And also if the estimated distances to the three anchors are same, then the position of an unknown node will be in the centre of the intersection area. Hence, the maximum localization error is shown in a red line. Here, the black shaded triangle represents the anchor node and the red dot represents the estimated position of an unknown node.

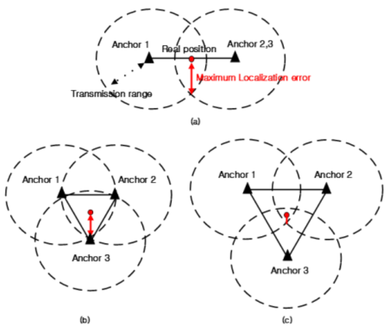

Fig 1.Relationship between the localization accuracy by considering the distance estimation and relative position of anchors

Fig.1 (a) and Fig.1 (b) compares the maximum localization error with respect to the shape formed by three anchor nodes. As shown in these figures, the localization error increases when three anchor are placed in a straight line. The localization error decreases when three anchors are placed in a triangle form.Fig.1 (b) and Fig.1 (c) compares the maximum localization error with respect to the area of triangle formed by three anchor nodes. As shown in these figures, the localization error increases when the area of a triangle formed by three anchor nodes is small. The localization error decreases when the area of a triangle formed by three anchor nodes is large. Thus from this analysis it is proven that the shape and the area formed by three anchors plays a major role in localization accuracy by multilateration. Hence, we define two theorems, which minimize the localization error by considering the shape and the area formed by anchors.

Theorem 1:
Let us assume three anchor nodes which have an identical transmission range R and are 1 hop from the unknown node. The estimated distance from an unknown node to three anchor nodes are also same. The localization error is minimized, when the shape formed by three anchor nodes is an equilateral triangle.
Proof. This theorem has been already well explained in [11] [12]. So we did not discuss about this in detail.

Theorem 2:
Let us assume three anchor nodes which have an identical transmission range R and are 1 hop from the unknown node. The localization error is minimized, when the area formed by three anchor nodes is maximum.

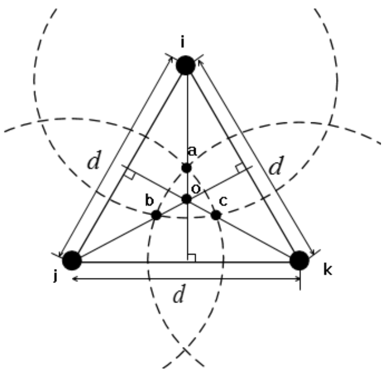

Fig 2. Illustrates the proof for theorem 2

Proof. If we assume three anchor nodes i, j and, k are 1 hop from the unknown node and form an equilateral triangle as shown in Fig.2, the position of an unknown node will be estimated at point o which is at the center of a triangle. The location error will be d_{ao}, d_{bo}, d_{co} which are all same. Then the maximum localization error E can be calculated as,

$$E = \sqrt{R^2 - \left(\frac{d}{2}\right)^2} - \left(\frac{\sqrt{3}}{6}\right) d \quad (3)$$

The area of a triangle reaches its maximum when the points a, b and c gathered at point o.Here, we can calculate the area of an equilateral triangle as $(\sqrt{3}/4)\, d^2$ and it reaches its maximum when d is $\sqrt{3}\, R$ in equation (3). That is the error E will be minimized to zero when the area formed by a triangle reaches its maximum.

From the above two theorems, we have found that the localization accuracy can be improved if the unknown node selects the three anchors which are within 1-hop based on the following conditions: 1) The three anchors in an equilateral triangle shape, 2) The area of an equilateral triangle formed by three anchors is large. From these two conditions, we propose an optimal anchor placement algorithm and reliable anchor selection scheme to improve the localization accuracy.

3.2. Proposed Optimal Anchor Placement Algorithm

To improve the overall localization accuracy by increasing the possibility of all unknown nodes to select the reliable anchors based on the conditions discussed above, we propose an optimal anchor placement algorithm. The conditions to improve the localization accuracy are, the unknown node should select three anchors that form an equilateral triangle with large area. Thus in this paper, we place anchor nodes in an equilateral triangle shape in range-free scheme.

In our proposed anchor placement algorithm, we assume that the network size L and the distance d between the anchors are given. By utilizing the network size L and the distance d, we can calculate the *height* h and number of rows num_row that the anchor nodes needs to cover the sensing field L can be find to estimate the number of anchor nodes n to place in the network. Proposed anchor placement algorithm follows few steps. First step is to assign the sensing field size L and the distance d between the anchor nodes. Second step is to calculate the number of anchor nodes n to deploy in the sensing field in such a way they form an equilateral triangle pattern with the help of sensing field size L, the distance d ,height h and number of rows num_row .

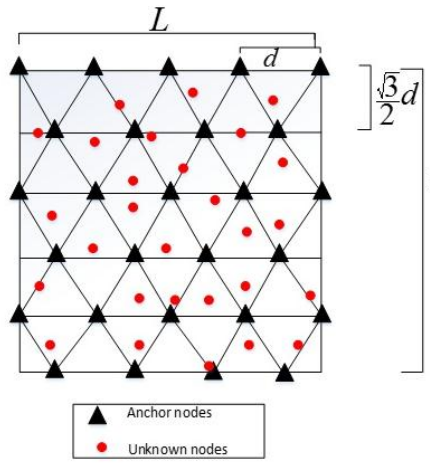

Fig 3.Anchor node placement in equilateral triangle layout

To place anchors in an equilateral triangle shape, we need to find the height h, number of rows num_row that the anchors need to cover the sensing field and the number of anchor nodes n.
The height h can be calculated with the distance d by,

$$h = \frac{\sqrt{3}}{2} \quad (4)$$

Then, the number of rows num_row that the anchor nodes need to cover the sensing field L is given by,

$$num\_row = \left\lceil \frac{L}{h} \right\rceil \quad (5)$$

As shown in Fig.3, the number of anchor nodes n need to deploy in the sensing field in order to form an equilateral triangle can be calculated by,

$$n = \left(\left(\frac{\left\lceil \frac{2L}{d} + 1 \right\rceil \left\lceil \frac{L}{h} \right\rceil}{2} \right) - \frac{\left\lceil \frac{L}{h} \right\rceil}{2} \right) \quad (6)$$

$\lceil . \rceil$ rounds a number to the next largest integer. The number of anchor nodes n need to place in the sensing field from the edge of network in an equilateral triangle with help of distance d, sensing field L and the height h be given as $\left(\left\lceil \frac{2L}{d} + 1 \right\rceil \left\lceil \frac{L}{h} \right\rceil\right)/2$, but to place anchor nodes according to Fig.3, by varying the number of anchors in alternating row ,it is subtracted with half the number of rows $\left(\left\lceil \frac{L}{h} \right\rceil\right)/2$.Thus the number of anchors in alternating rows will be higher than the other rows. When the anchor nodes reach the end of each row in the sensing field, it assigns in another row with help of distance d and height h to form an equilateral triangle with other anchors.

By varying the distance d between the two anchors, the number of anchor nodes n need to deploy in the sensing field can also be varied. Thus from our proposed optimal anchor placement algorithm, all unknown node can utilize the three reliable anchor nodes which are in equilateral triangle shape according to the conditions discussed above.

3.3. Reliable Anchor Selection Scheme

According to the conditions, to improve the localization accuracy, each unknown node should select three one hop anchors that form a shape close to an equilateral triangle with large area. But there is some difficulty in applying the two theorems in multi-hop network, because we cannot always select three anchors which form an equilateral triangle within one hop especially when the anchor density is low. If the selected three anchors are multi-hop from the unknown node, we define the normalized area of a triangle to apply the two theorems. The normalized area is defined as the area of a triangle formed by three multi-hop anchors that has been standardized with respect to one hop. That is, the normalized area formed by three anchor nodes i, j and, k from the unknown node u is given by,

$$Norm\_area = \frac{Area(i,j,k)}{h_{ui}, h_{uj}, h_{uk}} \quad (7)$$

Where $Area(i,j,k)$ is the area formed by three anchor nodes i, $j$and, k.

Finally, each unknown node selects the three anchors that form a shape close to an equilateral triangle as much as possible with the normalized area as large as possible from the β .Here β is fixed to 0.93~0.98. To select the three anchors, we formulate the optimization problem as follows:

$$\arg\min_{i,j,k} var(d_{ij}, d_{jk}, d_{ki}) \quad (8)$$

$$\text{s.t.} Norm\_area(i,j,k) \geq \beta \times Maximum\_area \quad (9)$$

$$i,j,k \in \Omega_A, i \neq j \neq k \quad (10)$$

Where $var(d_{ij}, d_{jk}, d_{ik})$ represents the variance of distances between the three anchor node combination. $Maximum\_area$ is the maximum normalized area among the available three anchor combination. Then unknown node selects the three anchor nodes from β by checking the three anchor node combination, which provides a maximum normalized area and also close to an equilateral triangle to estimate its position by multilateration.

3.4. Localization based on reliable anchor selection scheme

Once the unknown node finish selecting the three reliable anchors based on the conditions, the next step is to estimate its position by utilizing the distance. In the proposed algorithm, the unknown node estimates the distance by utilizing the average hop size calculated by the selected reliable anchors locally. This method can improve the accuracy of the average hop size by considering only the reliable anchors. If we assume that the unknown node u selects anchors i, j and, k as the reliable anchors, the average hop size of each anchors are calculated as ,

$$s_i = \frac{d_{ij} + d_{ij}}{h_{ij} + h_{ik}} \quad (11)$$

$$s_j = \frac{d_{ji} + d_{jk}}{h_{ji} + h_{jk}} \quad (12)$$

$$s_k = \frac{d_{ki} + d_{kj}}{h_{ki} + h_{kj}} \quad (13)$$

From the average hop size, unknown node u estimate its distances to the selected three reliable anchors by multiplying the average hop size with the corresponding hop count. The estimated distances are given by,

$$\hat{d}_{ui} = s_i \times h_{ui} \quad (14)$$

$$\hat{d}_{uj} = s_j \times h_{uj} \quad (15)$$

$$\hat{d}_{uk} = s_k \times h_{uk} \quad (16)$$

After estimating the distance to the three reliable anchors, each unknown node computes its position with multilateration based on the least square estimation. For example, the position of unknown node u having reliable anchors i, $j$and, k is computed by the following optimization model,

$$\arg\min_{[x_u, y_u]^T} var\left\{ \left(\hat{d}_{ui} - d_{ui}\right)^2 + \left(\hat{d}_{uj} - d_{uj}\right)^2 + \left(\hat{d}_{uk} - d_{uk}\right)^2 \right\} \quad (17)$$

Then the vector notation for three independent range estimates can be calculated as,

$$\left.\begin{aligned} {d_{ui}}^2 &= (x_i - x_u)^2 + (y_i - y_u)^2 \\ {d_{uj}}^2 &= \left(x_j - x_u\right)^2 + \left(y_j - y_u\right)^2 \\ {d_{uk}}^2 &= (x_k - x_u)^2 + (y_k - y_u)^2 \end{aligned}\right\} \quad (18)$$

We can linearize these equations by subtracting the bottom row from each of the remaining rows,

$$2\begin{bmatrix}(x_i - x_j)(y_i - y_j)\\(x_i - x_k)(y_i - y_k)\\(x_j - x_k)(y_j - y_k)\end{bmatrix}\begin{bmatrix}x_u\\y_u\end{bmatrix} = \begin{bmatrix}\hat{d}_{ui}^2 - \hat{d}_{uj}^2 - \|\mathbf{l}_i\|^2 + \|\mathbf{l}_j\|^2\\\hat{d}_{ui}^2 - \hat{d}_{uk}^2 - \|\mathbf{l}_i\|^2 + \|\mathbf{l}_k\|^2\\\hat{d}_{uj}^2 - \hat{d}_{uk}^2 - \|\mathbf{l}_j\|^2 + \|\mathbf{l}_k\|^2\end{bmatrix} \quad (19)$$

The usage of least square and pseudo inverse can provide a least square solution if the range estimates have unknown errors,

$$\hat{\mathbf{l}}_u = [\hat{x}_u, \hat{y}_u]^T = (\mathbf{K}^T\mathbf{K})^{-1}\mathbf{K}^T\mathbf{z}_u \quad (20)$$

The measurement vector $\mathbf{z}_u$ is,

$$\mathbf{z}_u = \begin{bmatrix}\hat{d}_{ui}^2 - \hat{d}_{uj}^2 - \|\mathbf{l}_i\|^2 + \|\mathbf{l}_j\|^2\\\hat{d}_{ui}^2 - \hat{d}_{uk}^2 - \|\mathbf{l}_i\|^2 + \|\mathbf{l}_k\|^2\\\hat{d}_{uj}^2 - \hat{d}_{uk}^2 - \|\mathbf{l}_j\|^2 + \|\mathbf{l}_k\|^2\end{bmatrix} \quad (21)$$

4. Simulation Results

This section describes the overhead caused by the proposed algorithm with DV-Hop. The simulation result compares the performance of the proposed optimal anchor placement algorithm with other anchor placement patterns and proposed reliable anchor selection scheme with the DV-Hop method.

4.1 Analysis of Communication Cost

In this section, we compare the communication cost of the proposed algorithm with the DV-Hop. The overall communication cost of DV-Hop is $2O(AS)$ [5], where A is the number of anchors and S is the number of sensor nodes (anchors and unknown nodes). Basically, DV-Hop method requires every anchor to flood in the network twice. All sensor nodes obtain its minimum hop count information from all the anchors during the first flooding (communication cost is$O(AS)$).Then the anchor broadcasts its average hop size to the entire network during the second flooding (communication cost is$O(AS)$). Our proposed scheme floods in the network only once to obtain the hop count information (communication cost is $O(AS)$) and the average hop size is computed only with the selected three reliable anchors locally and does not need to flood in the whole network .Thus the overall communication cost caused by the proposed method is less than the DV-Hop method.

4.2 Simulation Result

In this section, we compare the performance of our proposed methods with the existing methods through simulation. Performance of these algorithms are evaluated by finding the localization error which is defined as the Euclidean distance between the real and the estimated position of an unknown node. The unknown nodes are deployed randomly in the sensing field. Sensing field size is fixed to 25x25m^2.The simulation is repeated for 100 times to compute the mean localization error. In each simulation, unknown nodes are redistributed randomly.

4.2.1 Comparison of Various Anchor placement Patterns

In order to show the effectiveness of our proposed anchor placement algorithm, we compare the localization error obtained by various anchor node placement pattern in network. Here, we utilize square and random placement to compare with the proposed anchor placement pattern. In square placement, anchor nodes are placed in such a way that they form a square layout, in random placement, anchor nodes are placed randomly and in the proposed placement, the anchor nodes are placed in an equilateral triangle layout.

Fig 4 and 5 shows the localization error obtained by three placement patterns (Proposed, Square and Random) by following the proposed reliable anchor selection scheme. Here we vary the number of unknown nodes and anchor density in the sensing field. In all simulations, the transmission range of sensor nodes is fixed to 1m.

Fig.4 shows the mean localization error obtained by varying the number of unknown nodes. Anchor density is fixed to 6% in the network. As shown in Fig. 4, when the node density is increased gradually from 1100 to 1500, the mean localization error decreases in all three placement patterns. Among the three anchor placement patterns, the proposed anchor placement algorithm shows less localization error.

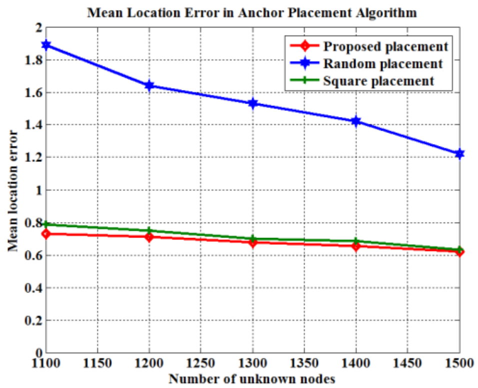

Fig 4.The mean localization error by varying unknown nodes (Proposed, Square and Random pattern)

Fig.5 shows the mean localization obtained error by varying the anchor density in all three placement patterns. Here the anchor density is increased from 6% to 12%. The unknown node is fixed to 1200. Thus by increasing the anchor density, the mean localization error decreases in all three placement patterns. But the proposed anchor placement shows less localization error compared to the square and the random placement.

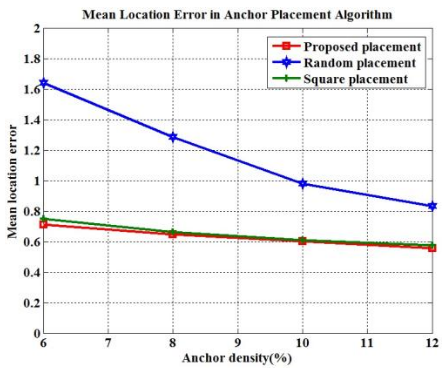

Fig 5.The mean localization error by varying anchor density (Proposed, Square and Random method)

In random placement, the possibility of unknown nodes to select the three reliable anchors close to an equilateral triangle shape with large area will be less and so the localization error by multilateration becomes large. This makes the random placement pattern to produce large localization error compared to the square and proposed placement. In square placement, the chance of selecting anchors according to the conditions can be higher than the random placement but lesser than the proposed placement. This allows the square placement pattern to produce less localization error compared to random placement and large localization error compared to proposed placement. In proposed placement, the number of unknown nodes to select the reliable anchors based on the conditions will be high compared to other two placement patterns. This allows the proposed placement algorithm to produce less localization error compared to square and random placement pattern.

4.2.2 Comparison of DV-Hop and Proposed Method

We compare the efficiency of our proposed reliable anchor selection scheme with DV-Hop by placing the anchor nodes according to the proposed optimal anchor placement algorithm. Here we vary the number of unknown nodes and anchor density in the sensing field and the simulation is repeated 100 times to compute the mean localization error.

Fig.6 shows the mean location error obtained by varying the number of unknown nodes. Anchor density is fixed to 6% in the network. When the node density is increased from 1100 to 1500, the mean localization error decreases in both DV-Hop and proposed method .But the proposed anchor selection method shows less localization error compared to DV-Hop.

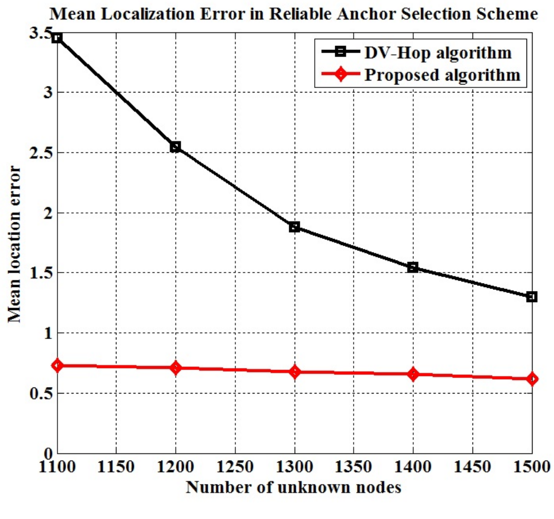

Figure 6.The mean localization error by varying unknown nodes

Fig.7 shows the mean localization error by varying the anchor density. Here the anchor density is increased from 6% to 12%. Here the unknown node is fixed to 1200.When the anchor density increases, the mean localization error decreases in both DV-Hop and proposed method. But the proposed method shows less localization error compared to DV-Hop.

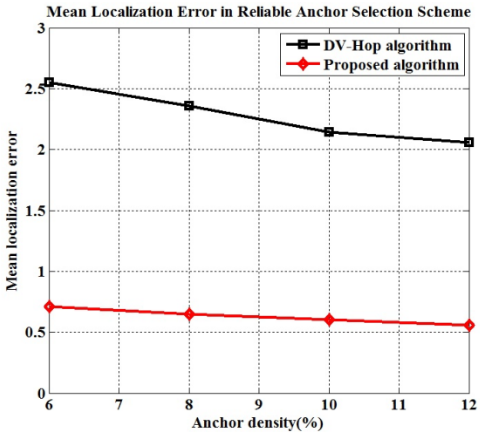

Figure 7.The mean localization error by varying anchor density

In DV-Hop, each unknown node estimates its distance by utilizing the average hop size which is obtained by considering all the anchors in the network. Hence it is difficult to estimate the distance accurately to all anchors especially when the shortest path is curved or different from the straight line. The localization error can be increased when the incorrect estimated distance is used to compute the position. When the node density is low, the hop length can be estimated inaccurately and shows large localization error. But when the node density is high, the hop size can be estimated accurately and shows less localization error. In proposed method, each unknown node selects only three reliable anchor nodes to estimate the position. Thus each unknown node estimates its distance by utilizing the average hop size which is calculated by considering only the selected three anchors in the network. Hence it estimates the distance accurately better than DV-Hop method. Whether the node density is low or high, the proposed method estimates the hop size accurately better than the DV-Hop method.

5. Conclusion

In this paper, we have studied the relationship between the localization accuracy by considering the distance estimation and relative positions of anchors. From the study we have found that there are two conditions need to be satisfied to improve the localization accuracy. To allow all unknown nodes to select the reliable anchors based on the two conditions, we propose an optimal anchor placement algorithm and reliable selection scheme. In multi hop environment, the unknown node cannot select the three reliable anchors within one hop. So we normalize the area of triangle formed by three anchors to apply in multi hop environment. Finally, each unknown node selects the three reliable anchor nodes which has maximum normalized area and also close to an equilateral triangle shape to estimate the position. Simulation results demonstrate that the proposed methods perform better than the existing methods.

6. Conflict of Interests

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

7. Acknowledgements
This research was supported by Basic Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2014R1A1A2057567).

References
[1] Rao.B and Minakakis.L, “Evolution of Mobile Location-based Services”, Communications of the ACM, vol.46, No.12, Dec. 2003, pp.61-65.
[2] Tian He, Chengdu Huang, Brian M. Blum, John A. Stankovic, and Tarek Abdel zahar. “Range-free localization schemes for large scale sensor networks”, In Proceedings of the 9th Annual International Conference on Mobile Computing and networking, Sep.2003, pp. 81-95.
[3] X Li, K Pahlavan, “Super-resolution TOA estimation with diversity for indoor geolocation”, IEEE Transactions on Wireless Communications, vol. 3, No. 1, Jan. 2004.
[4] K. Langendoen and N. Reijers, “Distributed localization in wireless sensor networks: a quantitative comparison”, Computer Networks, vol. 43, No. 4, Aug. 2003, pp. 499-518.
[5] D. Niculescu and B. Nath, “Ad Hoc Positioning System(APS)”, in Proc. of the IEEE International Conference on INFOCOM, Nov. 2001, pp. 2926-2931.
[6] Hichemsassi, Tawfiknajeh, Noureddineliouane, “A Selective 3-Anchor Dv-hop Algorithm Based On the Nearest anchor for Wireless Sensor Network”, International Journal of Computer, Information, Systems and Control Engineering,vol.8, No.10, 2014.
[7] Ahmad El Assaf, Slim Zaidi, SofieneAffes, and NahiKandil, “Range-free Localization Algorithm for Anisotropic Wireless Sensor Networks”,Vehicular Technology Conference (VTC Fall), 2014 IEEE 80th,Sept. 2014, pp.1-5.
[8] Sangwoo Lee, Bonhyun Koo, and Sunwoo Kim, “RAPS: Reliable Anchor Pair Selection for Range-Free Localization in Anisotropic Networks”,IEEE COMMUNICATIONS LETTERS,Vol.18,August 2014.
[9] VijayanthVivekanandan and Vincent W. S. Wong, “Concentric Anchor Beacon Localization Algorithm for Wireless Sensor Networks”,IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, Vol. 56, September 2007.
[10] H. Woo, S. Lee., and C. Lee, “Reliable Anchor Node Based Range-free Localization Algorithm in Anisotropic Wireless Sensor networks”, 2013 International Conference on Information Networking(ICOIN), Jan.2013, pp. 618-622.
[11] Moreno-Salinas D, Pascoal AM, Aranda J. "Optimal Sensor Placement for Multiple Target Positioning with Range-Only Measurements in Two-Dimensional Scenarios," Sensors. 2013; Vol. 13, No. 8, pp. 10674-10710.
[12] G. Han, D. Choi and W. Lim, "Reference Node Placement and SelectionAlgorithm Based on Trilateration for Indoor Sensor Networks", WirelessCommunications and Mobile Computing. Vol. 2009,No. 9,pp.1017-1027.
[13] Nan Zhou, Xiaoguang Zhao, Min Tan, “Deployment and Routing Method for Fast Localization Based on RSSI in Hierarchical Wireless Sensor Network”,2013 IEEE 10th International Conference on Mobile Ad-Hoc and Sensor Systems, Oct. 2013,pp. 614 – 619.
[14] Xueqing Wang, Shuxue Zhang, “Comparison of Several Sensor Deployments in Wireless Sensor Networks”, 2010 International Conference on E-Health Networking, Digital Ecosystems and Technologies (EDT, April.2010), pp. 236-239.
[15] Honghai Zhang, Jennifer C. Hou, “Maintaining Sensing Coverage and Connectivity in Large Sensor Networks”, Ad Hoc & Sensor Wireless Networks,Vol. 1, March.2005, pp. 89–124.
[16] R. Kershner, “The Number of Circles Covering a Set”, American Journal of Mathematics”, Vol. 61, No. 3, Jul.1939, pp. 665-671.
[17] Li Guohui, Wei Wei and Yang Bing, Zhang Shaoping,“A Novel Iterative Multilateral Localization Algorithm for Wireless Sensor Network”,Journal of Networks, Vol. 5, No. 1, Jan. 2010,pp. 112-119.
[18] Jifeng Cui, FengXu and Wei Zhou, “A Secure Localization Algorithm in Wireless Sensor Networks with Mobile Anchor Nodes”, Proceedings of 2013 International Conference on Information Science and Computer Applications, vol. 92, Sep.2013.