A Node Localization Algorithm in Wireless Sensor Network

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Abstract. In order to solve the problems such as complex topology computation and low positioning accuracy induced by the random error factors in the localization process of Wireless Sensor Network (WSN), a new node localization algorithm for WSN is proposed. Firstly, the preliminary position estimation of positioned network node is finished based on the linear parameter evaluation mechanism and evaluates the received anchor node information to calculate the linear parameter value for searching the best anchor triangle, then the precise positioning of the node is done by using the weighted evaluation method and triangle positioning parameters of different anchor nodes to multiple weighted average for obtaining the accurate location information of nodes. Simulation results show that this algorithm has higher localization accuracy and lower error compared with DV-hop algorithm and DV-distance algorithm.

1. Introduction
With the development of wireless communication technology and wireless sensor network (WSN), the network localization technology enjoys broad application prospect in fields like emergency communication, smart APP application, data transmission and industry 2.0.

A WSN node localization algorithm based on linear parameter weighting evaluation mechanism is proposed in this paper. Preliminary node localization is fulfilled by linear parameter determination method in combination with anchor node feedback information. Accuracy is improved with linear parameter weighting evaluation mechanism and triangle localization technology and the node localization accuracy of the algorithm is verified.

2. Analysis of node localization accuracy based on anchor node localization method
Since the algorithm in this paper belongs to anchor node localization algorithm, primary localization and coordinate calculation have to be made for specific anchor node coordinate when anchor node localization algorithm is adopted for the sensor network and the accuracy of this process relies much on the anchor node coordinate itself. Therefore, the localization accuracy in the anchor node localization method is analyzed and discussed at the first place in this paper.

When localization and ranging is performed for the node to be localized, the information like distance between the node to be localized and the anchor node and the hop count has to be known no matter which method is adopted. After the calculation analysis is made, several anchor nodes are selected to calculate the topological distance and distance at the same time to realize the localization of node coordinate based on the specific coordinate of the anchor node and the distance of the node to be localized (topological distance and angle). The localization accuracy becomes higher when there are more anchor nodes that the node to be localized can select at this moment. However, the distribution of topological location of the anchor node has greater influence on the calculation of node coordinate.
For example, when three anchor nodes are on the same straight line and the node to be localized is colinear with three anchor nodes, it is difficult for the angle information between the node to be localized and the anchor node to play the role. Therefore, the localization accuracy has to be analyzed according to the distribution of different topological positions of the anchor node.

2.1 The anchor nodes are on the same straight line or are approximately on the same straight line

Figure 1 shows the localization accuracy of the node O to be localized when the anchor nodes 1, 2 and 3 are on the same straight line.

In this condition, the positions between nodes 1, 2 and 3 satisfy:

\[ aL_{(1,2)} + bL_{(2,3)} + cL_{(1,3)} = 0 \]  

(1)

Where \( L_{(1,2)}, L_{(2,3)} \) and \( L_{(1,3)} \) represent the vector between the nodes; \( a, b \) and \( c \) are linear coefficients and the formula (1) is true only when \( a, b \) and \( c \) are all zero.

![Figure 1. The anchor nodes are in the three-point colinear condition.](image)

Since the nodes 1, 2 and 3 have linear relationship, the localization circle will be drawn with the node itself as the radius when three points receive the signal of point O. Therefore, three localization circles are colinear and they have two intersection points. As shown in Figure 1, since the anchor nodes 1, 2 and 3 are on the same straight line and the control circles corresponding to anchor nodes 1, 2 and 3 have two different intersection points, the location corresponding to node O will have two different estimated positions (location O and location O') and these two positions have mirror symmetry relationship with the straight line corresponding to the anchor node when the node O receives the distance and angle information sent by the three nodes. Therefore, in this condition, the localization accuracy of the node O will be greatly affected and it is extremely easy to determine the coordinate of node O on the mirror position.

2.2 Two anchor nodes are very close and the third anchor node is far away

When the anchor nodes 1, 2 and 3 are colinear in Figure 1, two different localization positions are shown since it is difficult to form anchor triangle. When anchor nodes 1 and 2 are closer, similar location error also occurs, as shown in Figure 2.

![Figure 2. Two anchor nodes are closer.](image)
In this condition, distance from the nodes 1, 2 and 3 to the point O is set to be $d_{01}$, $d_{02}$ and $d_{03}$ respectively and the distance between the nodes 1, 2 and 3 to be $d_{12}$, $d_{13}$ and $d_{23}$ respectively, and following expression is satisfied:

$$d_{1,2} \ll d_{1,3}$$  \hspace{1cm} (2)

$$d_{1,2} \ll d_{2,3}$$  \hspace{1cm} (3)

Considering the distance between the node O to be localized and each node is far during the localization, the control circles of nodes 1 and 2 will be coincided and will have two different intersection points with the control circle of node 3. The connection lines between the intersection points and node 1 and node 3 are symmetrical.

Let us set the cosine value of the included angle between the node O and the node 3 to be $\cos \angle 3$:

$$\cos \angle 3 = \frac{d_{1,3}^2 + d_{2,3}^2 - d_{1,2}^2}{2 \times d_{1,3} \times d_{2,3}}$$  \hspace{1cm} (4)

Then the specific coordinate of the position O to be localized is: the connection line of node 2 and node 3 is taken as the symmetry axis, the node 3 is taken as the center, the included angle position is the calculated angle as shown in formula (4) and the distance from the node 3 is $d_{03}$

### 2.3 The three anchor nodes are closer

When the anchor triangle is further changed in situation as shown in Figure 2, i.e. the distance between the anchor nodes 1, 2 and 3 is very short, as shown in Figure 3. The distance between the anchor 1, 2 and 3 is much less than the radius of the control circle. Therefore, the control circles of these three almost coincide.

As known from formula (4), the cosine value of the included angle between the coordinate of the node to be localized and the nodes 1, 2 and 3 satisfies respectively:

$$\cos \angle 1 = \frac{d_{1,2}^2 + d_{2,3}^2 - d_{1,3}^2}{2 \times d_{1,2} \times d_{2,3}}$$  \hspace{1cm} (5)

$$\cos \angle 2 = \frac{d_{1,3}^2 + d_{2,3}^2 - d_{1,2}^2}{2 \times d_{1,3} \times d_{2,3}}$$  \hspace{1cm} (6)

$$\cos \angle 3 = \frac{d_{1,3}^2 + d_{2,3}^2 - d_{1,2}^2}{2 \times d_{1,3} \times d_{2,3}}$$  \hspace{1cm} (7)

Since the distance between the nodes 1, 2 and 3 is very short, i.e. it satisfies:

$$d_{0,1} \approx d_{0,2} \approx d_{0,3}$$  \hspace{1cm} (8)

$$d_{1,2} \ll d_{0,3}$$  \hspace{1cm} (9)

The cosine value calculated according to formulas (5), (6) and (7) will be uncertain and the calculated localization coordinate of the node O may be unlimited in number, which results in failure of localization and the localization accuracy at this time will be in the unaccepted condition.

![Figure 3. Schematic of when three anchor nodes are closer.](image-url)
As shown from the three conditions above, the main error of the anchor node algorithm comes from the influence of anchor node topology position, so certain method shall be taken to overcome the influence of anchor node topology position on the localization accuracy during node localization so as to further improve the node localization accuracy while suitting different extreme topology structures. Therefore, linear parameter evaluation mechanism and weighting evaluation method are introduced in this paper combined with triangle localization parameters to localize accurately the node.

3. Algorithm

3.1 Determination of linear parameter

As known from the accuracy analysis in section 1, the topology positions of anchor nodes 1, 2 and 3 have great influence on node localization accuracy. The relative topology positions of three anchor nodes can be represented by the triangle, where the vertexes of the triangle are the anchor nodes 1, 2 and 3 and the three sides of the triangle are the distance between the anchor nodes 1, 2 and 3. Currently, when the researchers define the topology positions of the anchor nodes, the introduced linear parameters only include the coordinates of anchor nodes 1, 2 and 3. In practical application, the main factor determines the shape of any triangle is the size of each inner angle. Therefore, the linear parameter of the algorithm in this paper is the cosine value of the inner angle.

![Figure 4. Definition of anchor triangle.](image)

The linear parameter in this paper is defined as the maximum value of the cosine function of the inner angle of the anchor triangle as shown in Figure 4 (i.e. the minimum degree angle of the triangle formed by anchor nodes 1, 2 and 3). When the localization starts, the node O to be localized calculates in turn the cosine function value of the inner angle of the anchor triangle:

\[
\cos \angle 1 = \frac{d_{1,3}^2 + d_{1,2}^2 - d_{2,3}^2}{2 * d_{1,3} * d_{1,2}}
\]

(10)

\[
\cos \angle 2 = \frac{d_{2,3}^2 + d_{1,2}^2 - d_{1,3}^2}{2 * d_{2,3} * d_{1,2}}
\]

(11)

\[
\cos \angle 3 = \frac{d_{2,3}^2 + d_{1,3}^2 - d_{1,2}^2}{2 * d_{2,3} * d_{1,3}}
\]

(12)

Where \( \cos \angle 1 \), \( \cos \angle 2 \) and \( \cos \angle 3 \) represent respectively the cosine value of the inner angles corresponding to the anchor nodes 1, 2 and 3; \( d_{1,2} \), \( d_{1,3} \) and \( d_{2,3} \) represent respectively the distance between the three anchor nodes.

The expression of the linear parameter \( \mu_{\cos} \) in this paper is:

\[
\mu_{\cos} = \max \{ \cos \angle 1, \cos \angle 2, \cos \angle 3 \}
\]

(13)

As known from formula (13), the value of linear parameter \( \mu_{\cos} \) corresponds to the cosine function value of the node with minimum inner angle degree in the anchor triangle. Therefore, the value of \( \mu_{\cos} \) is within 0.5~1. When and only when the \( \mu_{\cos} \) value is approximate to 1, the three anchor nodes are approximately on the same straight line and the node localization accuracy at this time is the lowest. When the \( \mu_{\cos} \) value is close to 0.5, the anchor triangle corresponding to three anchor nodes is equilateral triangle and the accuracy of the node localization at this time is the highest.
3.2 WSN node localization.
The calculated $\mu_{\cos}$ in this paper can be used for node localization. Proper anchor node can be selected as per needs during node localization and the linear parameter $\mu_{\cos}$ of the anchor triangle can be calculated. Node localization can be performed when and only when $\mu_{\cos} \neq 1$; otherwise, anchor node will be selected again until $\mu_{\cos}$ satisfies $\mu_{\cos} \neq 1$.

Step 1: any anchor node sends its own coordinate position through broadcast mechanism to the sink node in the wireless sensor network, and the sink node sends this coordinate position to all the sensor nodes which will feed back to the sink node through Hello information group after receiving the coordinate position information sent by the sink node.

Step 2: after the node $O$ to be localized receives all the coordinate position information of the anchor nodes, three anchor nodes will be selected randomly. After cosine function value of the inner angle of the anchor triangle is calculated according to formulas (10) ~ (12), the linear parameter $\mu_{\cos}$ is calculated according to formula (13). Then go to step 3.

Step 3: the node $O$ to be localized continues with the random selection of anchor nodes and calculates $n$ groups of linear parameter $\mu_{\cos}$ according to step 3. The group of anchor nodes with the minimum $\mu_{\cos}$ value are taken as the anchor nodes. As known from formula (13), when the $\mu_{\cos}$ value is 0.5, the anchor triangle is equilateral triangle and the localization accuracy at this time is the best.

Step 4: according to the coordinates of the group of anchor nodes with the minimum $\mu_{\cos}$ selected in step 3, the anchor node coordinates are set to be $(x_1, y_1)$, $(x_2, y_2)$, and $(x_3, y_3)$ respectively, and the distance between the node $O$ and the anchor nodes is $d_1$, $d_2$ and $d_3$ respectively. If the coordinate of node $O$ is $(x, y)$, then the following relationship is satisfied:

\begin{align*}
(x - x_1)^2 - (y - y_1)^2 &= d_1^2 \quad (14) \\
(x - x_2)^2 - (y - y_2)^2 &= d_2^2 \quad (15) \\
(x - x_3)^2 - (y - y_3)^2 &= d_3^2 \quad (16)
\end{align*}

The simultaneous linear equation system according to formulas (14)~(16) can be represented to be the form of $AL = B$, where:

\begin{align*}
A &= 2E \begin{bmatrix} x_1 - x & y_1 - y \\ x_2 - x & y_2 - y \\ x_3 - x & y_3 - y \end{bmatrix} \\
B &= \begin{bmatrix} d_1^2 - d_3^2 - y_1^2 + y_3^2 - x_3^2 + x_1^2 \\ d_2^2 - d_3^2 - y_2^2 + y_3^2 - x_3^2 + x_2^2 \end{bmatrix} \\
L &= \begin{bmatrix} x \\ y \end{bmatrix} \\
(17) & \quad (18) & \quad (19)
\end{align*}

According to the calculation:

\begin{align*}
L &= (A^T A)^{-1} A^T B \\
(20)
\end{align*}

The value calculated according to formula (20) is the preliminary localization coordinate of the node $O$ to be localized.

3.3 Weighting evaluation and accuracy evaluation of the node coordinate
The coordinate accuracy of the node $O$ to be localized which is calculated according to formula (20) is closely related to the control radius of the anchor node. Therefore, the coordinate obtained through only one time of localization calculation will have greater accuracy error. Since there is $n$ groups of anchor angles in the localization process, there are $n$ linear parameters of $\mu_{\cos}$, $(x_1, y_1)$, $(x_2, y_2)$, ..., and $(x_n, y_n)$ are obtained according to formula (19), where $(x_n, y_n)$ is the localization coordinate obtained through No. $n$ group of anchor triangle for the node $O$ to be localized, and the corresponding
n groups of $\mu_{\cos}$ are $\mu_{\cos(1)}$, $\mu_{\cos(2)}$, $\ldots$, $\mu_{\cos(n)}$. Since different $\mu_{\cos}$ accounts for different weight, weighting evaluation has to be made for $\mu_{\cos}$ so as to improve the localization accuracy of the node.

For the No. n group of anchor triangles, the weight corresponding to $\mu_{\cos(n)}$ is $W_n$, where the following is obtained after normalization of $\mu_{\cos(1)}$, $\mu_{\cos(2)}$, $\ldots$, $\mu_{\cos(n)}$:

$$W_n = \frac{\mu_{\cos(n)}}{\sum_{i=1}^{n} \mu_{\cos(i)}}$$

(21)

The corrected coordinate $(X, Y)$ of the node O to be localized can be obtained after weighing of $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ according to the idea of formula (21):

$$(X, Y) = \sum_{i=1}^{n} W_i (x_i, y_i)$$

(22)

Formula (22) is the node coordinate of the node O to be localized after weighting evaluation, i.e. the estimated position of the node O to be localized after one time of localization process. In order to get the localization accuracy error, it is assumed that I times of localization process has to be performed, the location coordinates obtained from formula (22) are $(X_i, Y_i), (X_2, Y_2), \ldots, (X_n, Y_n)$ respectively, and the real coordinate of the node is $(M, N)$, then the accuracy error estimation $\text{error}$ of the node O to be localized after I times of localization process satisfies:

$$\text{error} = \sqrt{(X_i - M)^2 + (Y_i - N)^2}$$

(23)

The accurate error estimation of localization accuracy of the node O to be localized can be calculated according to formula (23).

### 4. Simulation experiment

In order to verify the performance of the algorithm in this paper, particularly considering the limited energy of the node during WSN localization and the characteristic of the anchor node that it does not move, such two aspects like localization accuracy and localization error are selected in this paper. Besides, DV-hop algorithm and DV-distance algorithm with better node localization performance currently are compared so as to verify the advantages of the algorithm in this paper. NS2 simulation platform is selected in this paper. Detailed simulation parameters are shown in Table 1.

| Parameter                        | Value          |
|----------------------------------|----------------|
| Area of network deployment region| 500m×500m      |
| Experiment duration (h)          | 5h             |
| Node deployment method           | Random distribution |
| Node cache (KB)                  | 5124K          |
| Whether the node travels         | NO             |
| Node density (number/m)          | <8             |
| Primary node energy (J)          | 2~10J          |
| Signal to noise ratio index      | 12dB           |
| Number of anchor nodes           | <50            |
| Control radius of anchor nodes   | 10m            |
| Number of nodes to be localized  | 20             |

Simulation is conducted through the parameters in Tab 1, where there are 20 nodes to be localized and 40 anchor nodes. Figure 5 shows the actual distribution of the network nodes and Figure 6~8 show the network node distribution obtained according to the algorithm in this paper, DV-hop algorithm and DV-distance algorithm. As shown in Figure 6, the localization performance of the algorithm in this
paper is the best, the position of the node to be localized fits well with Figure 5 and the absolute localization error obtained from formula (14) is 1.2m. On the other hand, the localization performance of DV-hop algorithm and DV-distance algorithm is not good and larger error exists between the node to be localized and its original position. As shown in Figure 7 and Figure 8, the absolute localization error is 3.4 m and 4.6 m respectively. This is because the localization error when the anchor triangle is in straight line condition can be avoided effectively by linear parameter evaluation mechanism in the algorithm of this paper. Besides, weighting evaluation mechanism is introduced in the algorithm of this paper to reduce the accuracy error through multiple times of localization. On the other hand, the DV-hop algorithm and DV-distance algorithm only adopt one time of localization mechanism and the error during the localization can not be corrected through multiple times of localization, so the localization accuracy error of the algorithm in this paper when the network nodes are evenly distributed is better than the algorithms of the comparison group.

Figure 5. Actual distribution of network nodes.

![Figure 5. Actual distribution of network nodes.](image)

Figure 6. Distribution of network nodes with algorithm in this paper.

![Figure 6. Distribution of network nodes with algorithm in this paper.](image)
5. Conclusion
A WSN node localization algorithm based on linear parameter weighting evaluation mechanism is proposed in this paper. Firstly, the way to search for the best anchor node is obtained with the method of anchor node coordinate calculation and by calculating the linear parameter. Then considering that the anchor node may have different types of abnormal topologies, weighting evaluation mechanism is introduced and multiple times of evaluation is adopted to reduce effectively the localization error during the localization. Finally, multiple times of location method is adopted to effectively improve the localization accuracy and reduce the error. The simulation experiment shows that the algorithm in this paper enjoys distinct advantages compared with traditional wireless network node localization technology and it can greatly improve the accuracy during localization and reduce the localization error, which is of strong practical significance.
In the next step, the complicated wireless sensor network localization in three-dimensional distribution structure will be studied according to the linear parameter weighting evaluation mechanism. Meanwhile, direct measuring mechanism will be introduced and topics like how to localize rapidly the node when the node is in moving condition will be studied so as to further improve the applicability of the algorithm in this paper.

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