Abstract

The problem that the localization accuracy of unknown nodes is not high in DV-Hop localization algorithm is about to be solved. According to this algorithm deficiency, an improved DV-Hop localization algorithm is proposed which was based on corrected the average hop distance error correction value $\delta$ to modify the average hop distance, to reduce the deviation between the average hop distance and the true average hop distance. Finally, the average hop distance of the traditional DV-Hop algorithm is modified effectively. Simulation results show that, the improved algorithm has reduced the average localization error of unknown nodes, improved the localization accuracy, and not require additional hardware.

Keywords: Wireless Sensor Networks (WSN); Node Localization; Average Hop Distance; Error Correction

1. Introduction

Node location is one of the key technologies in Wireless Sensor network (WSN, Wireless Sensor Networks). In most WSN applications, sensor nodes are randomly distributed, except some anchor nodes; most of nodes’ position is unknown. Therefore, only under the premise of the clear nodes’ position information, to realize the locating and tracking of the external target. According to localization mechanism, the existing localization algorithms can be divided into two types: range-based algorithm and range-free algorithm [1, 2]. Compared with range-based algorithm, the range-free algorithm has lower hardware requirements, and lower cost. Among the range-free algorithm, the DV-Hop [3, 4] algorithm is widely used which is one of the range-free localization algorithm, it is a distributed localization algorithm based on range-free, which is proposed by the Nicolescu and Nath in the project of Navigate. For the research of the DV-Hop improved algorithm, the country has also made some achievements, such as literature [5-9]. These improved algorithms to a certain extent though improve localization accuracy, but also increase the energy consumption and computing cost, etc. Therefore, the algorithms are still the room for improvement. It uses the product of the average hop distance between the nodes and the hops, to estimate the position of the unknown nodes. In order to improve the localization accuracy, an improved DV-Hop algorithm is put forward which based on average hop distance error correction method.

This paper proposes an improved DV-Hop localization algorithm which was based on corrected the average hop distance error correction value $\delta$ to modify the average hop distance, to reduce the deviation between the average hop distance and the true average hop distance. Finally, the average hop distance of the traditional DV-Hop algorithm is modified effectively. Simulation results show that, the improved algorithm has reduced the average localization error of unknown nodes, improved the localization accuracy, and not require additional hardware.
2. Proposed algorithm

2.1. DV-hop algorithm analysis

The process implementation of DV-Hop algorithm can be divided into three stages: (1) Measure the minimum hop counts to anchor nodes; (2) Calculate and broadcast the correction value; (3) Estimate the coordinates of unknown nodes.

The basic principle of DV-Hop is that using the product of the average hop distance $C_i$ and hop counts $hops$ between unknown nodes and anchor nodes to represent estimate distance $d_i$ between them. The express of $C_i$ and $d_i$ show as equation (1) ~equation (2).

$$C_i = \frac{\sum_{i \neq j} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{i \neq j} hops_{ij}}$$  

Among them, $(x_i, y_i)$ and $(x_j, y_j)$ are the coordinates of anchor nodes $i$ and anchor node $j$. $hops_{ij}$ is the number of hops between anchor node $i$ and anchor node $j$.

$$d_i = C_i \times hops$$

Analyzing the basic principle of DV-hop algorithm, its’ main error originated from that it is the product of hops and average hop distance, which used the hop distance instead of straight distance. When the estimated value and the actual value of the average hop distance have big deviation, localization error will be increased. Following example is show in Figure 1,

![Figure 1. The Error Schematic of DV-Hop Algorithm](image)

In Figure 1, A, B, C are anchor nodes, P is an unknown node. Solid line between nodes can communicate directly; dotted line between nodes cannot communicate directly, which is need the transition of the intermediate nodes. According to DV-Hop algorithm, calculate the average hop distance of A: $(75+40) / (4+4) = 14.375$, the estimate distance of PA is: $14.735 \times 1 = 14.375$, But the actual distance of PA is 30m, its’ error is very large.

2.2. The existing dv-hop improved algorithm

Traditional DV-Hop algorithm is not high location accuracy. To solve these problems, many scholars from the point of view of reducing average hop distance, proposed better improvement methods [10-15] to reduce error, such as literature [9], it was proposed that the improved method of the
average hop distance of the entire network. Defined the average hop distance of the entire network as \( cc \), see equation (3):

\[
cc = \frac{\sum C_i}{n}
\]

(3)

Among them, \( C_i \) is the average hop distance of a single anchor node, \( n \) is the number of anchor nodes.

Literature [10], use the local fixed method to consider about the closest anchor nodes and other anchor nodes. It is as the equation (4) ~ (5).

\[
d_{ij} = \frac{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{h_{ij}}
\]

(4)

\[
C_{ij} = \frac{(C_i + d_{ij})}{h_{ij}}
\]

(5)

Among them, \( j \) is others anchor node in data table of anchor node \( i \), \( h_{ij} \) is hop between anchor nodes \( i \) and \( j \), \( d_{ij} \) is the average hop distance between anchor node \( i \) and others anchor node.

Localization performance of these algorithms has been improved to some extent, but there are still errors, and there is room for improvement.

2.2. Improved dv-hop algorithm

This paper is mainly on the basis of analyzing the traditional DV-Hop algorithm and literature [9], according to the deficiencies in literature [9], puts forward to the improvement scheme, which is to modify the average hop distance, in order to reduce the localization error. First, this algorithm use the equation (3) to calculate the average hop distance of entire network \( cc \); then analyzing the deviation between the true distance and the calculating distance between anchor nodes, get the average hop distance error of entire network, so as to modify the average hop distance of entire network, to improve the precision of localization. Define \( \delta \) as the average hop distance error of the entire network:

\[
\delta = \frac{\sum |d_t - d_e|_{ij} / \text{hops}_{ij}}{n}
\]

(6)

Among them, \( |d_t - d_e|_{ij} \) is the absolute value of the difference of the actual distance and estimated distance between arbitrarily two anchor node \( i \) and \( j \). \( \text{hops}_{ij} \) is the smallest hop counts of arbitrarily two anchor node \( i \) and \( j \), \( n \) is the total numbers of nodes in networks.

In the localization process, the distance on the same path will be counted twice, and it will lead to increased computational overhead. Therefore, in order to reduce the amount of computation, to calculate the estimated distance between anchor node \( i \) and anchor node \( j \) which is on the same path, it is only to calculate \( d_{e_{ij}} \), not need to calculate \( d_{e_{ji}} \). \( d_t \) and \( d_e \) show as equation (7) and equation (8):

\[
d_t = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}
\]

(7)
For example, in Figure 1, A, B, C are anchor nodes. Calculate the average hop distance of the entire network $c_c$:

$$c_c = \frac{C_A + C_B + C_C}{3}$$

Use the hops between the anchor nodes and the average hop distance of the entire network $c_c$ to calculate the estimated distance of AB, AC, BC, using equation (7) to calculate the actual distance of AB, AC, BC, and then use the equation (6) to calculate the error correction values $\delta$ of the average hop distance of all the anchor nodes of the whole network the average hop distance error correction value:

$$\delta = \frac{\left| \frac{d_{AB} - d_t}{hops_{AB}} + \frac{d_{AC} - d_t}{hops_{AC}} + \frac{d_{BC} - d_t}{hops_{BC}} \right|}{3}$$

Among them, 3 is the number of anchor nodes in the Figure 1.

The schedule details of the improved algorithm of this paper as follows:

1. First, Each anchor node broadcasts the localization information to entire work, and its’ packet includes itself position information and hop value initialized to zero. Neighbor nodes receive the packet, save these information, only maintain the packet with minimum hop count on the same nodes, then hop add 1 and broadcast these message to others neighbor node. Through this mechanism, all nodes will get the minimum hop value distance from each anchor node all the nodes get the minimum hop and coordinate location away from each anchor node in the networks.

2. In the second stage, use the improvement scheme of this paper to correct the average hop distance error. First, use equation (1) and equation (3) to get the average hop distance of entire network, then take advantage of equation (6) to calculate the average hop distance error of all anchor nodes, and broadcast $\delta$ to the entire network, namely on the basis of the literature [9] increase a data broadcast stage. After this stage, all unknown nodes and anchor nodes know the average hop distance error of the entire network, so as to get a new equation on the average hop distance of entire network:

$$HopSize_{new} = c_c + k\delta$$

Among them, $k$ is a variable parameter used to balance on the size of the average hop distance, which is in [-1 1]. Its’ value depends on the specific network environment.

Combined with the minimal hop counts between unknown nodes and anchor nodes, solving the estimated distance of unknown nodes to anchor node:

$$d_i = HopSize_{new} * hops$$

3. Get three or more of the estimated distance between unknown nodes and anchor nodes, then use the maximum likelihood estimation method to calculate the coordinators of unknown node.

Assume that the coordinates of n anchor nodes as: $(x_1, y_1), (x_2, y_2)$⋯⋯$(x_n, y_n)$, the coordinates of the unknown node P is $(x, y)$, the distance of each anchor node distance to the unknown node P are $d_1, d_2, d_3$⋯⋯$d_n$, which can be expressed as equation (11).
\[
\begin{align*}
(x_1 - x)^2 + (y_1 - y)^2 &= d_1^2 \\
(x_2 - x)^2 + (y_2 - y)^2 &= d_2^2 \\
\vdots \\
(x_n - x)^2 + (y_n - y)^2 &= d_n^2
\end{align*}
\]

The equation (11) can be written into the form of \( AX = b \). Among them, \( A \) and \( b \) is as following:

\[
A = \begin{bmatrix}
2(x_1 - x_n) & 2(y_1 - y_n) \\
\vdots & \vdots \\
2(x_{n-1} - x_n) & 2(y_{n-1} - y_n)
\end{bmatrix}
\]

\[
b = \begin{bmatrix}
x_1^2 - x_n^2 + y_1^2 - y_n^2 + d_1^2 - d_n^2 \\
\vdots \\
x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 + d_{n-1}^2 - d_n^2
\end{bmatrix}
\]

Using a standard least squares method to solve the equation \( AX = b \), the solution is following:

\[
\hat{x} = (A^T A)^{-1} A^T b
\]

3. Simulation results

3.1. Experiment environment setting

In order to verify the performance of the improved algorithm of this paper, using Matlab 7.0 simulation, and the simulation results are compared and analyzed. In wireless sensor network, the \( N \) sensor nodes is deployed, the number of anchor nodes and unknown nodes are by the user to enter. The simulation area is 100 m * 100 m, these sensor nodes use randomly distributed way, the experimental results take the average of many times experiments, using the localization error formula to evaluate the overall performance of the algorithm. The equation as follows:

\[
error = \frac{\sqrt{(x_t - x_e)^2 + (y_t - y_e)^2}}{R} \times 100\%
\]

Among them, \((x_t, y_t)\) is the true coordinator of unknown node, \((x_e, y_e)\) is the estimation coordinator of unknown nodes, \( R \) is the communication radius. The sensor nodes is randomly distributed in the 100 m * 100 m square area as shown in figure 2 shows, it has 100 sensor nodes, its’ communication radius is 20 m, the number of anchor nodes is 20.

![Figure 2. The Diagram of the Sensor Nodes Randomly Distributed](image)
3.2. Experiment results and analysis

(1) Figure 3 compares the different values of the variables $k$, which has the impact of the localization of the improved algorithm of this paper. 200 sensor nodes is randomly deployed, communication radius is 30 m.

![Figure 3. Different Value of k on the Influence of the Localization Error](image)

In figure 3, we can conclude that when total number of nodes and anchor nodes are constant, the localization error depends on the value of the variable parameters $k$; when the parameters variable $k$ for setting value, localization error depends on the number of anchor nodes and all nodes. From three simulations curve shows that: when the value of $k$ is at $[0.3, 0.7]$, the algorithm the localization error is relatively lower, especially when the value of $k$ takes around $0.6$, in the following experiments the value of $k$ is set as $0.6$. But, under the different network, the better localization error corresponds to the value of $k$ is also different.

(2) By changing the number of anchor nodes, study the impact of the number of anchor nodes on the localization error, random distribution of 100 nodes. The nodes’ communication radius is set to 20 m, the number of the anchor nodes are set to 5, 10, 15, 20, 25, 30.

![Figure 4. The Relationship between the Number of Anchor Nodes and Localization Error](image)

It can be seen from Figure 4, when the number of nodes and the communication radius of nodes are constant, the localization error of two algorithms presents the trend of decreasing, with the increase of the proportion of anchor nodes. But, when anchor node proportion is more than a certain number, the two algorithm's traffic will also increase, the rate of localization error also reduce would be more and more slowly. Therefore, set the right number of anchor node to some extent can improve the localization precision. Localization accuracy of the algorithm of this paper can be improved by an average of about $5.8\%$, compared with the DV-Hop algorithm. Among them, when anchor nodes are 20, localization error of the algorithm of this paper can be reduced about $8\%$. 
(3) In order to study the impact of the nodes on the localization error, the number of nodes is set to 100, 150, 200, 250, 300, 350, communication radius is set to 20 m, and the number of anchor nodes is set to 20. Shown in figure 5, when the number of nodes is same, the localization error of the algorithm of this paper is lower than the DV-Hop algorithm. In addition, with the increase of nodes, the two algorithm’s localization error is reduced in a certain degree of. When the number of nodes is at 100, localization error is decreased by about 12%.

![Figure 5. The Relationship between the Number of Nodes and the Localization Error](image)

(4) In Figure 6, the number of all nodes is set to 100, the anchor node ratio is set as 10%, communication radius is set to 15 m, 20 m, 25 m, 30, 35 m, 40 m. Compared with DV-Hop algorithm, the average localization errors of the improved algorithm is decreased by about 6.8%. When the communication radius is 40m, the localization error of the DV-Hop algorithm is 30%, the localization error of the improved algorithm is 23.62%, the improved algorithm is better than DV-Hop algorithm.

![Figure 6. The Relationship between Communication and the Localization Error](image)

4. Conclusions

For DV-Hop algorithm of the deficiencies, the improved DV-Hop algorithm of this paper use the error of the real distance and the calculation the distance between anchor nodes, to modify the average hop distance of the entire network, so as to make over the average hop distance of entire network closer to the real value of the average hop distance closer. Eventually the localization accuracy is been improved, but also improve the efficiency of object detecting and tracking. But, the algorithm of this paper in communication and computing cost aspects has increased. Therefore, how to reduce the communication and computing cost is the focus of research in the future.

5. References