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Application of an Improved DV-HOP Algorithm in WSN

Hong Xie

(Liuzhou railway Vocational & Technical College, Liuzhou 545007, China)
gxlzxh2014@163.com

Abstract

As the DV-Hop algorithm in wireless sensing does not perform well in terms of accuracy, a DV-Hop sensor node location algorithm based on the Steffensen iteration method is presented in this paper. First, the wireless sensor nodes are located roughly through the DV-Hop algorithm; then, the location result is checked and corrected with the Steffensen iteration method, to realize accurate location. The simulation experiment shows that the node location accuracy is improved significantly by using the algorithm presented in this paper, which is more widely applicable.

***Keywords**: wireless sensor network; node location; DV-Hop algorithm; Steffensen iteration*

1. Introduction

In wireless sensor network (WSN), the node location information is the key to application. How to achieve accurately node localization is a main concern for wireless sensor network. In WSN, node localization mainly refers to the anchor node localization and unknown node localization. Among this, anchor node refers to a small number of nodes with GPS localization device, which cannot be widely used due to high energy consumption of GPS installation. Meanwhile, the localization of unknown node location has to localize through anchor nodes [1-3].

At present, WSN node localization consists of range-based and range-free algorithms [4]. Range-based algorithm primarily measures the range between adjacent nodes, calculates the range of surrounding unknown nodes through the actual range between nodes, which often uses RSSI, TOA, TDOA, AOA algorithms [5-6]. Range-free algorithm does not need to actually measure the nodes, but instead, it obtains the location of unknown nodes through estimation, which can reduce the damage to hardware. However, due to estimation, range-free algorithm has a not accurate localization with deviations, mainly consisting of centroid algorithm and DV-HOP algorithm [7]. Literature [8] introduced the maximum estimate strategy to nodes of DV-Hop algorithm, which effectively reduced the node errors and improved localization accuracy; Literature [9] introduced artificial bee colony algorithm to adjust the range error in DV-Hop, and achieved certain results; Literature [10] updated the range between minimum hop and average hop by eliminating long-range anchor nodes, in order to reduce the calculation error of the average hop range.

To reduce the sensor localization errors, this paper introduces Stephenson iterative method based on DV-HOP algorithm, in order to analyze the sensor node localization errors. First of all, this paper coarsely localize WSN by using DV-Hop algorithm; then adopts Steffensen iteration method to examine and correct the localization results of DV-Hop algorithm, and the simulation results show that the presented algorithm can effectively improve the localization performance.

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2. DV-Hop Algorithm and Error Analysis

2.1. DV-Hop Localization Algorithm

Specific steps of DV-Hop algorithm is as follows:

(1) Anchor nodes broadcast packets to the surrounding nodes, the unknown nodes receive the minimum hop count of anchor nodes, forward to the next node after plus 1.

(2) After anchor node receiving the information and hop count of other nodes, according to Equation (1), calculate the average range per hop for estimation.

$$HopSize_i = \sum_{j \neq i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \Big/ \sum_{j \neq i} hopS_{ij} \tag{1}$$

In the equation, are respectively coordinates of anchor node i and anchor node j, and $hopS_{ij}$ is the minimum hop count between anchor node i and anchor node j.

(3) The range between the anchor node and unknown node:

$$L_i = S_i \times HopSize \tag{2}$$

According to the range between the unknown node and anchor nodes, use the multilateral method to calculate coordinate of unknown nodes, specifically expresses as:

$$\begin{cases} (x_i - x_1)^2 + (y_i - y_1)^2 = L_1^2 \\ (x_i - x_2)^2 + (y_i - y_2)^2 = L_2^2 \\ \vdots \\ (x_i - x_j)^2 + (y_i - y_j)^2 = L_j^2 \end{cases} \tag{3}$$

Where, (x_i, y_i) is coordinate of unknown node; $(x_1 y_2), \ldots, (x_j, y_j)$ is the coordinate of anchor node recorded by the unknown nodes.

(4) Use (j-1) equations in Equation (3) to successively minus the last equation, and obtain a linear expression AX = b.

2.2. Error Analysis of DV-HOP Algorithm

In wireless sensor, this paper uses the product of hop count and correction value for all unknown nodes to represent the range, and the estimated range has great deviation from the actual range. Assuming that the hop count between the nodes to be determined and anchor nodes is 1, the results of basic DV-HOP algorithm are shown as Figure 1:

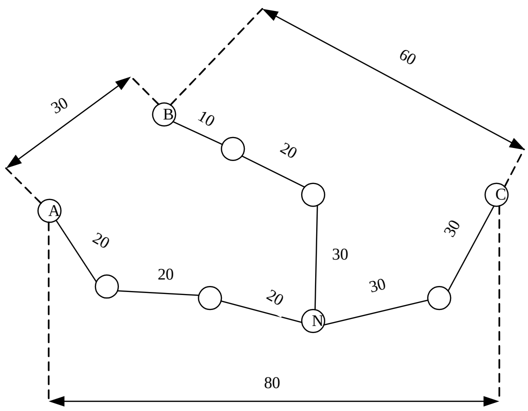

Figure 1. Schematic Diagram of DV-HOP Algorithm Error Analysis

Assuming node N is unknown node, nodes A, B and C are anchor nodes, and the range between three anchor nodes is shown in figure. Where, the hop count between A and B is 3, the hop count between B and C is 4, and the hop count between A and C is 5. Each anchor node can calculate its own correction value. Where, the correction value of node A is (30+80)/(3+5)=13.75, the correction value of node B is (30+60)/(3+4)=12.86, the correction value of node C is (60+80)/(4+5)=15.56. According to the principle of correction value from unknown nodes to anchor nodes, the correction value from node N to node C is 15.56. Therefore, the range between node N to three anchor nodes: NA is 3*15.56=46.68, NB is 3*15.56=46.68, NC is 2*15.56=31.12. Assuming that the range between N to three nodes is straight line, the straight-line range between N to node A is 60, the range between node N to node B is 60, the range between node C to node C is 60, therefore, the errors are respectively 60-46.68=13.32,60-46.68=13.32,60-31.12=28.88, and the error rate are respectively of 13.32/60=22.2%,13.32/60=25%,28.88/60=48.13%. Since in the actual link, the WSN distribution is more complex. By using this localization method, it is easy to cause the localization location of unknown node N to actually deviate from the real location.

From the above analysis, it can be found the node localization is affected by many factors, and there must be some errors by using DV-Hop algorithm to measure the range L. By introducing ε (random error vector in n-1 dimension), this paper obtains the following linear equations:

$$AX + \varepsilon = b \tag{4}$$

The solution of equations can be obtained by using the least squares method. However, each element of b contains L_j with errors, which seriously affect the accuracy of the least squares method [11].

Supposing f_n is the ranging error between unknown nodes and anchor nodes,

$$(x_i - x_j)^2 + (y_i - y_j)^2 = L_j^2 + f_j \tag{5}$$

According to Equation (3), the unknown node coordinates meet the following equation:

$$\begin{cases} (x_i - x_1)^2 + (y_i - y_1)^2 = L_1^2 + f_1 \\ (x_i - x_2)^2 + (y_i - y_2)^2 = L_2^2 + f_1 \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ (x_i - x_j)^2 + (y_i - y_j)^2 = L_j^2 + f_j \end{cases} \tag{6}$$

Solve the coordinate of unknown node (x_i, y_i), the below equation can be got

$$f(x_i, y_i) = \sum_{j=1}^{n} \left(\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} - L_j\right) \tag{7}$$

When Equation (7) obtains the minimum value, the total error is the minimum, and the localization of unknown nodes can get close to the true value, namely, meet the coordinate of unknown nodes in the following equation:

$$f(x_i, y_i)_{\min} = \min\left(\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} - L_j\right) \tag{8}$$

By adopting the above methods, DV-Hop localization error problem is successfully transformed into a nonlinear optimization problem, and then Stephenson iterative method is used to solve Equation (8), in order to obtain the improved sensor localization accuracy.

3. Steffensen Correction of DV-Hop Localization Error

3.1. Steffensen Algorithm

Nonlinear equation $f(x)=0$ can be transformed into equivalent equation:

$$x = \varphi(x) \tag{9}$$

In the equation, $\varphi(x)$ is called iterated function.

Steffensen iterative method is an improved fixed-point iterative method, being featured with quadratic convergence speed and calculation accuracy. The iterated function is:

$$\varphi(x) = x - \frac{(\varphi(x) - x)^2}{\varphi(\varphi(x)) - 2\varphi(x) + x} \tag{10}$$

Steffensen iteration equation is:

$$\begin{cases} x_k = \varphi(x_k), z_k = \varphi(y_k) \\ y_{k+1} = x_k - \dfrac{(y_k - x_k)^2}{z_k - 2y_k + x_k} \end{cases}, k = 0,1,2,\ldots \tag{11}$$

The process of Steffensen algorithm is as follows:

(1) Set the maximum number of iterations N and precision ε, and assume k=0.

(2) Calculate $y_k = \varphi(x_k)$.

(3) If $|x_{k+1} - x_k| < \varepsilon$, stop the calculation.

(4) If $k=N$, stop the calculation; otherwise, set $k=k+1$, go to Step (2).

3.2. Steffensen Correction of DV-Hop Localization Error

The necessary condition for Equation (8) to obtain the minimum is:

$$\frac{\partial f}{\partial x_i} = \frac{\partial f}{\partial y_i} = 0, (m < i \le n) \tag{12}$$

Where,

$$\begin{cases} \dfrac{\partial f}{\partial x_i} = \sum\limits_{\substack{m<i\le n \\ 1\le j\le m}} \left(2(x_i - x_j) - \dfrac{2l_{ij}(x_i - x_j)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}\right) \\ \dfrac{\partial f}{\partial y_i} = \sum\limits_{\substack{m<i\le n \\ 1\le j\le m}} \left(2(y_i - y_j) - \dfrac{2l_{ij}(y_i - y_j)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}\right) \end{cases} \tag{13}$$

Assuming,

$$\Delta_i = \sqrt{\left(\frac{\partial f}{\partial x_i}\right)^2 + \left(\frac{\partial f}{\partial y_i}\right)^2} \tag{14}$$

The problem of min(fitness()) optimal solution is transformed into the coordinate (x_i, y_i)

issue of unknown nodes when Δ_i taking the minimum. Specific steps are:

(1) According to the first step of Steffensen iterative formula (11), iterate the variables x_i and y_i, get:

$$\begin{cases} \bar{x}_i = \varphi(x_i) = \dfrac{\sum\limits_{1 \le j \le m} \left(x_j + \dfrac{l_{ij}(x_i - x_j)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}} \right)}{m} \\ \bar{y}_i = \varphi(y_i) = \dfrac{\sum\limits_{1 \le j \le m} \left(y_j + \dfrac{l_{ij}(y_i - y_j)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}} \right)}{m} \end{cases} \tag{15}$$

$$\begin{cases} \tilde{x}_i = \varphi(\bar{x}_i) = \dfrac{\sum\limits_{1 \le j \le m} \left(x_j + \dfrac{l_{ij}(\bar{x}_i - x_j)}{\sqrt{(\bar{x}_i - x_j)^2 + (y_i - y_j)^2}} \right)}{m} \\ \tilde{y}_i = \varphi(\bar{y}_i) = \dfrac{\sum\limits_{1 \le j \le m} \left(y_j + \dfrac{l_{ij}(\bar{y}_i - y_j)}{\sqrt{(x_i - x_j)^2 + (\bar{y}_i - y_j)^2}} \right)}{m} \end{cases} \tag{16}$$

Where, x_i and y_i is the estimated location of sensor nodes by using DV-Hop algorithm, and uses it as the initial iteration value.

(2) According to Formula (11), conduct updated iteration operation towards coordinates of unknown nodes:

$$\begin{cases} x_i' = \tilde{x}_i - \dfrac{(\tilde{x}_i - \bar{x}_i)^2}{\tilde{x}_i - 2\bar{x}_i + x_i} \\ y_i' = \tilde{y}_i - \dfrac{(\tilde{y}_i - \bar{y}_i)^2}{\tilde{y}_i - 2\bar{y}_i + y_i} \end{cases} \tag{17}$$

(3) Substitute new coordinate (x_i, y_i) of unknown sensor nodes into Formula (14), and calculate the value of Δ_i.

(4) When the number of iteration reaches to the set maximum or the iteration accuracy reaches the pre-set value, terminate iteration, calculate the coordinate of unknown nodes most close to the true value, and make the localization error to be minimal.

4. Algorithm Simulation and Analysis

To better explain the advantages of this algorithm, this paper compares the presented algorithm with DV-HOP algorithm and Literature [6] algorithm and selects the simulation platform in Windows 7 and Matlab2010. This paper selects the region of 100*100 for the simulation environment, selects 500 nodes, including 10 anchor nodes and 400 unknown nodes. All nodes are randomly distributed. Afterwards, this paper adopts the error formula in Literature, where, (x_i', y_i') and (x_i, y_i) respectively represent the unknown and actual unknown estimations, R represents the node communication radius, and N is the number of nodes. Results are as below

$$f = \frac{\sum_{i \neq j} \sqrt{(x_i' - x_i)^2 + (y_i' - y_i)^2}}{R \cdot N} \quad (18)$$

4.1. Impacts of Range Error on Localization Accuracy

Under different range errors, the change curves of average localization error of the presented algorithm, DV-Hop algorithm and Literature [6] algorithm are as shown in Figure 1. According to the figure, the presented algorithm has less localization error and higher localization accuracy. This paper adopts Steffensen iteration to further analyze and correct the results of DV-Hop algorithm, in order to obtain more accurate localization results.

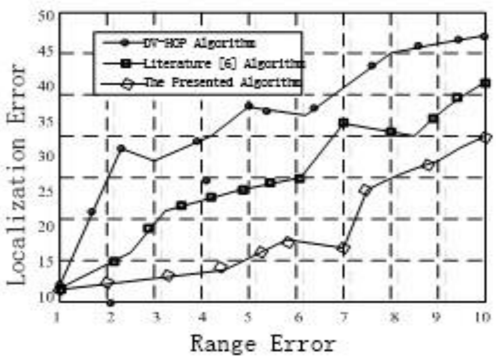

Figure 1. Changes of Range Error

4.2 Impacts of Node Number on Localization Accuracy

Under different number of nodes, the change curves of average localization error in presented algorithm, DV-Hop algorithm and Literature [6] algorithm are shown in Figure 2. With the increasing number of nodes, the average localization errors of all algorithms are slightly increased. However, compared with other two algorithms, the presented algorithm has smaller localization error. Therefore, the figure shows that density has a small impact on the presented algorithm, which can better conduct more accurate localization.

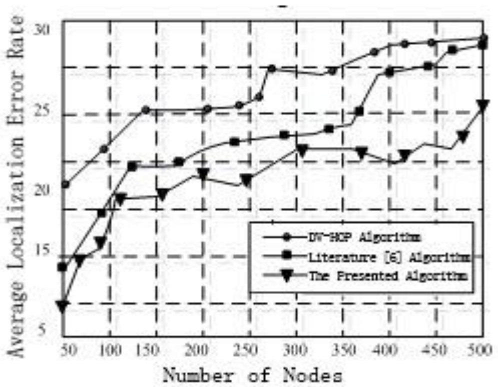

Figure 2. Changes of Anchor Node Number

4.3. Impacts of Network Measured Radius on Localization Accuracy

In different network connectivity, the change curves of average localization error in ADV-Hop, DV-Hop, DVHop-Steff algorithms are shown in Figure 3. According to Figure 3, compared with DV-Hop localization algorithm, ADV-Hop and DVHop-Steff algorithms can obtain more accurate localization. When the measured radius R is relatively small, DVHop-Steff algorithm has more obvious localization advantages than the comparative algorithms.

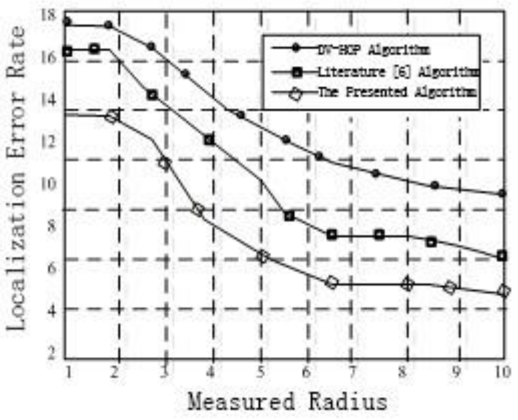

Figure 3. Changes of Network Connectivity

4.4. Network Energy Consumption Ratio of Each Algorithm

With the increased network running time, the changes of network energy consumption ratio in the presented algorithm, ADV-Hop algorithm and Literature [6] algorithm are shown in Figure 4. According to Figure 4, the energy consumption curve amplitude of DV-Hop algorithm is the maximum, indicating the energy consumption is unstable and consumes fastest, followed by Literature [6] algorithm and the presented algorithm. The results show that the presented algorithm can effectively improve the utilization rate of network energy, better extend the life of nodes, and better work under WSN monitoring environment with higher energy consumption requirements.

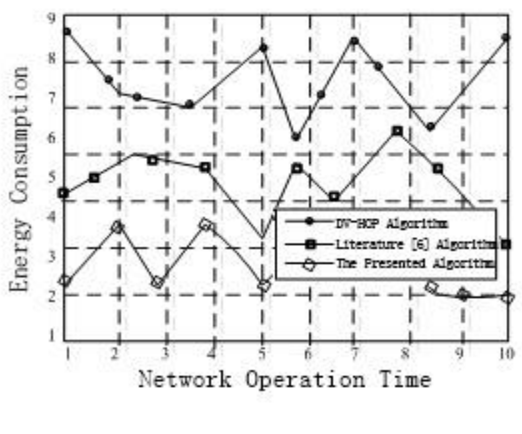

Figure 4. Network Energy Consumption Ratio of Each Algorithm

5. Conclusion

For the localization problems of DV-Hop localization algorithm, this paper introduces Steffensen iterative algorithm based on DV-HOP algorithm. First of all, this paper uses DV-Hop algorithm to generally localize WSN nodes; adopts Steffensen iterative method to analyze and correct the localization results of DV-Hop algorithm, and achieves accurate positioning. Compared with other localization algorithms, the simulation experiments show that the presented algorithm has improved the localization accuracy and has better practicability.

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Author

Hong Xie, (1967-), Resident of Pingnan, Guangxi, Associate Professor, Research Direction of Computer Communication Technology.

