



An Improved Localization Algorithm in WSN Based on Nodes Distribution Law and Revised Hop-Size of DV-Hop

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Abstract: In this paper, a new law is found in DV-Hop which is a classic algorithm based on range-free localization algorithm in WSN (Wireless Sensor Networks). There are stable distribution rules in both the locations of the unknown nodes with similar localization error and the locations of the beacon nodes with similar hop-size. Based on this law, the analytical reason is given and an improved localization algorithm is proposed to enhance the localization accuracy. The main idea is revising the hop-size according to the law and applying appropriate algorithm according to the location of the monitor area. The simulation experiments show that the new algorithm can improve the localization accuracy efficiently. *Copyright © 2013 IFSA.*

Keywords: Wireless sensor networks, DV-Hop, Localization accuracy, Hop-size, Nodes distribution law.

1. Introduction

DV-HOP [1] is a classic localization algorithm based on range-free method in WSN, and its main idea is that unknown node works out the estimated distance between selected beacon nodes and itself by the hops between them and the hop-size calculated by the reference beacon node, and then the unknown node calculates its estimated coordinates using Trilateration or Maximum Likelihood Estimation method.

In this paper, an improved DV-Hop is proposed based on nodes distribution law and revised hop-size. A simulation experiment about DV-Hop is made by the author. According to the results of the experiment, there are stable laws that the unknown nodes with big error mostly distribute in the edge of the WSN area and those with smaller error mostly

distribute in the middle of the WSN area. The analytical reason of the law is given and an improved method of DV-Hop is proposed. The improved DV-Hop can enhance the localization accuracy of WSN efficiently.

The rest of this paper is organized as follows. Section 2 gives a survey of the related works in DV-Hop research. Section 3 gives the analysis of DV-Hop error and improvement method. In Section 4, simulation results are shown and the analysis of the results is given. Finally, the conclusion of this paper is presented in Section 5.

2. Related Work

In this section, the author reviews the related researches of DV-Hop. The following literatures

improved DV-Hop at different aspects and enhanced the localization accuracy of WSN.

The algorithm of literature [2] proposes that the unknown nodes use more than one beacon node's hop-size and take weighted value of them to calculate the estimated coordinates to improve the accuracy of localization in DV-Hop.

The algorithm of literature [3] proposes that it modifies the estimated distance between the unknown nodes and beacon nodes, and the modified value is composed of the modified value of multi-hops and the error of hop-size, meanwhile, TLS is used in localization to enhance the accuracy of localization.

The algorithm of literature [4] analyzes the parameters of the DV-Hop, which affect the accuracy of localization, and finds out that 12 beacon nodes with proper communication radius in $100 \times 100 \text{ m}^2$ area can reduce the error of localization most efficiently.

The algorithm of literature [5] calculates the error of beacon nodes' hop-size, and modifies the hop-size of the whole network and figures out the estimated unknown nodes' coordinates which are outside the monitored area.

The algorithm of literature [6] uses a new 2-D hyperbolic curve instead of trilateration to calculate the estimated coordinates, and gets the finally coordinates by the modified value.

The algorithm of literature [7] introduces collinearity threshold and hop threshold to the progress of localization, and selects the beacon nodes with proper topology and nearby the unknown nodes to calculate the estimated coordinates. Finally, the coordinates of unknown nodes are worked out by Centroid.

The algorithm of literature [8] uses approximate three collinear laws to get the weighted hop-size, and judges the validity of beacon nodes by threshold to enhance the accuracy of localization.

The algorithm of literature [9] calculates the estimated coordinates of beacon nodes by DV-Hop, and then calculates the error of beacon nodes' coordinates as the modifying value and finds out the set of proper beacon nodes, by which the unknown nodes figure out and modify their coordinates to enhance the accuracy of localization.

The algorithm of literature [10] uses the comparison of signal strength to figure out many candidate areas and find out the intersection of those areas, and then it uses a method to scan the intersection area to calculate the coordinates of unknown nodes.

The algorithm of literature [11] introduces GA to localization algorithm, and adopts the Adrenaline Parameter in the calculation to control the operation of GA. Furthermore, it integrates Centroid and DV-Hop to enhance the accuracy of localization.

In this paper, the distribution rule of the error of unknown nodes and hop-size of beacon nodes in DV-Hop is given, and the reason is described. Moreover, a new localization algorithm is proposed

using the law mentioned above to enhance the accuracy of localization. The simulation experiments show that the new localization algorithm can promote the accuracy of localization efficiently.

3. Analysis of DV_Hop Error and Improvement Method

3.1. Analysis of DV_HOP Error

In this paper, the authors perform large amounts of simulation experiments of DV-Hop and analyze the distribution rule. The experiment parameters are as follows: $100 \times 100 \text{ m}^2$ square area, communication radius is 30 m, the amount of nodes is 200, the percentage of beacon nodes is 30 %.

In Fig. 1, the red star stands for beacon node, and the blue circle stands for unknown node, and both horizontal ordinate and vertical ordinate are the length of the area, the unit is meter. In Fig. 2, the localization result is shown that the blue circle stands for the estimated coordinate of unknown node and the blue line stands for the error of localization.

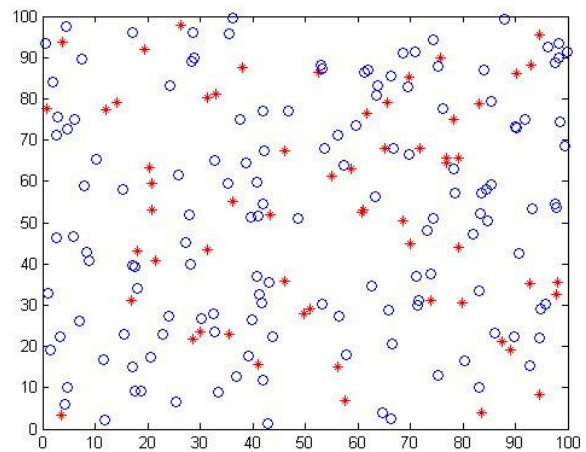


Fig. 1. Distribution of nodes.

It can be seen from Fig. 1 and Fig. 2 that the unknown nodes with biggish error mostly distribute in the edge of the WSN area, and those with smaller error mostly distribute in the middle of the WSN area. After a lot of experiments, the distribution law is stable.

According to the experiments, the comparison is made in the real coordinates of unknown nodes with the estimated coordinates of unknown nodes calculated by DV-HOP. The calculation method of the estimated coordinates is shown in expression 1, and the average error of the localization is shown in expression 2. The unknown nodes are classified into two classes according to the average error of the localization. One class holds the errors that are larger than the average error while the other corresponds to those errors that are smaller than the average error.

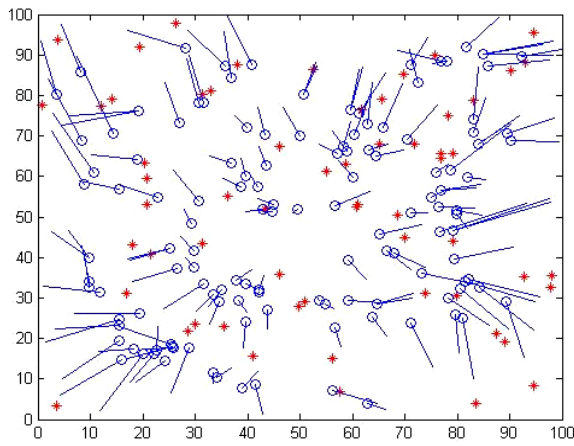


Fig. 2. Distribution of the error of localization.

$$LE = \frac{\sqrt{2((X_r - X_e)^2 + (Y_r - Y_e)^2)}}{ComR} \quad (1)$$

$$LEa = \frac{\sum_{i=1}^n \sqrt{2((X_{r_n} - X_{e_n})^2 + (Y_{r_n} - Y_{e_n})^2)}}{n * ComR} \quad (2)$$

In expression 1, (X_r, Y_r) is the real coordinate of unknown node, (X_e, Y_e) is the estimated coordinate of unknown node, ComR is the communication radius.

In expression 2, n is the amount of unknown nodes, (X_{r_n}, Y_{r_n}) is the real coordinate of number n unknown node, (Y_{r_n}, Y_{e_n}) is the estimated coordinate of number n unknown node, ComR is the communication radius.

The distribution of the location of the unknown nodes with the error value larger than the average error is shown in Fig. 3, and the distribution of the location those with the error value smaller than the average error is shown in Fig. 4. It can be seen from Fig. 3 and Fig. 4 that the unknown nodes with large error are mostly distributed in the edge of the monitored area, and those with small error are mostly distributed in the middle of the monitored error, on the contrary.

Reason 1:

According to DV-Hop, the calculation method of estimated coordinates can accumulate error in two steps, one of them is the calculation and selection of hop-size and the other is the simulation of hops, furthermore, the error of hop-size is most effective. In DV-HOP, unknown nodes obtain hop-size from the beacon nodes nearby themselves, and then it can be concluded from Fig. 3 and Fig. 4 that the distribution of the error coincides with the location of the unknown nodes, so that the reason that arouses the error accompany with location is the accumulation error of the hop-size of the beacon node in particular area.

Reason 2:

The Maximum Likelihood Estimation (MLE) is used in calculation of estimated coordinates, and

unknown nodes calculate the distance with all of the beacon nodes. The unknown nodes in the edge of the area lead to large error by the expression of hop-size multiplied by hops because of the accumulation of large hops with the beacon nodes in the other edge of the area which causes the distribution rule of the unknown nodes with large localization error.

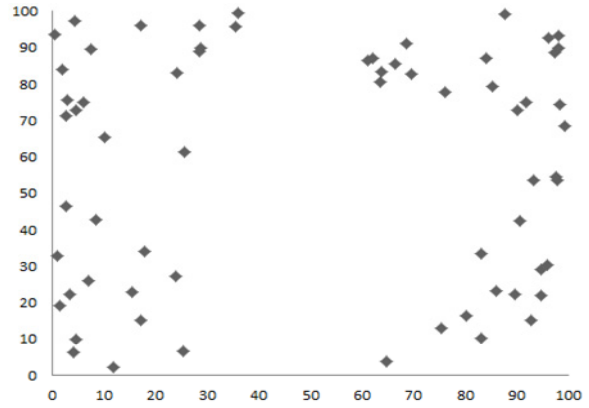


Fig. 3. Distribution of the unknown nodes with the error value more than average error.

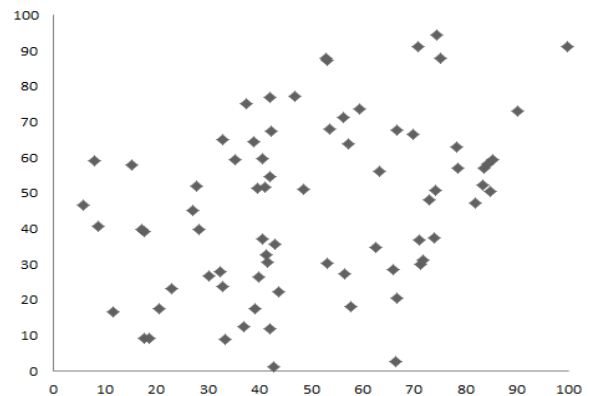


Fig.4. Distribution of the unknown nodes with the error value less than average error.

According to above analysis, the authors calculate the hop-size of each beacon node by expression 3 and the hop-size of the average hop-size of the whole network by expression 4. Moreover, the distribution of the beacon nodes according to the classification by hop-size is shown in Fig. 5.

$$EJDanchors = \frac{\sum_{i=1}^{anchors_n} \sqrt{2((X - X_{anchors_n})^2 + (Y - Y_{anchors_n})^2)}}{\sum_{i=1}^{anchors_n} Path(anchors_n)} \quad (3)$$

$$EJDnodes = \frac{\sum_{i=1}^{nodes_n} \sqrt{2((X - X_{nodes_n})^2 + (Y - Y_{nodes_n})^2)}}{\sum_{i=1}^{nodes_n} Path(nodes_n)} \quad (4)$$

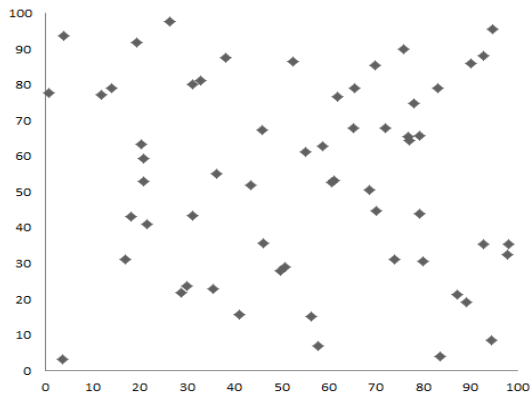


Fig. 5. Distribution of beacon nodes.

In expression 3, $EJD_{anchors}$ is the hop-size of beacon node, (X, Y) is the coordinate of current beacon node, $anchors_n$ is the amount of beacon nodes, $(X_{anchors_n}, Y_{anchors_n})$ is the coordinate of number “anchors_n” beacon node, $Path(anchors_n)$ is the hops between current beacon node and number “anchors_n” beacon node.

In expression 4, EJD_{nodes} is the hop-size of node, (X, Y) is the coordinate of current node, $anchors_n$ is the amount of beacon nodes, which is real coordinate, $nodes_n$ is the amount of the nodes of the whole network, $(X_{nodes_n}, Y_{nodes_n})$ is the coordinate of number “nodes_n” node, $Path(nodes_n)$ is the hops between current node and number “nodes_n” node.

The average hop-size is calculated by expression 5.

$$EJD_{average} = \frac{\sum_{i=1}^{nodes_n} EJD(nodes_n)}{nodes_n} \quad (5)$$

In expression 5, $EJD_{average}$ is the average hop-size of all the nodes in network, $nodes_n$ is the amount of the nodes in network, $EJD(nodes_n)$ is number $nodes_n$ node's hop-size.

According to the average hop-size, the authors classify the location of beacon nodes in DV-HOP, and select those with the hop-size whose distance between average hop-size and itself is smaller than 1m as one class, and others as the other class. The distribution of the location of beacon nodes is shown in Fig. 5 and Fig. 6.

The distribution of all the beacon nodes is shown in Fig. 5. The distribution of the beacon nodes with the error between average hop-size and its own hop-size less than 1 m is shown in Fig. 6. It can be perceived from Fig. 6 that the location of the beacon nodes with hop-size which is similar to average hop-size distributes mostly in an annulus area.

3.2. Improved Algorithm

According to Fig. 6, the authors figure out the distribution scope of the annulus of the beacon nodes' positions by calculating the coordinates. The

beacon nodes out of the annulus area ask for the hop-size from those in the annulus area in order to modify the hop-size and reduce the accumulation of the error aroused by hop-size. A new algorithm is proposed according to above theory to enhance the accuracy of localization. The algorithm steps are as follows.

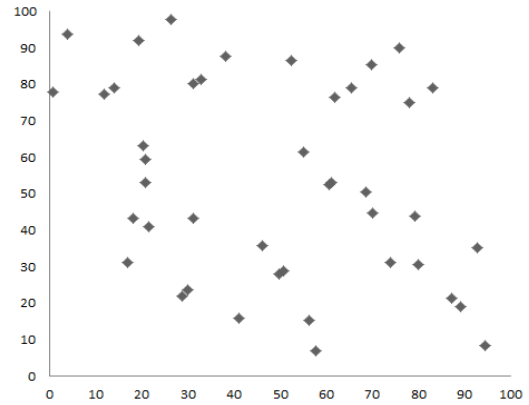


Fig. 6. Distribution of the beacon nodes with the error between average hop-size and its own hop-size less than 1 m.

Step 1:

Calculate the minimum hops between unknown nodes and each beacon node. Beacon nodes broadcast their position information to the whole network and record the hop-timer which is 0 as its default value. The receiving node records the position information and minimum hops from one beacon node and ignore the information with more hops from the same beacon node. And then the receiving node adds 1 to the hop-timer and transmits the information to next node. After this step, each node gains the position information and minimum hops of each beacon node in the network.

Step 2:

Calculate hop-size between unknown node and beacon node. Each beacon node calculates its hop-size according to the position information and hop information recorded from step 1 using expression 6:

$$HopSize_i = \frac{\sum_{j \neq i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j \neq i} h_j} \quad (6)$$

In expression 6, (x_i, y_i) , (x_j, y_j) is the coordinates of beacon node i and beacon node j , h_j is the hops between beacon node i and beacon node j ($i \neq j$).

According to the distribution of beacon nodes, the distribution scope can be worked out. The beacon nodes out of the annulus area ask for the hop-size of those in the annulus area to modify the accumulation error so as to find out more accurate hop-size, and then the hop-size is more similar to the average hop-size.

Beacon nodes broadcast the new hop-size with life-cycle field to nearby network. Unknown nodes

receive and record the first information which arrives at the earliest. After that, unknown nodes calculate the distance between selected beacon nodes and themselves by the new hop-size and hops.

Step 3:

Calculate estimated coordinate of unknown node using MLE: $(x_1, y_1), (x_2, y_2), (x_3, y_3), \dots, (x_n, y_n)$ are the coordinates of n beacon nodes. $d_1, d_2, d_3, \dots, d_n$ are the distance between them and an unknown nodes D . (x, y) is the coordinate of D .

Distance is calculated by expression 7:

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = d_1^2 \\ \vdots \\ (x_n - x)^2 + (y_n - y)^2 = d_n^2 \end{cases} \quad (7)$$

In expression 7, each formula subtracts the last formula from formula 1 to formula $n-1$, and expression 8 can be gained:

$$\begin{cases} x_1^2 - x_n^2 - 2(x_1 - x_n)x + y_1^2 - y_n^2 - 2(y_1 - y_n)y = d_1^2 - d_n^2 \\ \vdots \\ x_{n-1}^2 - x_n^2 - 2(x_{n-1} - x_n)x + y_{n-1}^2 - y_n^2 - 2(y_{n-1} - y_n)y = d_{n-1}^2 - d_n^2 \end{cases} \quad (8)$$

The linear equation of expression 8 is $AX=b$, what A , X , and b are stands for is as expression 9:

$$A = \begin{bmatrix} 2(x_1 - x_n) & 2(y_1 - y_n) \\ \vdots & \vdots \\ 2(x_{n-1} - x_n) & 2(y_{n-1} - y_n) \end{bmatrix}, \quad (9)$$

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

$$X = \begin{bmatrix} x \\ y \end{bmatrix}$$

Calculate the coordinate of D using standard least mean square error criterion: $\hat{X} = (A^T A)^{-1} A^T b$.

Step 4:

Calculate the coordinates of the unknown nodes in the edge of the area using trilateration. $(x_a, y_a), (x_b, y_b)$, and (x_c, y_c) is the coordinates of node A, B, C , d_a, d_b , and d_c are the distance between them and node D , (x, y) is the coordinate of D , the calculation method is as expression 10:

$$\begin{cases} \sqrt{(x - x_a)^2 + (y - y_a)^2} = d_a \\ \sqrt{(x - x_b)^2 + (y - y_b)^2} = d_b \\ \sqrt{(x - x_c)^2 + (y - y_c)^2} = d_c \end{cases} \quad (10)$$

The coordinate of node D can be gained by expression 10, and it is as expression 11.

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 2(x_a - x_c) & 2(y_a - y_c) \\ 2(x_b - x_c) & 2(y_b - y_c) \end{bmatrix}^{-1} \begin{bmatrix} x_a^2 - x_c^2 + y_a^2 - y_c^2 + d_c^2 - d_a^2 \\ x_b^2 - x_c^2 + y_b^2 - y_c^2 + d_c^2 - d_b^2 \end{bmatrix} \quad (11)$$

4. Simulation Experiments and Analysis

The parameters include $100 \times 100 \text{ m}^2$ square area, 30 m communication radius, 200 nodes, 30 % beacon nodes.

Based on DV-Hop, revise hop-size to improve the algorithm.

Calculate the distance between each beacon node and the center of the area as D by expression 12. Create the annulus area according to the D_{\min} and D_{\max} which are the radius of outside circle of the annulus and the radius of the inside circle of the annulus respectively. If D is between D_{\min} and D_{\max} , calculate the hop-size by expression 6, else, ask for the hop-size from the beacon node which is most nearby the annulus area and take this as its own hop-size.

Through a large amount of experiments, the priori knowledge can be gained, and in this condition of experiment, D_{\min} is 44 m, and D_{\max} is 50 m.

$$Dist = \sqrt{(X - X_{center})^2 + (Y - Y_{center})^2} \quad (12)$$

In expression 12, $Dist$ is the distance between the current beacon node and the center of the $100 \times 100 \text{ m}^2$, (X, Y) is the coordinate of the current beacon node, (X_{center}, Y_{center}) is the center coordinate of the square area.

Pseudo-code is as follows:

```

Begin
Calculate the distance between each beacon node
and the center of the area
For i<-to the amount of beacon nodes
Begin
If distance>Dmin&&distance<Dmax then
Hopsize(i)=calculated hop-size
End
End
For i<-to the amount of beacon nodes
Begin
If !(distance>Dmin&&distance<Dmax) then
J=minimum hops of Dmin—Dmax
Hopsize(i)=Hopsize(j)
End
End
End

```

According to the annulus scope determined above, select the unknown nodes with large localization error in the edge of the area and calculate the estimated coordinates by trilateration. It can be seen in Fig. 7.

It can be perceived from the comparison in Fig. 7 with Fig. 2 that the error of localization is decreased

and the accuracy of localization is increased. In this article, the authors perform 100 times experiments, and the localization accuracy is consistently improved with an average 3% improvement. The effect size is relevant to the degree of even-distributed and distribution density, and the result is that the more evenly the unknown nodes distribute the more accurately they can be located. It can be draw a conclusion that the localization of WSN can be improved through the new algorithm proposed in this paper.

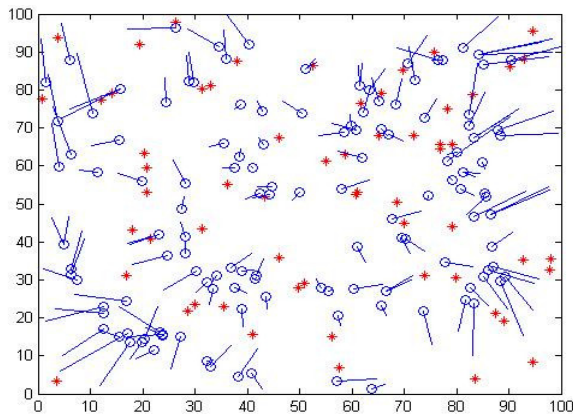


Fig. 7. The localization error of improved algorithm.

5. Conclusions

In this paper, the research is performed on the distribution of the unknown nodes with the different localization error of DV-Hop in WSN; meanwhile, the distribution of the beacon nodes is also arranged. The experiments are operated on those rule mentioned above in order to prove and analyze reasons. It is also found out that the localization error is accumulated by the hop-size error and the multi-hops from MLE, so that an improved algorithm is proposed according to the hop-size of the beacon nodes with smaller hop-size error selected by the law of distribution in the monitored area. The experiments show that the new algorithm can improve and enhance the localization accuracy of WSN efficiently.

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