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AN OPTIMAL DV-HOP LOCALIZATION ALGORITHM BASED ON ERROR CORRECTION

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Abstract. *The node localization technology is one of the key technologies for wireless sensor network (WSN), and the distance vector-hop (DV-Hop) algorithm is paid attention widely due to its easy realization. However, there exist a multiple of localization errors in the localization process, and the errors are transferred and accumulated. An optimal DV-Hop localization algorithm based on error correction is put forward, which is referred to as the error correction DV-Hop (ECDV-Hop) algorithm in the paper. For the optimal algorithm, the average range of each hop in the whole network is used to estimate the range between nodes. And the particle swarm optimization (PSO) algorithm is introduced to calculate the coordinate of each node, in which the average iteration method is adopted. The simulation experiment results show that the ECDV-Hop algorithm can improve the localization speed and reduce the localization error.*
Keywords: Error correction, Wireless sensor network, Node localization, DV-Hop algorithm

1. **Introduction.** Wireless sensor network is composed of massive small-sized sensors with low-power dissipation, low cost, perceptual computing and communications capacity. The self-organizing network system is constructed by means of wireless communications. And the node localization technology has become one of the key WSN technologies, which is applied extensively [1].

The node localization in WSN is classified into the range-based algorithm and the range-free algorithm, and the main difference is whether the localization information is obtained directly. For the range-based algorithm, the ranging technology is used to obtain the range information, which has a high localization precision but requires the extra equipment. And the common range-based technology covers received signal strength indicator (RSSI), time of arrival (TOA), time difference of arrival (TDOA), and angle of arrival (AOA). For the range-free algorithm, the localization is performed only by the connectivity relationship among the neighbor node, which has a low localization precision but requires no extra equipment. And the common range-free technology includes the centroid algorithm, the convex programming localization algorithm and the DV-Hop algorithm. The DV-Hop algorithm has been used widely due to the easy implementation, but its localization precision needs to be improved. For the conventional DV-Hop algorithm, the hop range is used to substitute the straight-line range, which results in relatively larger errors. In the original research, the genetic algorithm [2] and the simulated annealing algorithm [3,4] were used to optimize the DV-Hop algorithm by many scholars. Recently, the PSO algorithm [5,6] is used to optimize the DV-Hop algorithm. For the PSO algorithm, the hop range and the iteration operation are adopted, which results in the error transferring and accumulation. In the paper, aiming at the defects of the algorithms above, the DV-Hop algorithm is optimized in two stages, namely, the average hop range correction and the iteration error correction, with the considerably practical value.

The remainder of the paper is organized as follows. The principle of the DV-Hop algorithm is reviewed and analyzed in Section 2. Then, the ECDV-Hop algorithm is presented in Section 3. In Section 4, the simulation experiments are carried out and the results are analyzed. Finally, conclusions are given with the importance and the further research of the optimal algorithm in Section 5.

2. The Principle of the DV-Hop Algorithm.

The localization process of the DV-Hop algorithm is made up of three stages.

Stage 1. The minimum hop value is recorded.

The data packet is broadcast from the anchor node to the neighbor node, and the minimum hop among the node is obtained by the unknown node. And the list $\{ID, x_i, y_i, hop_i\}$ is stored, where ID denotes the identification number of each anchor node; hop_i denotes the minimum hop between the unknown node and anchor node i; (x_i, y_i) denotes the coordinate of anchor node i.

Stage 2. The range among the node is estimated.

After the position information and hop of other anchor nodes are obtained by each anchor node, the average hop range is estimated by Formula (1).

$$C_i = \frac{\sum\limits_{i \neq j} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum\limits_{i \neq j} hops_{ij}} \tag{1}$$

where (x_i, y_i) and (x_j, y_j) represent the coordinates of anchor nodes i and j, $hops_{ij}$ represents the minimum hop between anchor nodes i and j, and C_i represents the average hop range of anchor node i.

Stage 3. The coordinate of the node is calculated.

The estimation range between the unknown node and the anchor node is expressed in Formula (2), which is shown as follows.

$$d_i = C_i * hop_i \tag{2}$$

In general, because there are more than three anchor nodes in networks, the three-bonier measurement method is adopted to calculate the coordinate [7]. Accordingly, Formula (3) is got, which is shown as follows.

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = d_1^2 \\ (x_2 - x)^2 + (y_2 - y)^2 = d_2^2 \\ \qquad\qquad \vdots \\ (x_n - x)^2 + (y_n - y)^2 = d_n^2 \end{cases} \tag{3}$$

3. The Error Correction DV-Hop (ECDV-Hop) Algorithm.

3.1. Correcting the average hop range.

The defect of the DV-Hop algorithm is that the hop range is adopted to substitute the straight-line range in order to reduce the error between estimation value and actual value for the range between the unknown node and anchor node. In the paper, the network-wide average hop range C is adopted to substitute the average hop range C_i of anchor node i, and the error between the actual range and the estimation range for all the anchor nodes in the DV-Hop algorithm is analyzed to obtain the error existing in the network-wide average hop range, by which the error δ between the network-wide average hop range and the actual average range is reduced. Accordingly, the corrected average hop range C_{new} is obtained.

C and δ are defined as follows.

$$C = \frac{\sum C_i}{n} \tag{4}$$

$$\delta = \frac{\sum\limits_{i \neq j} \mid dt_{ij} - de_{ij} \mid}{\sum\limits_{i \neq j} hops_{ij}} \tag{5}$$

where $|dt_{ij} - de_{ij}|$ is the absolute value of difference between the actual range and the estimation range that is between two network-wide arbitrary anchor nodes i and j. And the range between anchor nodes i and j is calculated repeatedly. Then, the actual range and the estimation range between anchor nodes i and j are expressed in Formulas (6) and (7).

$$dt_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{6}$$

$$de_{ij} = C * hops_{ij} \tag{7}$$

Therefore, the corrected average hop range is obtained, which is shown in Formula (8).

$$C_{new} = C + k\delta \tag{8}$$

where k represents the variable parameter, and its value is determined by the network environment. The estimation range between the unknown node and the anchor node is corrected, which is shown as follows:

$$d_i = C_{new} * hop_i \tag{9}$$

3.2. **Correcting the iteration error in the PSO algorithm.** The PSO algorithm is adopted to optimize the DV-Hop algorithm, in which optimization is affected by iteration.

Assuming the swarm scale of the PSO algorithm as N, each particle is composed of position vector and speed vector, which are expressed as $X_i = \{x_{i,1}, x_{i,2}, \ldots, x_{i,D}\}$, $V_i = \{v_{i,1}, v_{i,2}, \ldots, v_{i,D}\}$. And the optimal position vector of individual is $p_i = \{p_{i,1}, p_{i,2}, \ldots, p_{i,D}\}$, the current optimal position vector of swarm is $p_g = \{p_{g,1}, p_{g,2}, \ldots, p_{g,D}\}$. The speed and position are updated repeatedly according to the optimal value of the individual and the swarm in the process of the particle swarm searching, which is shown in Formulas (10) and (11).

$$V_{t+1,i} = \omega \times V_{t,i} + C_1 \times rand() \times (p_{t,i} - X_{t,i}) + C_2 \times rand() \times (p_{g,t} - X_{t,i}) \tag{10}$$

$$X_{t+1,i} = X_{t,i} + V_{t+1,i} \tag{11}$$

where ω is the inertia weight, C_1 and C_2 are the learning factors, the subscripts t and $t+1$ represent the current value and the corresponding value updated, and $rand()$ is the random function in $(0, 1)$.

In the node localization of WSN, due to the influence from the outside environment and the randomicity of the reference node selected, the error is generated and repeatedly transferred. Therefore, the iterative average algorithm is used to calculate the position information for iteration of each time, so as to correct the iteration error.

$$\begin{cases} x_{i,t+1} = \frac{(x_{i,t} + x'_{i,t+1})}{2} \\ y_{i,t+1} = \frac{(y_{i,t} + y'_{i,t+1})}{2} \end{cases} \tag{12}$$

where $(x'_{i,t+1}, y'_{i,t+1})$ is the localization coordinate of $t+1$ iteration that is got for the first time, and $(x_{i,t+1}, y_{i,t+1})$ is the localization coordinate of $t+1$ iteration that is got for the last time. Then, the iteration operation is continued.

For the PSO algorithm, the bigger ω is, the stronger the overall search ability becomes, but the weaker the partial search ability becomes. So the self-adaptive method is used to determine ω, which is shown as follows.

$$\omega = \begin{cases} \omega_{\min} - \frac{(\omega_{\max}-\omega_{\min})\times(f-f_{\min})}{(f_a-f_{\min})}, & f \le f_a \\ \omega_{\max}, & f > f_a \end{cases} \tag{13}$$

where f is the current target function value of particle, $\omega_{\max}$ and $\omega_{\min}$ are the maximum weight and the minimum weight, and f_a and $f_{\min}$ are the average target function value and the minimum target function value.

The fitness function is used to evaluate the advantages and disadvantages of particle individual and lead search direction of the PSO algorithm in solution space. The specific function is got according to the solution process of Formula (3), which is in Formula (14).

$$f(x,y) = \sum_{i=1}^{n} \sqrt{(x_i - x)^2 + (y_i - y)^2 - d_i^2} \tag{14}$$

where (x, y) represents the coordinate of the target node, and (x_i, y_i) represents the coordinate of the ith reference node.

3.3. **Correcting the DV-Hop algorithm process.** For the conventional DV-Hop algorithm, there exist relatively larger errors. The ECDV-Hop algorithm of the paper is presented by the following steps.

Step 1. The sensor node is deployed randomly in the wireless network monitoring area, including the anchor node and the unknown node for localization.

Step 2. The minimum hop from all the nodes to each anchor node is recorded by all the nodes.

Step 3. The correction method presented in Section 3.1 is adopted to correct the average hop range.

Step 4. N particles are generated randomly, and the parameter related, the speed and the position are initialized. The position is the coordinate of the corresponding sensor node.

Step 5. The improved PSO algorithm proposed in Section 3.2 is adopted to optimize the DV-Hop algorithm.

Step 6. The optimization is halted when the halt conditions are satisfied, and the ultimate coordinate of the sensor node is decided according to the position of the optimal particle.

4. **Simulation Experiments and Result Analysis.** The simulation experiments are carried out on Matlab7. The anchor node and the unknown sensor node are deployed randomly in the square area of 100m×100m, in which the communications radius is expressed as $R = 10$m. In order to show the superiorities of the ECDV-Hop algorithm, the DV-Hop algorithm of the three-bonier measurement method, and the standard PSO algorithm are compared by the experiments. And the parameters are randomly selected as follows: the number of the particles is 20, the biggest iteration time is 500, and the largest speed of the particle is 5m/s. In the general conditions, the learning factor is $C_1 = C_2 = 1.4962$, and the inertia weight is $\omega_{\max} = 0.9$, $\omega_{\min} = 0.25$.

4.1. **Experiment on the localization speed comparison.** The average localization time (ms) of the unknown sensor node is shown in Figure 1. It can be seen that the average localization time of the ECDV-Hop algorithm is less than that of the DV-Hop algorithm and that of the PSO algorithm, which enhances the localization speed of the sensor node and satisfies the requirements of the real-time localization.

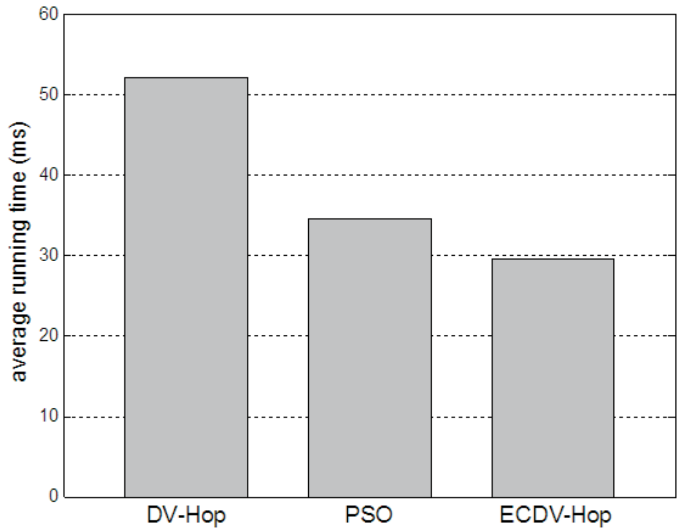

Figure 1. The comparison of average running time

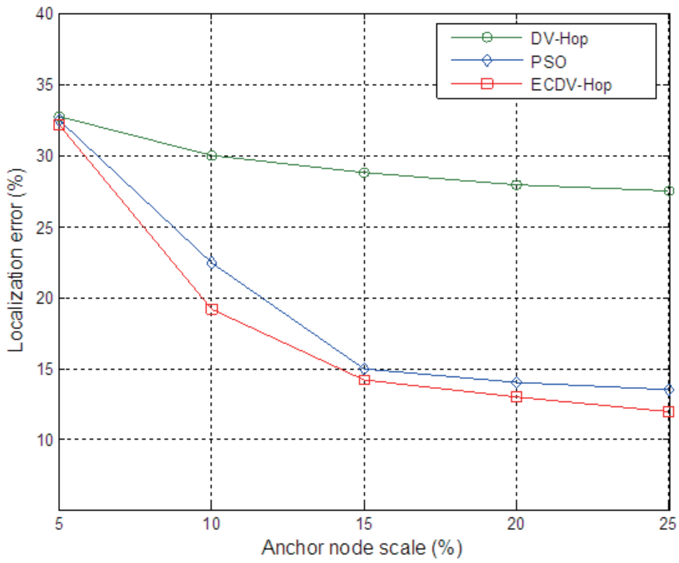

Figure 2. The anchor node scale and localization error

4.2. **Experiment on changing the anchor node scale.** In the experiment, the total number of the nodes is set to be 150. Under the conditions of different anchor node scales, the average localization error is shown in Figure 2. It can be clearly observed that the localization error is larger when the anchor node scale is smaller; the average localization error accordingly decreases with the increase in the anchor node scale. The comparison results show that in the same localization precision, for the ECDV-Hop algorithm, the anchor node number required is the smallest, and the cost is decreased as well; in the conditions with the same anchor number, the localization precision of the sensor node is improved by the ECDV-Hop algorithm greatly.

4.3. **Experiment on changing the total number of node.** In the experiment, the anchor node scale is set to be 15%. Under the conditions of different total number of nodes, the localization errors existing in different algorithms are shown in Figure 3. From the result analysis, it can be observed that compared with the DV-Hop algorithm and

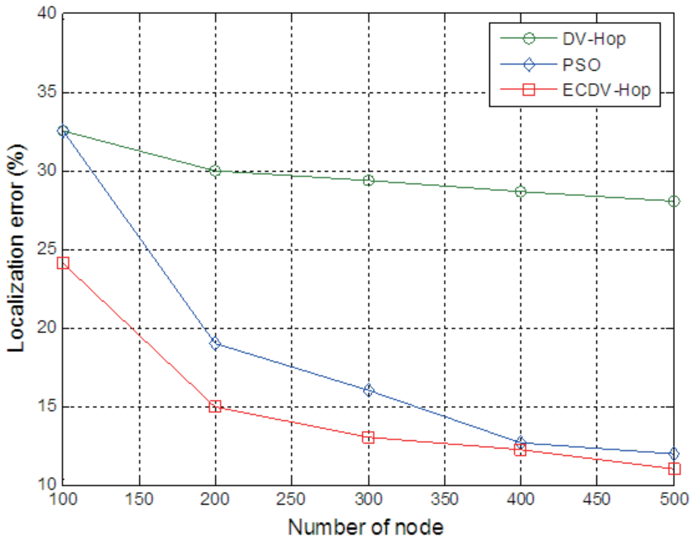

FIGURE 3. The number of node and localization error

the PSO algorithm, the ECDV-Hop algorithm reduces the negative influence of the error accumulation in the localization iteration process, which improves the node localization precision to some extent.

5. **Conclusions.** In order to improve the node localization precision in WSN, on the basis of analyzing the defect of the DV-Hop algorithm, the ECDV-Hop algorithm is put forward, which corrects the error in each stage of the DV-Hop algorithm effectively. And the superiorities of the optimal algorithm are proved by the simulation experiments, which has the faster localization speed and the higher localization precision. With the rapid development of WSN and the PSO algorithm, the optimal algorithm of the paper will show its broader prospect and more practical value. In the future work, the proposed ECDV-Hop algorithm will be researched further to improve the localization precision and will be applied in WSN practically.

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