Iterative L-M Algorithm in WSN – Utilizing Modifying Average Hopping Distances

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Abstract—Wireless Sensor Networks (WSN) are getting more and more attention for various applications. In addition, localization plays an important role in WSN. This article focus on the large errors of DV-Hop (Distance Vector-Hop) localization algorithm in net topology of randomly distributed notes. A CLDV-Hop (Correct Levenberg Marquardt DV-Hop) algorithm in DV-Hop based on modifying average hopping distances is proposed. Firstly, hop count threshold is to optimize the anchor node during a data exchange. The weighted average hop distance of unknown nodes nearest the three anchor nodes are selected as its average hop distance according to the minimum mean square criteria. Finally, L-M (Levenberg Marquardt) algorithm is used to optimize the coordinate of unknown node estimated by least squares. The simulation results show that, under the conditions of existing overhead and for a given simulation environment, CLDV-Hop algorithm has higher positioning accuracy than existing improved algorithms. The accuracy is improved 33%-41% compared with DV-Hop algorithm.

Keywords—wireless sensor networks, DV-Hop algorithm, localization, L-M algorithm

1 Introduction

Wireless Sensor Network (WSN) consists of a large number of sensor nodes distributed in the area with perceptive, processing and transmitting environment information. It is often applied in environmental monitoring, medical service, military investigation, industrial diagnosis and intelligent space [1]. Whatever the field is, researches lack of objectives and sensor nodes localization are meaningless. Therefore, node localization technology has become an important research topic in WSN [2].

At present, Global Positioning System (GPS) can achieve the node localization of WSN. However, taken price, volume, energy consumption and environment into account, it is impossible to use GPS massively [3]. Many researchers have proposed various positioning algorithms, which can be divided into range-based localization algorithms (Range-Based) and range-free localization algorithm (Range-Free) [4]. The former requires measuring absolute distance and angle between neighboring nodes. The latter can only implement localization, based on the connectivity of the network, such as centroid algorithm [3-5], convex programming algorithm [6], DV-Hop algorithm [7] and Approximate Point-in-triangulation Test (APIT) algorithm [8]. Range-Based has a higher requirement to hardware and it needs repeated measurements to obtain reasonable positioning accuracy. Therefore, it will cost a large amount of computation and communication. Range-Free positioning mechanism has been used widely in large-scale WSN with its economization, power-saving and simplicity.

DV-Hop is a typical Range-Free localization algorithm with simple implementation and high positioning accuracy. However, the positioning accuracy of the proposed algorithm is still inadequate in the random distribution of nodes in the WSN. Many scholars have put forward corresponding improvement schemes to solve the problems aiming at high accuracy, stability and efficiency. Reference [9] presented the improved measurement algorithm based on cosamp for image recovery. Reference [10] presented detecting wormhole attacks in Wireless Sensor Networks using hop count analysis. The algorithm set maximum necessary hop count between the sensor nodes and the same neighbor. The algorithm has been improved by above literatures. However, it still cannot meet the requirements of accuracy. Reference [11] proposed using the triangle inequality for constraining the distance from unknown nodes to multi-hop anchor nodes. While using the weighted hyperbolic for positioning. Reference [12] proposed a new method for distance computing from anchor nodes to unknown nodes using the weighted least squares method for location calculation. The CLDV-Hop algorithm proposes and compares with the algorithms in reference [11], [12] through simulation analysis. The results show that the proposed algorithm has higher positioning accuracy and stability in the network topology in randomly-distributed nodes.

The related work includes: Firstly, brief introduction of DV-Hop algorithm and reason analysis of the positioning error. Secondly, elaborate improvement of CLDV-Hop algorithm. Thirdly, the positioning accuracy of CLDV-Hop algorithm, the existing improved algorithm and the traditional DV-Hop algorithm is simulated from the average positioning error, the normalized positioning error and root mean square when the sim**u**lation environment is the same. Fourthly, the application environment and conclusion of CLDV-Hop algorithm are given according to simulation experiment.

2 Algorithm description and error analysis

2.1 DV-Hop algorithm

The localization process of DV-Hop algorithm [7, 13] is as follows: The traditional DV-Hop algorithm was put forward by Niculescu and Nath. The basic idea of the algorithm is to estimate distance between the unknown nodes and anchor nodes according to the product of average per hop distance and hops between unknown nodes and anchor nodes, and then adopt the trilateral law location to obtain the information of node position. Figure 1 illustrates the network topology, i, j, k represent three anchor nodes, p represents unknown node.

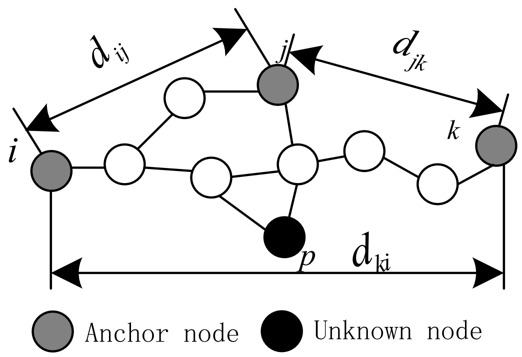

Fig. 1. Network structure diagram

First of all, all the nodes in the network receive the hop distance of anchor nodes using the typical distance vector exchange protocol. The nodes can obtain the packet structure as shown in Figure 2. From figure 1, it can be seen that the number of hops among anchor nodes i, j, k are $h_{ij} = 3$, $h_{jk} = 4$, $h_{ik} = 6$; the hops of unknown node p and three anchor nodes are $h_{ip} = 3$, $h_{jp} = 2$ and $h_{kp} = 4$.

Anchor node ID	(x_i, y_i)	hop Initialization is zero

Fig. 2. DV-Hop information exchange packet structure

Then, all anchor nodes receive location information and hop counts from other anchor nodes. Hereby, average hop distance of each anchor node can be estimated by HS, which can be represented as:

$$HS_i = \frac{\sum_{j \neq i} d_{ij}}{\sum_{j \neq i} h_{ij}} \tag{1}$$

Where, $d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ and $(x_i, y_i), (x_j, y_j)$ are the coordinates of anchor i and j, h_{ij} is the minimum hop count between anchor i and j. For example, for unknown node p in Figure 1, the average hop-sizes calculated by i, j and k are 3, 2 and 4 respectively. The average hops distance of anchor nodes i, j, and k are denoted as $\mathrm{HS}_i = (d_{ij} + d_{ik})/(3+6)$, $\mathrm{HS}_j = (d_{ji} + d_{jk})/(3+4)$ and $HS_k = (d_{ki} + d_{kj})/(4+6)$.

When the average hop distance of anchor nodes is calculated, it is broadcasted to the network through the controlled flooding method. The unknown nodes only record the average hop distance value of the first anchor node. For Figure 1, unknown node p receives the average hop distance information from anchor node j firstly. Therefore, the distance from p to anchor nodes i, j, k are denoted as $d_{pi} = 3 \times \mathrm{HS}_j$, $d_{pj} = 2 \times \mathrm{HS}_j$ and $d_{pk} = 4 \times \mathrm{HS}_j$.

Finally, when the unknown nodes obtain three or more distance from the anchor nodes, the trilateral positioning method can be executed to solve the estimated coordinate of the unknown nodes. Supposing there are n unknown nodes, m represents anchor nodes, then the location of unknown node p can be estimated through Eq. (2):

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = d_1^2 \\ \vdots \\ (x_m - x)^2 + (y_m - y)^2 = d_m^2 \end{cases} \tag{2}$$

The above equations can be transformed into $AX = b$. Among them,

$$A = 2\begin{bmatrix} x_1 - x_m & y_1 - y_m \\ \vdots & \vdots \\ x_{m-1} - x_m & y_{m-1} - y_m \end{bmatrix}, \quad b = \begin{bmatrix} x_1^2 - x_m^2 + y_1^2 - y_m^2 + d_m^2 - d_1^2 \\ \vdots \\ x_{m-1}^2 - x_m^2 + y_{m-1}^2 - y_m^2 + d_m^2 - d_{m-1}^2 \end{bmatrix}, \quad X = \begin{bmatrix} x \\ y \end{bmatrix} \tag{3}$$

Therefore, $AX = b$ uses the least squares method to estimate the unknown node coordinates as $\tilde{X} = (A^T A)^{-1} A^T b$.

2.2 Positioning Error Analysis

The positioning accuracy of DV-Hop algorithm in WSN mainly depends on hop count, average hop distance and position calculation.

Hop-count information As shown in Figure 3, the network communication model of an anchor node is assumed as a disk shape. Assuming the information nearest the anchor node received by its surrounding unknown nodes as an anchor node in the center of the disk. d_{pi} is the distance from unknown node p to anchor node i, d_{qi} is the distance from unknown node q to anchor node i. It can be seen in Fig. 3, $h_{pi} = h_{qi} = 2$ and $d_{pi} = HS_i \times h_{pi}$, that is $d_{pi} = d_{qi}$, in fact $d_{qi} = HS_i \times h_{qi}$. Therefore, the hop count information brings a lot of errors for the location.

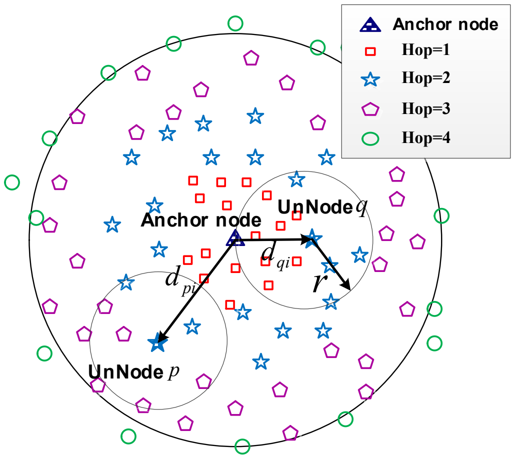

Fig. 3. Hops and positioning accuracy analysis

The Average Hop Distance: From the process of DV-Hop algorithm in the above, it can be seen that the actual distance between the node and anchor node is the product of hop count and the average hop distance. Therefore, the positioning accuracy of the whole network is directly affected by the average hop distance. As shown in Figure 3, the WSN nodes are randomly distributed, the route among anchor node i, j, k is not a straight line, and using average method instead of measuring distance is inherently existing error. If only using the average hop distance of the anchor node nearest the unknown nodes as the average hop distance to estimate the unknown nodes, the network cannot be reflected wholly.

Therefore, the DV-Hop algorithm replaces the distance as the product of the hop count and the average hop distance. The positioning error is not only related to the hop count but also the average hop distance.

Positioning Calculation: In the DV-Hop algorithm, if three or more anchor nodes of an unknown distance are known, the coordinate of unknown nodes can be estimated by trilateral and multilateral localization. In fact, multilateral localization is sensitive to the ranging error. When the ranging error is large, the estimated coordinates calculated through multilateral localization method have greater deviation than real coordinates [14]. In addition, it is found that in the process of simulation, when $A^T A$ is ill conditioned matrix, the estimated coordinates of unknown nodes not only have large error but the positioning accuracy and stability is also poor through multilateral localization method, sometimes even have incorrect results.

3 CLDV-Hop Algorithm

Through the above analysis of the positioning error, the algorithm is improved from three aspects without changing the original algorithm of the structure.

3.1 Weighted average hop distance based on least mean square criterion

Traditional DV-Hop algorithm in the calculation of the average hop distance uses unbiased estimation criteria. However, in the randomly-distributed WSN, the error obeys Gaussian distribution. Using mean square error of the average hop distance is more reasonable than deviation or variance [15]. Therefore, this paper uses a least mean square error criterion to calculate the average hop distance, that is:

$$f_\varepsilon = \sum_{j \neq i, i=1}^{N} (d_{ij} - HS_i \cdot h_{ij})^2 \tag{4}$$

Set $\frac{\partial f_\varepsilon}{\partial HS_i} = 0$, the average hop distance of anchor nodes can be presented as:

$$HS_i = \frac{\sum_{j \neq i, i=1}^{N} (h_{ij} d_{ij})}{h_{ij}^2} \tag{5}$$

In the second stage of DV-Hop algorithm, the average hop distance of the anchor node received by the unknown node is the average hop distance. Considering the distribution of nodes in Wireless Sensor Networks it is not uniformed. Because, only by estimating the average hop distance from a single anchor node to the anchor node around the unknown nodes distance may cause deviation of the local positioning accuracy greatly and the positioning accuracy of the whole network is not stable. Therefore, the positioning accuracy of the whole network can be improved considering the average hop distance of multiple anchor nodes.

In this paper, an improved weighted average hop distance is proposed. The average hop distance of nearest multiple anchor nodes received by the unknown nodes is normalized weighted, and small average hop distance is given large weights. The specific calculation process is as follows:

If the unknown node can receive the information of N anchor nodes, the average hop distance of the anchor node i is denoted as HS_i, hops between unknown node p and anchor node i is denoted as h_{pi}, and the weight calculation formula based on weighted average hop distance is as follows:

$$W_i = \frac{1/h_{pi}}{\sum_{j=1}^{N} \frac{1}{h_{pj}}} \tag{6}$$

Combined with the network topology of Figure 1, the weight of anchor nodes i, j, k are $4/13, 6/13$ and $3/13$ respectively. Through equation (6), the distance of unknown nodes at different positions in the average hop distance is given different weights. The closer gives larger weight, which can not only reflect the unknown nodes make full use of the recent information of anchor nodes, but also obtain more accurate and reasonable average hop distance. It can be seen from the error analysis of DV-Hop that the accumulated error becomes larger and larger with the increase of hop count. Therefore, choose the average hop distance of the three anchor nodes nearest the unknown nodes as the average hop distance to calculate the average hop distance of unknown nodes. In Figure 1, the average hop distance of the unknown nodes is calculated as,

$$C_p = HS_i * W_i + HS_j * W_j + HS_k * W_k \tag{7}$$

According to equation (7), combined with the network topology structure of Figure 1, it can be known that the estimated distance between the unknown node p and the anchor nodes can be re expressed as $\tilde{d}_{pi} = 3 \times C_p$, $\tilde{d}_{pj} = 2 \times C_p$ and $\tilde{d}_{pk} = 4 \times C_p$.

3.2 Improved threshold based on hop packet format

From the first phase of DV-Hop positioning, it can be known that all anchor nodes send data packets to the surrounding nodes and the format is shown in Figure 2. The anchor nodes send data packets to the surrounding nodes. The nodes of WSN are randomly distributed and the range is uncertain; therefore, the data packets transmitted by the anchor nodes are large which leads cumulative error to be larger and larger. To tackle this problem, the data packet format can be improved from the anchor nodes by adding the transmission range of node hops of anchor packet with lifetime limit; that is, the method of limiting the maximum value of the hop count hop_M. Among them, hop_M is obtained by multiple simulation experiments. However, hop_M restriction also affects the positioning accuracy directly. Since the smaller the value of hop_M is, the less anchor nodes is able to explain the unknown nodes communication.

In wireless sensor network, anchor nodes information is very important. When there have few or less than three anchor nodes communication, it will lead to lower positioning accuracy and even unable to locate. Therefore, to select appropriate hop_M, the related factors includes communication radius, the proportion of anchor nodes and wireless sensor network range.

ID	(x_i, y_i)	hop Initialization Is zero	hop_M

Fig. 4. The modified packet format

As shown in Table 1, the range of wireless sensor network is the area with 100m*100m and the proportion is 20% with anchor nodes. Communication radius is set as R, the maximum hop count between nodes is h_{MAX}, and setting the optimal hop count threshold hop_M is simulated. The percentage of the positioning accuracy improvement is Ac_I compared with the DV-Hop algorithm. The simulation is 100 times, the maximum value is found through the function max (max (Hop1)) each time. h_{MAX} is the maximum hop count of the 100 times simulation.

Table 1. the optimal threshold hops selection

Communication radius R/m	h_{MAX}	hop_M	Ac_I
20	9	6	5.2%
30	6	4	7.8%
40	4	3	6.1%

3.3 Optimal location estimation based on L-M method

Supposing (x, y) is the coordinate of an unknown node p, anchor node distance m can be given. (x_i, y_i) is the known coordinate of the $i^{'}th$ anchor node receiver , and d_i is the distance from anchor node $i^{'}th$ to the unknown node p. Supposing there are n unknown nodes, the location of unknown node p can be estimated according to equation (8):

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = d_1^2 \\ \vdots \\ (x_m - x)^2 + (y_m - y)^2 = d_m^2 \end{cases} \tag{8}$$

These equations can be transformed into $AX = b$ .Therefore, $\mathbf{AX} = \mathbf{b}$ can be solved according to the least square method, and the estimated coordinate of unknown node should be,

$$\mathbf{X} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{b} \tag{9}$$

Convert type (8) into:

$$F(X) = \sum_{i=1}^{m}((x_i - x)^2 + (y_i - y)^2 - d_i^2)^2 = \mathbf{r}(X)^{\mathrm{T}}\mathbf{r}(X) \tag{10}$$

In the formula, X is the unknown node coordinate (x, y), and $\mathbf{r}(X)$ is the residual function. Therefore, the estimated coordinates of the unknown nodes can be transformed into the unconstrained least squares of equation (10), which is min F(X). L-M method has obvious advantages in dealing with nonlinear least squares optimization. In this paper, the L-M method is used to optimize the method [16]. The iterative formula of L-M algorithm can be expressed as:

$$X^{(k+1)} = X^{(k)} - \left[J\left(X^{(k)}\right)^T J\left(X^{(k)}\right) + \mu diag\left(J\left(X^{(k)}\right)^T J\left(X^{(k)}\right)\right)\right]^{-1} J\left(X^{(k)}\right)^T J\left(X^{(k)}\right) \tag{11}$$

Where, $X^{(0)}$ is the initial value (x, y) solved by the least squares of the unknown nodes according to formula (7). k is the iterative variable, μ is the damping parameter and $\mu > 0$. $\mathbf{r}(X^{(k)})$is,

$$\mathbf{r}(\mathrm{X}^{(\mathrm{k})}) = (r_1(X^{(k)}), (r_2(X^{(k)}), \ldots, (r_m(X^{(k)}))$$

$\mathbf{J}(X^{(k)})$ is the Jacobi matrix consisted of residual function $\mathbf{r}(X)$ in the first derivative at $X^{(k)}$,

$$\mathbf{J}(X) = \begin{bmatrix} \frac{\partial r_1(X)}{\partial X_1} & \frac{\partial r_1(X)}{\partial X_2} & \cdots & \frac{\partial r_1(X)}{\partial X_m} \\ \frac{\partial r_2(X)}{\partial X_1} & \frac{\partial r_2(X)}{\partial X_2} & \cdots & \frac{\partial r_2(X)}{\partial X_m} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial r_n(X)}{\partial X_1} & \frac{\partial r_n(X)}{\partial X_2} & \cdots & \frac{\partial r_n(X)}{\partial X_m} \end{bmatrix} \tag{12}$$

The algorithm steps on the iterative refinement of unknown nodes are summarized as follows:

Step1. Obtaining the estimated value X of unknown coordinate through multilateral positioning method and take the estimated value X as the initial value $X^{(0)}$ of L-M algorithm. Set the damping parameter μ, amplification factor ν and the maximum number of iterations $gx_{\max}$, and let $k=0$.

Step2. Calculate $F(X^{(k)})$, $\mathbf{r}(X^{(k)})$;

Step3. Calculate $\mathbf{J}(X^{(k)})$ and calculate $\Delta X = X^{k+1} - X^{k}$ according to the formula (11). Determine whether $k > gx_{\max}$ is established; if it is established, the optimal solution is $X^{*} = X^{(k+1)}$, iteration ends; otherwise, go to step 4.

Step4 If $F(X^{(k+1)}) < F(X^{(k)})$, let $\mu = \mu/\nu$, go to step 5; otherwise, l=0, let $\mu = \mu \times \nu$, go to step 5;

Step5 Let $k = k+1$, go to step 2;

3.4 Process of the CLDV-Hop positioning algorithm

In order to solve the accuracy of DV-Hop algorithm, a wireless sensor network localization algorithm based on the average hop distance correction (L-M) optimization is proposed. The minimum mean square criterion and the weighted hop count are used to estimate the average hop distance to make the result more accurate. Moreover, the hop count is optimized to reduce the accumulated error; meanwhile, the L-M optimization algorithm is used to refine the positioning results iteratively.

CLDV-Hop algorithm steps are as follows:

Step1 Network initialization, at the same time, the simulation related variables are given in this paper (Table 2).

Step 2: Anchor nodes send information by flooding broadcast including its ID, coordinates, hops and hop threshold hop_M.

Step 3: Use the shortest path algorithm to compute nodes hop count, calculate the average hop distance of each anchor node through formula (5) and broadcast it to the network and the unknown nodes. Weighted average hop distance is obtained from the nearest three anchors. The distance between unknown nodes and anchor nodes is estimated through the product of the hop count and average hop distance.

Step 4: The least square solution $X_i^{(0)}(x_i, y_i)$ of the unknown node i is obtained through formula (9).

Step 5: Using $X_i^{(0)}(x_i, y_i)$ as the initial value of L-M algorithm for iterative refinement, the estimated coordinate X(2,UN Amount) of unknown nodes is achieved.

Step 6: The CLDV-Hop algorithm is evaluated by mean position error, normalized mean position error and root mean square error.

Table 2. Simulation variables and parameters

Variable	Description (parameter setting)
Border Length	Area length(100*100)
Node Amount	Total number of nodes(100)
Simulation Times	Simulation times(100)
Anchor Amount	Anchor nodes(10， 20， 30)
UN Amount	Unknown nodes
Hop_M	Maximum number of hops
R	Communication radius(15,20,25,30,35,40)
U	Damping parameter of L-M algorithm(2)
V	Amplification factor of L-M algorithm(1.5)
Var	Independent variable of L-M algorithm[x,y]
$gx_{\max}$	Maximum number of iterations(20)
h(i,j)	Jump number matrix (initial 0)
X(2,UN Amount)	Estimated coordinates of unknown nodes
Anchor(2,Anchor Amount)	Anchor node coordinates
UN(2,UN Amount)	Actual coordinates of unknown nodes
Dall (i, j)	Distance matrix between nodes
Dhop (Anchor Amount,1)	Average hop distance of anchor nodes
UNW Dhop (UN Amount,1)	Average hop distance of unknown nodes

4 Simulation and Experiment

In order to verify the performance of the improved algorithm, it uses 2014b MATLAB platform to simulate and analyze the CLDV-Hop positioning algorithm that proposed in this paper compared with the relevant methods. The other simulation parameters are referenced in table 1.

4.1 Simulation Parameters and Definitions

Network simulation environment settings are that WSN area size is 100x100m, 100 sensor nodes are arranged in the area randomly (including the unknown nodes and anchor nodes). In order to verify the stability of the algorithm, the algorithm simulation has 100 times and take the average value. The relevant definitions involved are as follows,

1. Suppose the actual position of node i is T_i, the estimated position is $\tilde{T}_i$. The average location error of the entire network can be defined as $e = \dfrac{\sum_{j=1}^{N}\sum_{i=1}^{K}\left|T_i - \tilde{T}_i\right|}{KN}$.

2. Normalized average location error $\overline{e} = \frac{e}{r}$: r is the communication radius.
3. To evaluate the performance of algorithms, it usually using the root mean square as a performance measurement of the algorithm. The specific formula is:

$$\delta_{M,N} = \sqrt{\frac{\sum_{i=M}^{N} (e(i) - r(i))^2}{M - N + 1}}, M > N \cdot \tag{13}$$

Where, $e(i)$ is an estimated value, $r(i)$ is the true value, M is the number of anchor nodes, $N = 1$.

4.2 Algorithm Performance Analysis

Figure 5 is the random distribution of network nodes. Where the red are anchor nodes and the black are unknown nodes.

Figure 6 is the positioning deviation of unknown nodes which can be seen from Figure 6. Setting the communication radius is 30, the anchor node proportion is 20%, and the improved positioning accuracy is significantly higher than DV-Hop algorithm.

Figure 7 and 8 compare with the literature [11], which uses weighted hyperbolic positioning algorithm (denoted as WDV-Hop) and literature [12]. It uses the new algorithm to compute the distance of unknown nodes, anchor nodes (denoted as NDV-Hop) and conventional DV-Hop algorithm. The relationship of the normalized average position error and the total number of nodes of the several algorithms is simulated.

In Figure 8, the communication radius is 20, hop_M is 6, the anchor nodes are 15. It can be seen that, with the increase of the total number of network nodes, the CLDV-Hop algorithm proposed is lower than the average localization error. In Figure 8, the communication radius is 30, hop_M is 4, the anchor nodes are 15. It can be seen that, when the total number of nodes are 150, DV-Hop algorithm error is 9.64, NDV-Hop algorithm error is about 7.24. WDV-Hop algorithm is about 6.95 approximately, while CLDV-Hop algorithm proposed is only 5.96. From Figure 7 and 8, it can be seen that, different communications radius have great impact on positioning accuracy. However, WSN have problems with optimal communication radius and practical application in several tests to select an optimal communication radius.

Figure 9 simulates the positioning error changes with the node communication radius. Set the anchor node proportion is 20%, hop threshold changes with the radius of communication and different values. It can be seen from the figure of DV-Hop algorithm, if the communication problems of the optimal radius exist, the optimal communication radius should be chose in practical application.

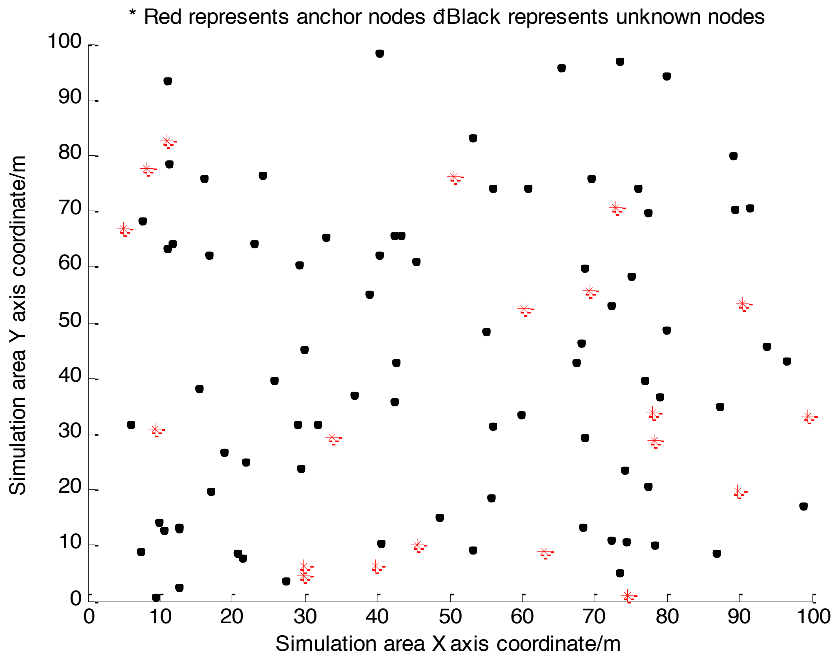

Fig. 5. Random distribution of network nodes

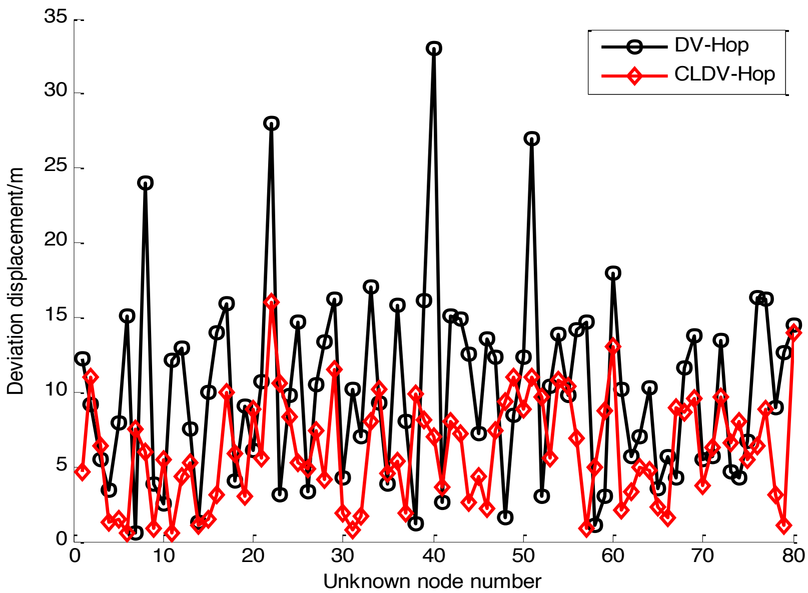

Fig. 6. Positioning deviation of unknown nodes

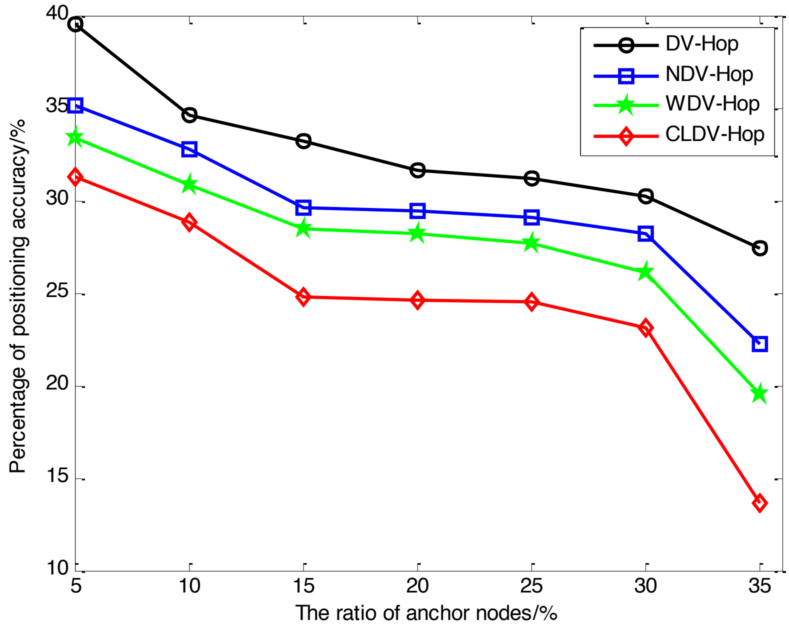

Fig. 7. Localization error varying radio of anchors (R=20m)

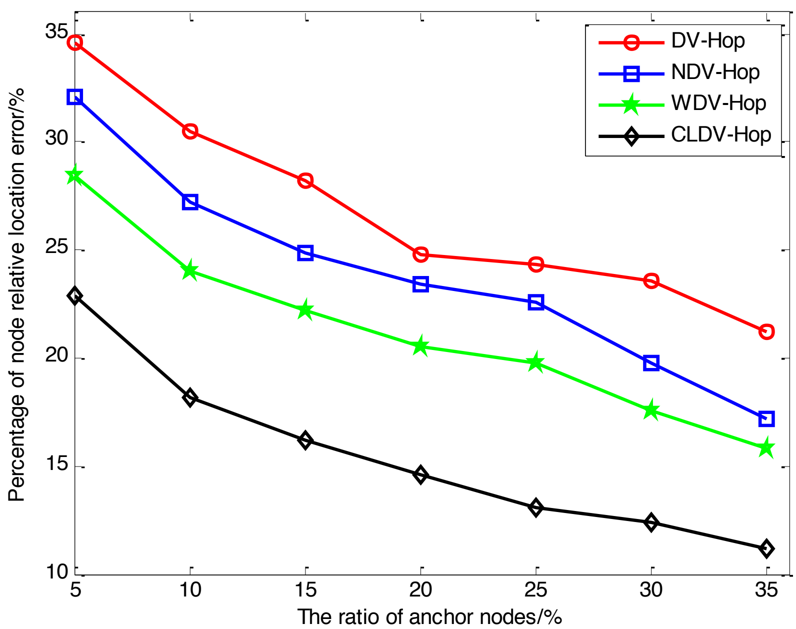

Fig. 8. Localization error varying radio of anchors (R=30m)

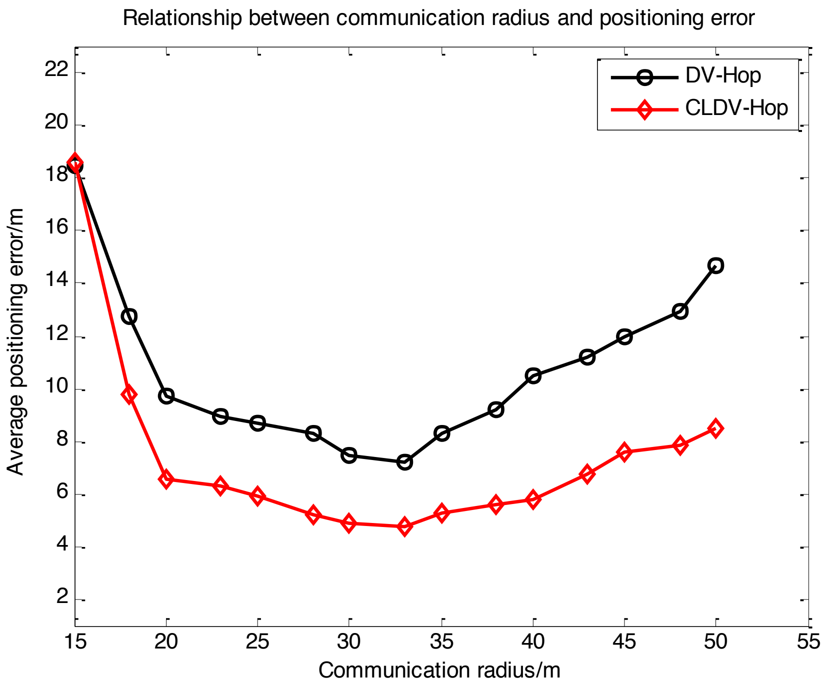

Fig. 9. Influence of communication radius on positioning accuracy (anchor ratio 20%)

Table 3 is the comparison of the performance between DV-Hop and CLDV-Hop algorithm. The communication radius is set as 30, hop_M is 4. It can be seen that, the average positioning error of the improved algorithm is much smaller than the traditional algorithm. The positioning accuracy increases about 33%-41% with the difference anchor nodes ratio. The normalized root mean square error of CLDV-Hop is only from $1/3$ to $1/2$ of DV-Hop algorithm. CLDV-Hop algorithm has obvious advantages in positioning performance.

Table 3. Algorithm performance comparison

Anchor node Proportion /%	DV-Hop		CLDV-Hop	
	NAE/m	*NRMSE*	*NAE/m*	*NRMSE*
20	10.7310	0.5532	5.8806	0.2188
30	8.2267	0.4817	4.8973	0.1563
40	9.2332	0.5024	5.4490	0.1822

5 Conclusions

This paper proposes iterative algorithm for L-M in WSN, based on modifying average hopping distances. It can be used in large-scale wireless sensor network positioning monitoring with randomly-distributed nodes, such as geological disaster monitoring, water pollution monitoring and forest fire monitoring. The following conclusions can be drawn through the simulation experiment:

1. Problems of the optimal anchor nodes exist in DV-Hop algorithm. Reasonable jump threshold number (rounding far anchor nodes) setting can not only improve the positioning accuracy, but also reduce the amount of communication. The unknown node should communicate with at least three or more anchor nodes.
2. Since DV-Hop localization accuracy can be influenced by average hop distance, the error can be reduced by selecting the weighted average hop distance of nearest three anchor nodes as the average hop distance of the unknown node.
3. Larger errors exist when DV-Hop algorithm uses maximum likelihood estimation or multilateral localization algorithm for over determined equations of least square solution. Higher accuracy can be achieved by transforming into nonlinear least squares optimization and then optimized by L-M.

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