A New Improved Range Free Algorithm Based on DV-Hop in Wireless Sensor Network

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Abstract—In emerging wireless sensor networks application, localization issue attracts the most attention in recent years. DV-Hop algorithm is a typical range free nodes localization algorithm in WSNs but the localization accuracy of sensor nodes is still low for some applications. In this paper, an improved algorithm based on DV-Hop algorithm is proposed. In the improved algorithm, the localization accuracy is increased from two aspects. Firstly, the improved algorithm proposes a new method and calculates the average hop distance. Secondly, the improved algorithm increases the numerical computation accuracy and improves the stability of the operation by solving the equations through QR decomposition. The simulation results show that the improved algorithm is superior in localization accuracy than DV-Hop algorithm.

Index Terms—Wireless sensor network, DV-Hop algorithm, localization, QR decomposition

I. INTRODUCTION

With the development of the micro-electronics and wireless communications technology, wireless sensor networks(WSNs) have aroused much public attention due to their wide spread application such as military monitoring, health-care, environmental monitoring, traffic management, smart home, and so on [1]. Wireless sensor network is a new technology about acquiring and processing information, and can self-organization [2]. It consists of a large number of sensor nodes, which are low-cost, low-power and small-size. The sensor nodes distributed randomly in given area and it can monitor and collect environmental or the monitoring object information. But in wireless sensor networks, it is meaningless if there is no location information in monitoring information. So the node location information is one of the key issues and has attracted widespread attention in WSNs.

The most popular localization way is to install the GPS (Global Positioning System) receivers, GPS is a way to acquire the location information of sensor nodes. But providing each node with localization hardware GPS receiver is unrealistic. GPS is unavailable in indoor environments and is inadequate for energy-constrained networks. At the same time the cost of each sensor node is increased. Therefore, other localization algorithms need to be developed in WSNs.

Many localization algorithms for WSNs have been proposed to estimate the location of sensor nodes in recent years. The localization algorithms can be classified as the range-based and range free according to whether there is a need for actual measurement of the distance sensor nodes or sensor nodes' relative angle [3].

Range-based algorithms require absolute point-to-point distance or angle information to compute the location of unknown nodes, such as Time Difference of Arrival (TDOA) [4], Time of Arrival (TOA), Angle of Arrival (AOA) [5] and Received Signal Strength Indication (RSSI) [6]. These algorithms are of high precision but depend on additional hardware to get accurate measurements, so make them more expensive. On the other hand range-free algorithms depends on connectivity information, they don't use absolute point-to-point distance or angle information and costly hardware, which makes it more practical, such as DV-Hop algorithm [7], Approximate Point-in-Triangulation test algorithm (APIT) [8], Amorphous algorithm and Centroid algorithm [9].

Because the high cost of the range-based algorithm, the low cost range-free location algorithm has been widely used in recent years. In this paper, we focus on the range free localization algorithm and propose an improved DV-Hop algorithm. The improved localization algorithm enhances the localization accuracy of the unknown nodes without increasing extra hardware and communication traffic.

In the new improved localization algorithm, localization error is reduced in following two aspects. First, the range measurement error is decreased using the new way. Second, the localization error is reduced by solving a system of n equations through *QR* (*Q*:orthogonal matrix, *R*: upper triangular matrix) decomposition. Simulation results show that the

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localization accuracy of unknown nodes is increased comparing with typical DV-Hop algorithm.

The rest of this paper is organized as follows: Section 2 introduces the related work about this paper. Section 3 explains the DV-Hop algorithm. Section 4 analyzes the localization error of DV-Hop algorithm. In Section 5 the improved DV-Hop algorithm is discussed briefly. In Section 6 simulation results of DV-Hop and improved algorithm are shown. Finally in Section 7, we conclude the whole work of this paper.

II. Related Work

This part of the paper presents four classical range free localization algorithms that are related to our work. They are DV-Hop algorithm, APIT algorithm, Amorphous algorithm and Centroid algorithm respectively. In these range free localization algorithms, the sensor nodes are divided into two types. The nodes that their coordinates is known are called anchor nodes. On the contrary the nodes that their coordinates is not known are called unknown nodes. In this paper, we emphasizes on the range free localization algorithm-DV-Hop algorithm.

The DV-Hop algorithm was proposed by Niculescu and Nathin 2001 [10]. In DV-Hop algorithm, anchor nodes broadcast their packets to all the nodes in the wireless sensor network. The format of the packet is $\{id, x_i, y_i, HopCount_i\}$. The initial value of the hop count is zero. The neighbor nodes of it only record the packets with minimum hop count, then the hop count value add one and broadcast the packet to other neighbor nodes. Then it computes average hop size on the basis of the actual distance between anchor nodes. In the end, we use the product of minimum hop counts and the average hop distance to estimate the coordinates of the unknown nodes.

The APIT algorithm was put forward by Prof. T. He in 2003 [11]. Its principle is to coverage the overlapping area of the triangles which includes the unknown node. The unknown neighbor node selects three nodes from its neighborhood, then tests whether the unknown node is in the triangle that surrounded by the three neighbor anchor nodes. The process is repeated until all of the ternary combination is exhausted or reaches the required time. Then, it calculates the centroid location of all the triangle overlap area as the coordinates of the unknown node.

The Amorphous algorithm requires prior information of network density, it uses offline hop distance estimation. It is proposed to generate a comparatively accurate position on distributed processors via local information.

The centroid localization algorithm was proposed by N. Bulusu and J. Heidemann in 2000 [12]. In centroid algorithm the anchor nodes broadcast their own *ID* and locations to their neighbor nodes. When the number of anchor nodes required localization has exceeded a certain threshold or a certain time, the centroid of the polygon composed by the anchors is the localization of the unknown node.

The DV-Hop algorithm is a typical range free localization algorithm. Its advantage is simplicity, feasibility, cost-effectiveness and high coverage and so on. But its major disadvantage is its poor localization accuracy. To improve the localization accuracy, many scholars have proposed many algorithms to improve the localization accuracy of the algorithm.

In [13], the proposed algorithm adds a correction to the hop count between the anchor nodes and the unknown nodes by using the RSSI of the received packets. With the new idea, the distance between sensor nodes can be more accurately computed in DV-Hop localization algorithm.

In [14], the algorithm uses error correction value δ to modify the average hop distance, to reduce the deviation between the average hop distance and the true average hop distance. The improved algorithm has effectively reduced the average localization error of unknown nodes and improved the localization accuracy.

In [15], the algorithm used WLS algorithm. The location of unknown nodes is refined by using extraneous information obtained by solving the equations.

In [16], the improved algorithm introduces threshold M, it uses the weighted average hop distances of anchor nodes within M hops to calculate the average hop distance of unknown nodes.

In [17], the algorithm proposed a new type of weighted DV-Hop algorithm based on correction factor in WSNs based on the selecting of referenced anchor nodes and the calculation method of the average hop distance from the unknown node. Firstly, the unknown nodes record the average hop distance from all anchor nodes in one hop distance. Secondly, the percentage error is introduced as the correction factor to calculate the average hop distance for the unknown node.

In [18], the author analyzed the relationship between DV-Hop localization error and the col-linearity, and then proposed an algorithm to select the anchor nodes which can meet the condition of hop count threshold and col-linearity to participate in the localization procedure. Because it is hard to decide if the region of the anchor node is in one hop area, then Voronoi diagram is adopted to divide the sensor network into several regions. It can get the anchor node information in every Voronoi polygon. With the information and col-linearity condition, the algorithm can estimate the unknown node’s localization.

Although the literature mentioned above improved the accuracy of the algorithm in studying nodes’ localization, they just focus on average hop distance. There are few scholars take the solving process of equation into account. In this paper, we propose a new improved localization algorithm based on DV-Hop algorithm. The algorithm considers not only the average hop distance but also the solving process of equation. The simulation results show that the improved localization algorithm can increase the accuracy of the nodes localization.

III. DV-HOP ALGORITHM

DV-Hop localization algorithm is a widely used range free algorithm in WSN. It is a suitable for not only sensor nodes which have three or less neighbor anchor nodes but also for the sensor nodes which have more than three neighbor nodes. The advantages of the DV-Hop algorithm are as follows: the low hardware requirements, simplicity of operator and low energy consumption. In this section, we describe the original and classical DV-Hop algorithm. The implementation of the algorithm includes three steps.

Step 1: Each anchor node in WSN broadcasts a packet to its neighboring nodes, which includes the node' s id, position information and the hop count value initialized to 0. Each anchor node receives the packet and records the minimal hop count value from each anchor node. The anchor node also forwards the packet to its neighbor node and ignores the larger hop count value from the same anchor nodes. Through this process, all the nodes will get the minimum hop count value from every anchor nodes.

Step 2: The anchor nodes calculate the average hop distance using the following formula (1).

$$HopSize_i = \frac{\sum_{i \neq j} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{i \neq j} h_{ij}} \quad (1)$$

In formula (1), (x_i, y_i), (x_j, y_j) are the coordinates of the anchor node i, j, h_{ij} is the hop count between node i, j. $HopSize_i$ is the average hop distance. Anchor nodes broadcast calculated average hop distance group with a lifetime field to the network. The unknown node records the first received average hop distance, and forwards it to the neighbor nodes. After obtaining average hop distance, unknown nodes compute the distance to each anchor node according to the hop count value obtained in step1. The distance can be estimated by formula (2).

$$d_{ij} = HopSize_i * h_{ij} \quad (2)$$

Step 3: Calculate the coordinates of the unknown nodes by using the trilateration method or maximum likelihood estimation method.

IV. ANALYSIS OF DV-HOP ERROR

DV-Hop algorithm supposes that the product of the minimum hop count value and the average hop distance is the estimated distance between the nodes. But the average hop distance often brings error which used the hop distance instead of straight distance. When the estimated value and the actual value of the average hop distance have large deviation, localization error will be increased. The error principal of DV-hop algorithm is shown in Fig 1. In Fig. 1, the black nodes represent anchor nodes, the white node with an "*U*" represents the unknown node. *D1*, *D2* and *D3* are the true distance between the anchor nodes. The average hop distance is calculates by formula (3). In formula (3) $average_A, average_B$ and $average_C$ is the average hop distance of A,B and C.

$$average_A = \frac{D1 + D3}{2+5}, \quad average_B = \frac{D1 + D2}{2+5}$$
$$average_c = \frac{D2 + D3}{5+5} \quad (3)$$

The three average hop distances are broadcast in WSN, the unknown nodes record the average hop distance from the first arrived packet. So the estimated distances between U and A, B and C are calculated by formula (4). In formula (4), D_{UA}, D_{UB} and D_{UC} are the estimated distances separately. From the formula (4), $D_{UA} = D_{UB}$, but seen from Fig. 1, we can see clearly that $|UA| \neq |UB|$. So the distance error is very large using the DV-Hop algorithm in the anisotropic network.

$$D_{UA} = \min\{average_A, average_B, average_C\} \times 2$$
$$D_{UB} = \min\{average_A, average_B, average_C\} \times 2 \quad (4)$$
$$D_{UC} = \min\{average_A, average_B, average_C\} \times 3$$

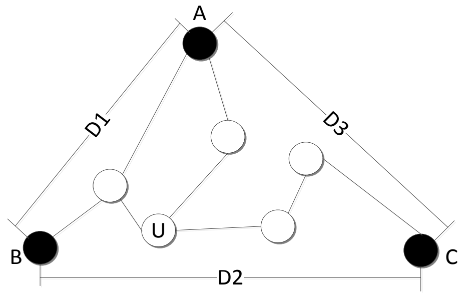

Fig. 1. The error principal of DV-hop algorithm.

V. THE IMPROVED DV-HOP ALGORITHM

Through analyzing the steps of the DV-Hop algorithm, the main impact factors in nodes localization accuracy are in Step 2 and Step 3, the calculation of average hop distance in Step 2 and the calculation of the unknown nodes localization in step 3. In this paper, we make some improvements in the calculation of average hop distance and the unknown nodes localization.

In step 2, the anchor nodes calculate the average hop distance using the formula (1). But we select any anchor nodes which their distance less than or equal to the radio range. In step 3, it solved the equations through QR decomposition.

The main steps of the new DV-Hop algorithm are as follows:

Step 1: Each anchor node in WSN broadcasts a packet to its neighboring nodes, which includes the node's id, position information and the hop count value initialized to 0. Each anchor nodes received the packet and recording the minimal hop count value from each anchor node. The anchor node also forwards the packet to its neighbor node and ignores the larger hop count value from the same anchor nodes. Through this process, all the nodes will get the minimum hop count value from every anchor nodes.

Step 2: The anchor nodes calculate the average hop distance using the following formula (5).

$$HopSize_{R-i} = \frac{\sum_{i \neq j} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{i \neq j} h_{ij}}, |ij| \leq R \quad (5)$$

In formula (5), (x_i, y_i), (x_j, y_j) are the coordinates of the anchor node i, j, the distance of the nodes i, j is less than or equal to the radio range. R is radio range of the network. h_{ij} is the hop count between node i, j. $HopSize_{R-i}$ is the new average hop distance. If the distance is more than the radio range of the network, the error of the average hop distance is big corresponding.

Anchor nodes broadcast calculated average hop distance group with a lifetime field to the network. The unknown node records the first received average hop distance, and forwards it to the neighbor nodes. After obtaining average hop distance, unknown nodes compute the distance to each anchor node according to the hop count value obtained in step 1. The distance can be estimated by formula (6). d_{R-u} is the estimated distance between the unknown nodes u and the anchor nodes *j*. h_{uj} is the hops between unknown node u and anchor node *i*.

$$d_{R-u} = HopSize_{R-i} * h_{uj} \quad (6)$$

Step 3: Each unknown node calculates its location by least square method, solving the equations through QR decomposition.

Let (x, y) be the coordinate of the unknown node u. The coordinate of the of ith anchor node is (x_i, y_i), Let d_i donate the distance between the unknown node u and the *i*th anchor node. When the unknown node u receives more than three distances of the anchor nodes, we can use least square method to estimate the coordinate of the unknown node *u*. The coordinate of the unknown node u is estimated through the following formula (7):

$$\begin{cases} (x-x_1)^2 + (y-y_1)^2 = d_1^{\,2} \\ (x-x_2)^2 + (y-y_2)^2 = d_2^{\,2} \\ \vdots \\ (x-x_n)^2 + (y-y_n)^2 = d_n^{\,2} \end{cases} \quad (7)$$

The formula (7) can be written into the form of $AU = B$. Among them, A and B is as following formula (8), formula (9) and formula (10).

$$A = \begin{bmatrix} 2(x_1 - x_n) & 2(y_1 - y_n) \\ \vdots & \vdots \\ 2(x_{n-1} - x_n) & 2(y_{n-1} - y_n) \end{bmatrix} \quad (8)$$

$$B = \begin{bmatrix} x_1^{\,2} - x_n^{\,2} + y_1^{\,2} - y_n^{\,2} + d_n^{\,2} - d_1^{\,2} \\ \vdots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 + d_n^2 - d_{n-1}^2 \end{bmatrix} \quad (9)$$

$$U = \begin{bmatrix} x \\ y \end{bmatrix} \quad (10)$$

Suppose $A \in \mathbb{R}^{n\times 2} (n \geq 2)$ is full rank, The *QR* decomposition of A is $A = QR$, $\left[Q, \hat{Q}\right] \in \mathbb{R}^{n\times 2} (n \geq 2)$. There is the following equation (11). The equality is true if and only if $RU = Q^T B$, so the least square solution is as following formula (12).

$$\begin{aligned} \|AU - B\|_2^2 &= \left\| \left[Q, \hat{Q}\right]^T (\mathrm{AU} - \mathrm{B}) \right\|_2^2 \\ &= \left\| \left[Q, \hat{Q}\right]^T (QRU - B) \right\|_2^2 \\ &= \left\| \begin{matrix} RU - Q^T B \\ -\hat{Q} B \end{matrix} \right\|_2^2 \\ &= \|RU - Q^T B)\|_2^2 + \|Q^T B)\|_2^2 \\ &\geq \|RU - Q^T B)\|_2^2 \end{aligned} \quad (11)$$

$$\begin{aligned} U &= (\mathrm{A}^T \mathrm{A})^{-1} A^T B \\ &= (\mathrm{R}^T \mathrm{Q}^T \mathrm{QR})^{-1} R^T Q^T B \\ &= (\mathrm{R}^T \mathrm{R})^{-1} R^T Q^T B \\ &= R^{-1} Q^T B \end{aligned} \quad (12)$$

The algorithm has a fast speed, high numerical stability and high accuracy and stability.

VI. Analysis of Simulation Result

In order to verify the localization performance of the new improved DV-Hop algorithm, the algorithm is simulated through MATLAB R2012b. In this section, the authors provide the simulation results and analysis the results of the localization error.

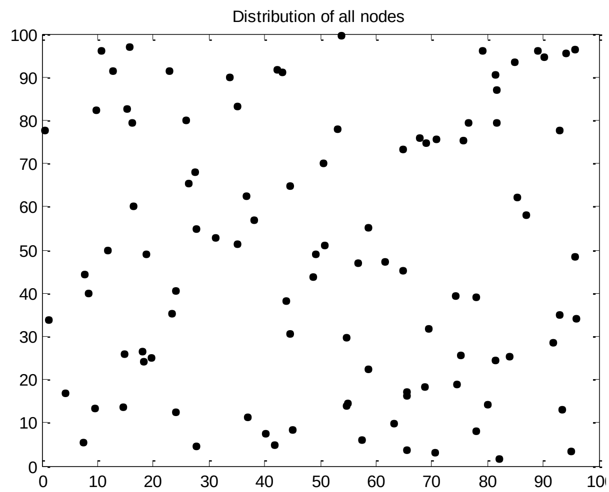

Fig. 2 (a). Distribution of 100 sensor nodes.

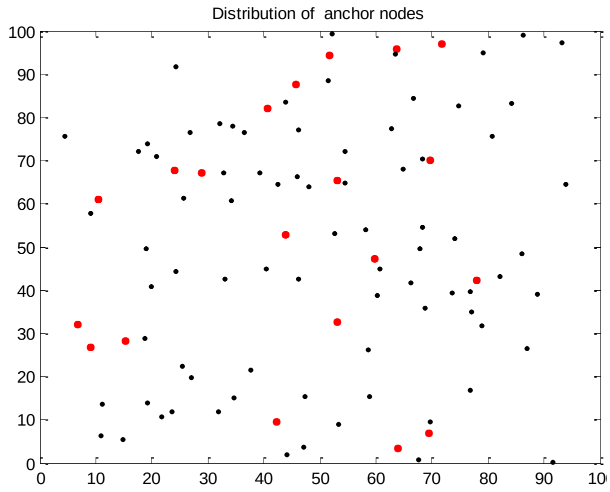

Fig. 2 (b). Distribution of anchor nodes.

It is assume that there are 100 sensor nodes which spread randomly in the two dimensional area of 100m×100m, the proportion of anchor nodes can be adjusted according to the communication connectivity of the network. The sensor nodes are distributed in this area randomly.

The distribution of the nodes are as shown in Fig. 2 (a) and Fig. 2 (b), Fig. 2 (a) is the distribution of 100 sensor nodes while Fig. 2 (b) is the proportion of anchor nodes. The black * represents unknown nodes and red * represents anchor nodes. The distribution of the nodes is shown in Fig. 2. The experiment repeated 100 times.

The estimated coordinate of the unknown nodes is (x_i, y_i), the actual coordinate is (x_{ai}, y_{ai}), n is the number of the unknown nodes, R is the radio range in the network. In the paper, the localization error is tested through $e_{average}$ and $e_{nor\_average}$, the formulas are shown in (13) and (14). The localization error can be reflected from $e_{average}$ and $e_{nor\_average}$.

$$e_{average} = \frac{\sum_{i=1}^{n}\sqrt{(x_i - x_{ai})^2 + (y_i - y_{ai})^2}}{n} \tag{13}$$

$$e_{nor\_average} = \frac{\sum_{i=1}^{n}\sqrt{(x_i - x_{ai})^2 + (y_i - y_{ai})^2}}{nR} \times 100\% \tag{14}$$

The average localization error of both DV-Hop algorithm and improved DV-Hop algorithm is compared in conditions of different number of sensor nodes as follows. In the simulation area of 100 m×100 m, the communication radius is 25m and the number of sensor nodes is 10, 15, 20, 25, 30, 35, 40, 45 and 50.The simulation result is shown in Fig. 3.

It can be seen from Fig. 3 that when the communication radius and number of nodes constant, the number of the sensor nodes is increased, the average localization error of the two algorithms are all decrease. But when the number of the sensor is the same, average localization error of the new improved algorithm is lower than DV-Hop algorithm. When the number of sensor nodes is 30, the average localization error of the improved algorithm is less 3.2 m than DV-Hop algorithm.

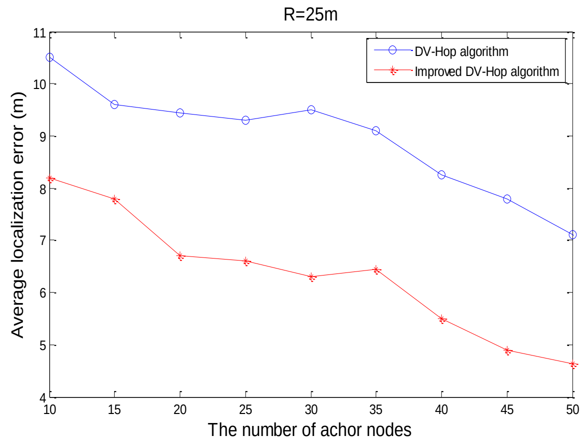

Fig. 3. The average localization error with different number of sensor nodes.

The normal average localization error of DV-Hop algorithm and improved DV-Hop algorithm is compared in conditions of different communication radius as follows. In the simulation area of 100 m×100 m, the communication radius is 15m, 20m, 25m, 30m, 35m and 40m, and the number of sensor nodes is 20%, 30% and 40% respectively. The simulation result is shown in Fig. 4, Fig. 5 and Fig. 6.

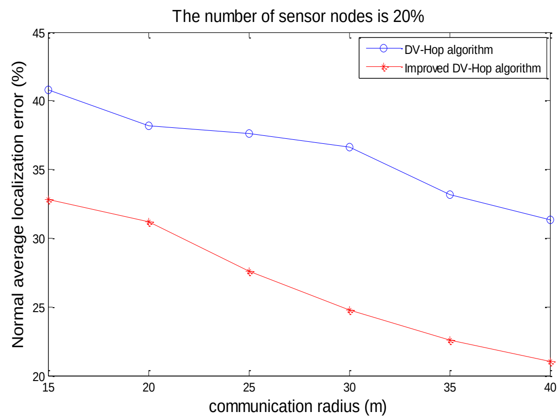

Fig. 4. The normal average localization error with different communication radius (sensor nodes is 20%).

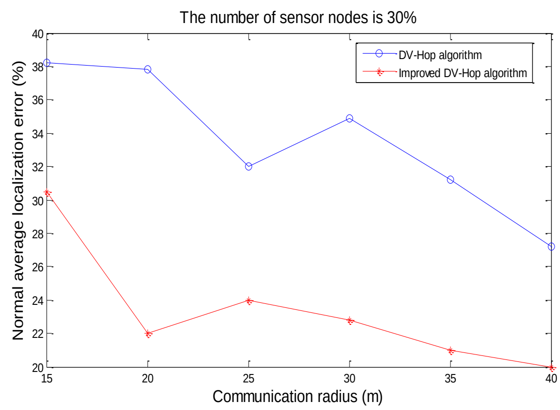

Fig. 5. The normal average localization error with different communication radius (sensor nodes is 30%).

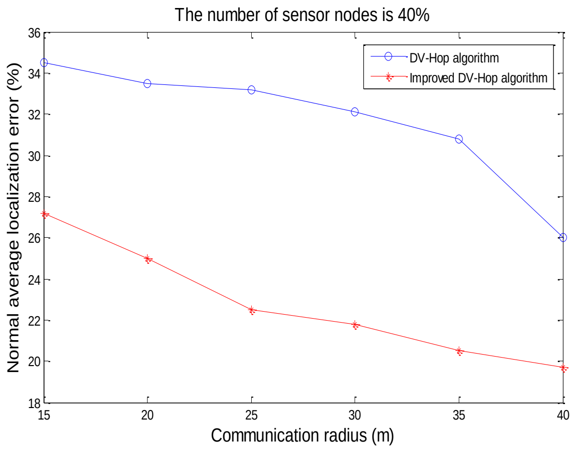

Fig. 6. The normal average localization error with different communication radius (sensor nodes is 40%).

It can be seen from Fig. 4, Fig. 5 and Fig. 6 that when the number of nodes constant, the communication radius is increased, the normal average localization error of the two algorithms are all decrease in general. But when the communication radius is the same, the normal average localization error of the new improved algorithm is lower than DV-Hop algorithm.

As can be seen from the simulation, the improved algorithm is superior than the DV-Hop algorithm. In theory, the improved algorithm guarantees unknown nodes can receive the average hop distance from the anchor nodes within communication radius, thus the average hop distance error can be decreased; the improved algorithm solves the equations through QR decomposition which can increases the numerical computation accuracy and improves the stability of the operation. These two measures reduce the localization error and improve the positioning accuracy of sensor nodes in WSNs. In summary, the simulation results show that, among the above two algorithms, the improved algorithm is more superior than DV-Hop algorithm.

VII. Conclusions

In this paper, we present a new improved DV-Hop algorithm which reduced the unknown nodes localization error without additional hardware. In step 2, the improved algorithm calculates the average hop distance selecting any two sensor nodes that the distance of them is less than communication radius. In step 3, the improved algorithm solves the equations through QR decomposition which can increases the numerical computation accuracy and improves the stability of the operation. The simulation results show that the performance of the improved algorithm is superior than DV-Hop algorithm in all simulation cases. However, the improved algorithm still has some deficiencies, such as when the number of sensor nodes is constant, the normal localization error is not always decreased. Therefore, in the future we will extend this issue of node localization in WSNs.

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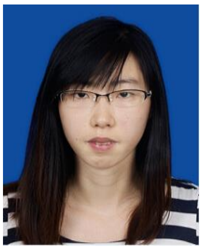

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