An Empirical Study of DV-Hop Localization Algorithm in Random Sensor Networks *

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***Abstract*—Node localization is an important problem for location-dependent applications of wireless sensor networks. Aiming at the positioning problem of wireless sensor networks node location, an improved DV-Hop localization algorithm is proposed in this paper. The proposed method firstly recalculates the hop-size and sends different correction along different directions instead of computing a single correction to be broadcasted into the networks. Then we empirically evaluate the difference between distance estimate and actual distance through a number of simulation experiments statistical results. We find empirical parameter to improve the accuracy of distance estimate. Simulation results show that the performance of the proposed scheme outweighs classical DV-Hop algorithms, especially in lower connectivity.**

Keywords—Localization, DV-Hop, Wireless sensor networks

I. INTRODUCTION

With the development of sensor techniques, low-power electronic and radio techniques, low-power and inexpensive wireless sensors networks have appeared and been put into application. Many applications of WSN are based on sensor self-positioning, such as battlefield surveillance, environments monitoring, indoor user tracking and others, which depend on knowing the location of sensor nodes. Because of the constraint in size, power, and cost of sensor nodes, the investigation of efficient location algorithms which satisfy the basic accuracy requirement for WSN meets new challenges [1].

Recently, many localization algorithms for sensor networks have been proposed. Most of them suppose that the networks are consisted of a small number of anchor nodes, which know their position by using GPS or other methods, and a large number of the unknown nodes which positions need to be commutated with the help of the anchor nodes. People use trilateration, triangulation, and maximum likelihood estimation to get the position [2]. The trilateration and maximum likelihood estimation are mainly used to figure out its position when an unknown node knows three or more than three anchor nodes' position information.

Based on whether it is required to measure the actual distance between nodes or not, the localization algorithms can be divided into two categories: Range-based and Range-free. The range-based algorithms need some extra-hardware to measure the exact distance or orientation between unknown nodes and anchor nodes, and then use the information to localize nodes. Range-free algorithms use estimated distance instead of range distance to localize nodes. Several ranging techniques are often used for range measurement, such as angle-of-arrival (AOA) [3], received signal strength indicator (RSSI) [4], time-of-arrival (TOA) [5], and time difference of arrival (TDOA) [6]. Due to conquer the drawbacks of the high cost and energy consumption in the range-based algorithm, solutions in range-free localization are being pursued without using any additional hardware. There are many range-free algorithms: Centroid algorithm [7], APIT algorithm [8], DV-hop algorithm [9], and MDS-MAP algorithm [10].

In the range-free localization algorithms, Niculescu et al [9] proposed the DV-Hop localization scheme, which is similar to the traditional routing schemes based on distance vector. In the DV-Hop algorithm, the node firstly counts the minimum hop values from the anchor nodes and then computes the distance between the node and anchor node by multiplying minimum hops and average distance of each hop. At last, the node estimates its position through trilateration or maximum likelihood estimators.

To enhance the localization accuracy, some improved DV-Hop methods have been reported. In the paper [11], a constraint is assumed in DV-Hop by confining the range from the unknown node to anchor node in the smallest range to the anchor nodes. In [12], 2-D Hyperbolic location algorithm is introduced to obtain the nodes' position estimate instead of the traditional trilateration or maximum likelihood estimators. Shuang tian et al [13] proposed RSSI-based DV-Hop algorithm, which incorporates RSSI and DV-Hop to implement unknown nodes localization together. In our previous work [14], we proposed an improvement of DV-Hop algorithm based on collinearity, which introduced the concept of normalized collinearity into the selection phase of beacon nodes and chose the best available anchor terns to accomplish more accurate localization.

In this paper, we improved the distance estimate between unknown nodes and anchor nodes in the first and second phase of DV-Hop algorithm without additional hardware. In the proposed scheme, we firstly recalculate the hop-size and send different correction along different directions instead of computing a single correction to be broadcasted into the networks. Then we analyze the source of the error of distance estimate between unknown nodes and anchor nodes. In order to evaluate reasonably the difference between distance estimate and actual distance, we make a number of simulation

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experiments to deeply research how to obtain better localization accuracy and localization robustness. Fortunately, we find empirical parameter to improve the accuracy of distance estimate. Simulation results shows that localization accuracy and localization robustness of improved DV-Hop algorithm is superior to those of classical DV-Hop algorithm whether in random deployment networks or in uniform deployment networks

The rest of this paper is organized as follows: Section II describes DV-Hop algorithm and proposes improved DV-Hop algorithm. The section III evaluates the algorithm performance by simulations and makes experiments to validate our algorithm. And Section IV draws the conclusion.

II. IMRPOVED DV-HOP LOCALIZATION SCHEME

A. The Fundamental of DV-Hop

In [9], Niculescu and Nath proposed the DV-Hop, which is a distributed, hop by hop localization algorithm. In the first step, each anchor node broadcasts a beacon to flood through the network containing the anchors location with a hops value initialized to one. Each receiving node maintains the minimum hops value per anchor of all beacons it receives. Beacons with higher hops values to a particular anchor are defined as stale information and will be ignored. Through this mechanism, all nodes in the network will get the minimal hops to every anchor node.

In the second step, once an anchor gets hops value to other anchors, it estimates an average distance for one hop, which is then flooded to the entire network. When they have the hop-distance and hops to other anchors, they will estimate the distance from themselves to all anchors that they can calculate by multiplying average hop-distance by hops. The average hop-distance is estimated by anchor i using the following formula:

$$C_i = \frac{\sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum h_i} \tag{1}$$

Where (x_i, y_i), (x_j, y_j) are coordinates of anchor i and j, h_i is the hops between beacon i and all other beacons.

Each anchor node broadcasts its average hop-distance to the network using controlled flooding. Every unknown node will receive the first correction as its average hop-distance and throw away the other correction from other anchors.

In the last step, Let (x, y) be the unknown node M location and (x_i, y_i) is the known location of the i 'th anchor node receiver. Let's define the i 'th anchor node distance to unknown nodes if d_i, well then, there is the following formula:

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = d_1{}^2 \\ (x - x_2)^2 + (y - y_2)^2 = d_2{}^2 \\ \vdots \\ (x - x_i)^2 + (y - y_i)^2 = d_i{}^2 \end{cases} \tag{2}$$

The coordinates of M is computed by the following formula:

$$A = -2 \times \begin{bmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ \vdots & \vdots \\ x_{n-1} - x_n & y_{n-1} - y_n \end{bmatrix} \tag{3}$$

$$B = \begin{bmatrix} d_1{}^2 - d_n{}^2 - x_1{}^2 + x_n{}^2 - y_1{}^2 + y_n{}^2 \\ d_2{}^2 - d_n{}^2 - x_2{}^2 + x_n{}^2 - y_2{}^2 + y_n{}^2 \\ \vdots \\ d_{n-1}{}^2 - d_n{}^2 - x_{n-1}{}^2 + x_n{}^2 - y_{n-1}{}^2 + y_n{}^2 \end{bmatrix} \tag{4}$$

$$X = \begin{bmatrix} x \\ y \end{bmatrix} \tag{5}$$

Because $AX = B$, so we can obtain the solution:

$$X = \left(A^T A\right)^{-1} A^T B \tag{6}$$

B. Improved DV-Hop Algorithm

In this subsection, we improve DV-Hop algorithm focus on step 2 and step 1.

In step 2, after obtained the hop values to other anchor nodes, an anchor node could estimate an average size for one hop. For simplicity, classical DV-Hop algorithm chooses to compute a single correction to be broadcasted into the networks. However, in fact, it is more reasonable to send different correction along different directions because it will make full use of all kinds of information in the whole networks. Thus, the format of the package is {Anchor-ID, HOP-SIZE (i)}, which means that each anchor node has different hop-size from itself to other different ID anchor nodes. Once one anchor node j gets hop information to other anchor nodes, it will calculate different hop-size from itself j to different i anchor nodes.

$$C_i = \frac{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{h_{i,j}}, \quad i \neq j, \text{all landmarks } i \tag{7}$$

After obtained the hop-size, anchor node broadcasts its hop-size to networks along the different directions. Unknown nodes will receive the correction from the closest anchor node and drop subsequent correction from other anchor nodes. Then they will estimate distance from themselves to all anchor nodes through multiplying different hop-size by corresponding hops. In order to estimate distance to closest anchor node, we suppose the hop-size between anchor node j and the surrounding unknown nodes equals to the mean of all other hop-size in different direction.

In step 1, an empirical model is developed to more reasonably evaluate the hop count from unknown nodes to anchor nodes. In [15], Nagpal et al. summarized distance estimate can be overestimated between unknown nodes and anchor nodes for the reason that there is not enough intermediate nodes for the shortest communication path in random networks. Therefore, they proposed an empirical method of the distance estimate through smoothing. They pointed out that the low resolution adds an average error of approximately 0.5r to the distance estimates. This paper is largely enlightened from the above idea, and continued to deeply investigate how much difference between distance estimate and actual distance. In order to reduce the local error of hops unknown node collects, each node collects its hops of neighbor unknown nodes and calculates a mean of the neighbor values and itself.

$$New\_hops = \frac{\sum h_j + h_i}{C_{neb} + 1} - \varepsilon, \ j \in neb(i) \quad (8)$$

h_i represents the hops an unknown node i collects from itself to all anchor nodes. C_{neb} represents the count value unknown node i have how many one-hop neighbor unknown nodes. ε represents the possible difference between distance estimate and actual distance which can be affected many factors such as the degree of networks connectivity and network topology.

In our initial experiment, we make a number of simulation experiments to explore how the networks parameters affect parameter ε. Fortunately, we find these most common facts and how to set empirical parameter ε to obtain better localization accuracy and localization robustness.

In the random deployment networks, equation (8) can be rewritten as follows:

$$New\_hops = \begin{cases} \frac{\sum h_j + h_i}{C_{neb} + 1} - 0.5, & con \le 6 \\ \frac{\sum h_j + h_i}{C_{neb} + 1} - 0.3, & 6 \prec con \le 12 \\ \frac{\sum h_j + h_i}{C_{neb} + 1}, & 12 \prec con \end{cases} \quad (9)$$

con represents the degree of networks connectivity. The main source of error in distance estimate arises from the discrete distribution of nodes, especially the degree of connectivity. However, in the uniform deployment networks, since the networks topology is more reasonable and the hole of networks dramatically reduces, the error in distance estimate also reduces. Thus, equation (8) can be rewritten as follows:

$$New\_hops = \begin{cases} \frac{\sum h_j + h_i}{C_{neb} + 1} - 0.3, & con \le 6 \\ \frac{\sum h_j + h_i}{C_{neb} + 1}, & con \succ 6 \end{cases} \quad (10)$$

III. SIMULATION RESULTS

To validate our algorithm, sensor networks consist of 100 sensor nodes distributed in an 60×60 m2 region. The connectivity of sensor networks is controlled by the radio range of sensor node. Every experiment result is the mean of ten times simulation results. We will simulate the DV-Hop algorithms and proposed algorithms in random deployment and in uniform deployment networks.

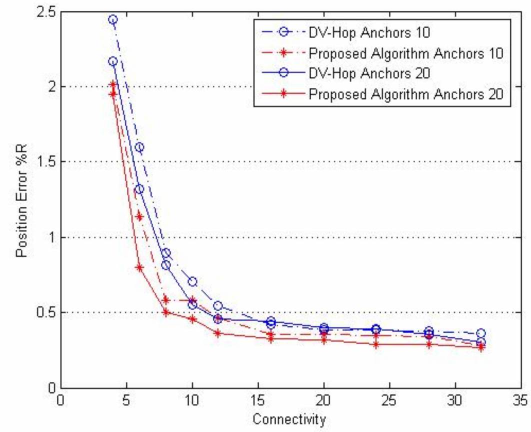

Fig. 1 Localization Error in Random Networks

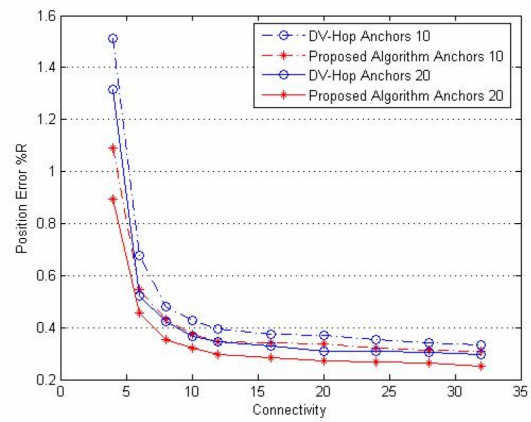

Fig. 2 Localization Error in Uniform Networks

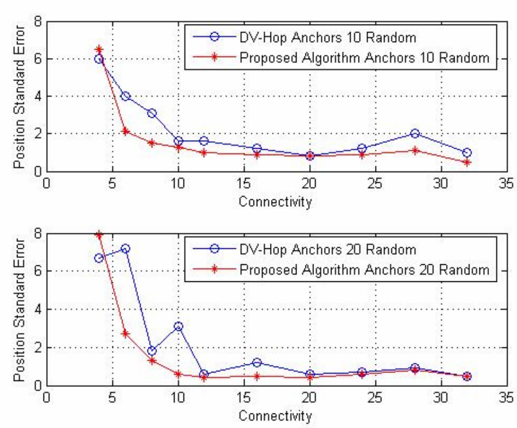

Fig. 3 Standard Deviation of Localization Error in Random Networks

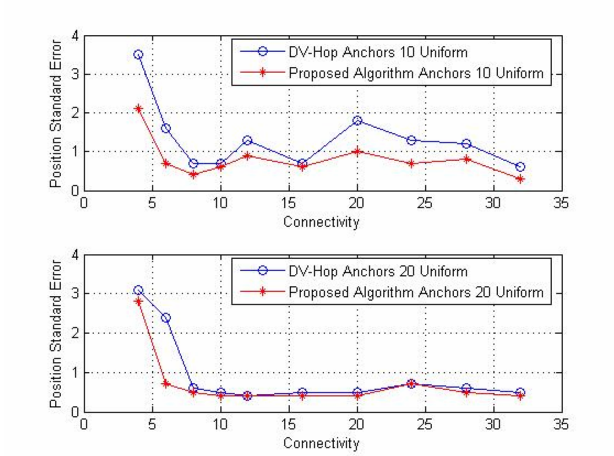

Fig. 4 Standard Deviation of Localization Error in Uniform Networks

Figure 1 shows the variation of the average localization errors with the degree of connectivity. The improved DV-Hop algorithm can achieve better localization accuracy than the classical DV-Hop algorithm in random deployment networks. For the same degree of connectivity, position errors of the proposed algorithm reduce about 10% to 40% than that of classical DV-Hop, particularly in the lower connectivity. For example, in Figure 1, with 10 and 20 anchor nodes (10% and 20%) and connectivity 6, the improved DV-Hop algorithm has an average error of about 1.15R and 0.76R, where the DV-Hop has an average error of about 1.6R and 1.35R. The same current can be seen in Figure 2. Moreover, the placement of anchor nodes will obviously affect the proposed algorithm and DV-Hop algorithm. Simulation results show that the more regular networks topology, the lower the localization error.

As shown in Figure 3 and Figure 4, whether in random deployment networks or in uniform deployment networks, Standard Deviation of the localization error of the proposed algorithm is relative lower than that of classical DV-Hop algorithm. It means that the fluctuation of localization error of proposed algorithm is less than that of classical DV-Hop algorithm. Thus, compared to DV-Hop, the localization performance of improved DV-Hop algorithm is more robust.

IV. CONCLUSIONS

In this paper, we proposed an improved DV-Hop algorithm for positioning the unknown nodes. We firstly recalculate the hop-size and send different correction along different directions instead of computing a single correction to be broadcasted into the networks. Then we analyze the source of the error of distance estimate between unknown nodes and anchor nodes. In order to evaluate reasonably the difference between distance estimate and actual distance, we statistic a number of simulation experiments results to deeply research how to obtain better localization accuracy. Fortunately, we find empirical parameter to improve the accuracy of distance estimate. Simulation results shows localization accuracy and localization robustness of improved DV-Hop algorithm outweighs those of classical DV-Hop algorithm whether in random deployment networks or in uniform deployment networks.

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