An Improved Multihop Distance Estimation for DV-Hop Localization Algorithm in Wireless Sensor Networks

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***Abstract*—Range-free, distributed localization method is an important and challenging issue in wireless sensor networks. Typical hop-count-based method always assumes that the average hop size for different hop count is the same. In this paper, we analyze the hop progress for different hop counts, and modify the assumption as the hop progress is the same for different hop counts except the 1-hop. We propose two improved DV-Hop estimation distance methods based on the new assumption. simulation result shows that the proposed methods obtain more accurate estimation distance and get better performance of localization.**

Keywords-* *Distance estimation; DV-Hop; Hopsize; localization.

I. INTRODUCTION

In wireless Sensor Networks(WSN), the localization method is an important support technology. A typical WSN consists of a large number of nodes that have limited sensing, communicating and processing capabilities. Many applications of WSN, such as Environmental monitoring, target tracking[1], request the knowledge of node's position. Also, many of routing protocols request node's location information. However, because of limited resources, only a small portion of nodes can get their position information in advance by GPS or manual configure. Thus, The localization algorithm becomes one of the most important issues in WSN research.

Existing localization methods can be divided into two classes, Range-based algorithms and Range-free algorithms. Range-based algorithms need the distance or angle information between unknown nodes and anchor nodes. The distances can be measured by the received signal strength (RSS), the time-of-arrival (TOA) , time difference of arrival (TDOA) or angle of arrival (AOA), when the distance information is obtained, the position can be calculated by multidimensional scaling method (MDS) [2], semi-definite programming method (SDP) [3], or multilateration method. Range-free algorithms depend on connectivity information, such as DV-hop algorithm [4], approximate point-in-triangulation test algorithm (APIT) [5], and Centroid [6], and so on.

The Range-based methods usually have more accurate localization result, but they need additional hardware to measure distance. As a cost-effective solution, Range-free localization methods are more attractive. We divide these range-based methods into two main categories: distance estimation algorithms and area-based algorithms. Distance estimation algorithms estimate the distance between nodes by hop count information. Area-based algorithms determine the possible area of node by communication range or other connectivity information.

The basic idea of many distance estimation algorithms is to seek a transformation from hop count information h to an unknown distance d. A lot of research has been done in distance estimation algorithms. DV-Hop algorithm is one of the famous range-free localization algorithm, the main idea of DV-Hop is to estimate an average size of one hop using a few anchor nodes, then its distance is estimated as product hop count and average hop-size.

Some researchers have tried to derive the hop-size by analyzing the relation between the distance and the hop count under the assumptions of disk communication model and Poisson node distribution. The recursive k-hop probability method was proposed in [7], it gives the conditional probability that any two sensors with distance x are k-hop neighbors. Some researchers have derived the expected hop progress (LAEP) with an arbitrary node density[8] [9]. LAEP algorithm can estimate the distance between any two sensors. In contrast to LAEP algorithm, which calculate the expected hop-size by average node density, LEHL[10] algorithm calculate the expected hop-size based on the local node density to improve localization accuracy.

The aforementioned algorithms only use the hop count information to estimate the distance. Some researchers have suggested that taking into account the information of neighbors can obtain more accurate estimation distance. [11] proposed a improved DV-Hop method using neighbor information. It defined a Neighbor-Hop parameter and derived the relationship between neighbor-hop parameter and average hop-size, then utilized this relationship to adjust distance estimation.

The hop-count-based neighbor partition (HCNP) [12] utilized hop count information and the information on the number of neighbors with hop count $h \pm 1$ to estimate the distance.

In this paper, we study the DV-Hop localization algorithm. The classical DV-Hop algorithm and other hop-count-based algorithms always assume that the hop-size is the same for different hop count. However, this assumption is not satisfied in reality, especially when the hop count is

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small. We analyze the hop-size of different hop count, and propose two new hop-size estimate methods to improve the estimation distance.

The rest of the paper is organized as follows. Section II reviews the classical DV-Hop algorithms, and presents some related works. Section III presents the proposed algorithms. Section IV give some simulation results and conclusion is made in Section V.

II. REVIEW OF DV-HOP ALGORITHM

The basic idea of DV-Hop algorithm is to estimate an average hop size using a few anchor nodes, then the distance between unknown nodes and anchor nodes can be obtained by multiplying hop count by average hop-size. The classical DV-Hop algorithm comprises of three steps.

First, all nodes get the minimum hop count to all anchor nodes. DV-Hop algorithm utilize the Controlled flooding to broadcast the location information of anchor nodes and obtain the minimum hop count between nodes and anchor nodes. When networks are large, it will be required more communication cost, we set a max hop count, all nodes To reduce the consumption of communication, thus all nodes only obtain the information of the max hop neighbor anchor nodes.

In the second step, the anchor node have the location information of other anchors and the hop count between them. Then the average hop size of each anchor node can be calculated as

$$HopSize_i = \sum_{j=1, j\neq i}^{m} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \Bigg/ \sum_{j=1, j\neq i}^{m} h_{ij} \; . \quad (1)$$

where， m represents the number of anchor nodes; h_{ij} represents the hop count between i and j. (x_i, y_i), (x_j, y_j) are coordinates of anchor i and anchor j.

Then every anchor node broadcasts its hop size throughout the networks. When an unknown node receives the hop size information, the estimation distance between itself and the anchor node can be calculated as

$$d_{ij} = HopSize_j \times h_{ij} \, . \quad (2)$$

There have many improved method has been proposed in this step. The average hop size is calculated by least squares method [13] instead of (1).

In the third step, the position of unknown node can be obtained by triangulation method or multilateration method. We can obtain the system of equations for each unknown nodes

$$(x_i - x)^2 + (y_i - y)^2 = d_i^2 \, . \quad (3)$$

There have several methods to linearize this non-linear system of equations. We adopt the converting method.

There have the same non-linear part $x^2 + y^2$, therefore this non-linear part can be regarded as a new variable $w = x^2 + y^2$, and the system of equations becomes a linear system with three variables. Thus the new linear system of equations can be written in matrix form:

$$\mathbf{Ax} = \mathbf{b} \quad (3)$$

where

$$\mathbf{A} = \begin{bmatrix} -2x_1 & -2y_1 & 1 \\ -2x_2 & -2y_2 & 1 \\ \vdots & \vdots & \vdots \\ -2x_n & -2y_n & 1 \end{bmatrix}, \; \mathbf{x} = \begin{bmatrix} x \\ y \\ w \end{bmatrix}, \; \mathbf{b} = \begin{bmatrix} d_1^2 - x_1^2 - y_1^2 \\ d_2^2 - x_2^2 - y_2^2 \\ \vdots \\ d_m^2 - x_m^2 - y_m^2 \end{bmatrix}$$

The least squares solution of this linear system of equations should be:

$$\mathbf{x}_{\mathrm{LS}} = (\mathbf{A}^{\mathrm{T}}\mathbf{A})^{-1}\mathbf{A}^{\mathrm{T}}\mathbf{b} \quad (4)$$

III. THE PROPOSED METHOD

The DV-Hop algorithm calculate the average hop size and estimate the distance under the assumption that the average hop size for different hop count is the same. But this assumption is not always satisfied in reality. Thus we analyze the excepted distance for different hop count and derive a new model to describe the relationship between the hop count and the distance, then we propose two improved methods under the new model.

A. Network model

We assume that all nodes with the same communication range R are randomly deployed in a 1×1 square area according to a uniform distribution and can form a connected network. Let N denote the number of nodes, m denote the number of anchor nodes.

The distance of 1-hop nodes has a clear bound, the upper bound of 1-hop distance is R, and the lower bound of 1-hop is zero. The nodes are deployed according to a uniform distribution, let z denote the distance between destinations node and the source node, the probability distribution function of z is given as $f(z) = (2z / R^2)$. Thus, the expectation distance of 1-hop can be calculated

$$E(z) = \int_0^R z f(z) dz = \frac{2}{3} R \, . \quad (5)$$

The distance of 2-hop nodes has a clear lower bound R, but distance bounds of other hop count are not clear. Thus the expected distance of h-hop have no closed-form solution.

Let E(h) denotes the expected distance of h-hop nodes, and E(h-1) denotes the excepted distance of (h-1)-hop nodes. The hop progress of h-hop is defined as E(h)-E(h-1).

In order to the study the hop progress for different hop count, we set up such a scenario: the source node is set to be located in the center of the area whose coordinate is (0.5, 0.5). We calculate the average distance for different hop counts to the source node, and it approximate the expected distance of h-hop nodes. The result is shown in Fig. 1.

Fig. 1 shows the relationship between hop count and average distance with different node density. The slope increase with the number of nodes increases. The average distance of 1-hop for different node density are almost equal to 0.667, the result comply with the aforementioned analysis.

Fig. 2 shows the hop progress with different node density for different hop count. It is observed that the hop progress of 1-hop is almost equal for different number of nodes. The differences between the hop progress for adjacent hop count is reduces as hop count increases. Also it can be observed that the hop progress increases as the number of nodes increases.

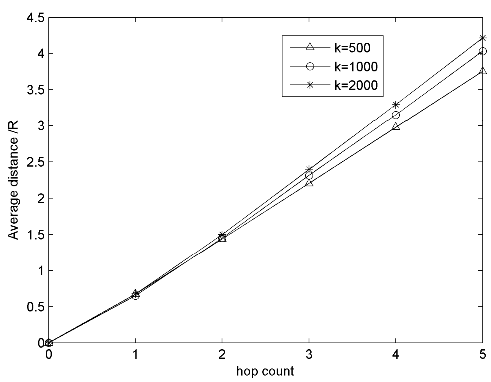

Fig. 1. Normalized Average distance for different hop counts .

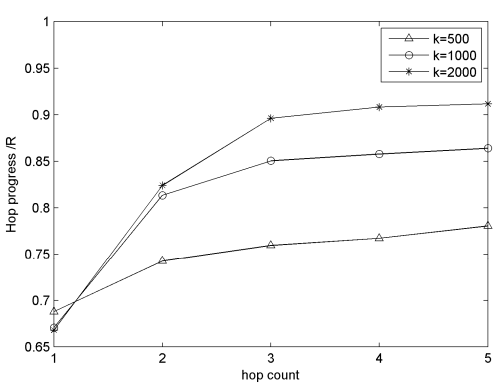

Fig. 2. Normalized hop progress for different hop counts.

The basic idea of DV-Hop method is that linear approximation the relationship between the expected distance and the hop count, such as (2). But this is not satisfied in reality, thus DV-Hop method has a large distance estimation error.

Based on aforementioned analysis, the hop size of 1-hop is always equal 0.667, thus, a new model can be derived as

$$d = HopSize_i(h-1) + \alpha . \quad (6)$$

B. *Method A: the communication range R is known*

Based on (6), if the communication range R is known, $\alpha = 2R/3$, the average of hop size can be obtained by

$$HopSize_i = \sum_{j=1, j\neq i}^{m} \left(\hat{d}_{ij} - 2R/3\right) \Big/ \sum_{j=1, j\neq i}^{m} \left(h_{ij} - 1\right). \quad (7)$$

Where $\hat{d}_{ij} = (x_i - x_j)^2 + (y_i - y_j)^2$ denotes the real distance between anchor i and anchor j.

Furthermore, we can obtain more accurate estimation by least square method. The relationship between the real distance and the estimation distance between anchor nodes i and j according to (6) can be shown as

$$\hat{d}_{ij} = HopSize_i \times \left(h_{ij} - 1\right) + 2R/3 + \delta_{ij} . \quad (8)$$

Where δ_{ij} represents the estimation error.

According to the least squares method, minimum the sum of all estimation error

$$f = \sum_{i\neq j} \delta_{ij}^2 = \sum_{i\neq j} \left(\hat{d}_{ij} - HopSize_i h_{ij}\right)^2 . \quad (9)$$

Let $\partial f / \partial Hopsize_i = 0$, the average hop-size of anchor node i can be calculated as

$$HopSize_i = \frac{\sum_{j=1, j\neq i}^{m} \left(\hat{d}_{ij} - 2R/3\right)\left(h_{ij} - 1\right)}{\sum_{j=1, j\neq i}^{m} \left(h_{ij} - 1\right)^2} . \quad (10)$$

Then the distance between unknown node u and the anchor node i can be calculated by

$$d_{iu} = HopSize_i \times \left(h_{iu} - 1\right) + 2R/3 . \quad (11)$$

When hop count $h_{iu} = 1$, the estimation distance $d_{iu} = 2R/3$.

C. *Method B: the communication range R is unknown*

Sometimes, the communication range R is unknown, and in some cases, such as the anchor node located in the bound of the area, the expected of 1-hop distance is not equal

$2R/3$. Thus, there have two variables in Eq. (6), it requires two or more other anchor nodes' information to solute this system of equations. This requirement is easy to satisfied because the localization algorithms in 2-D condition requires three or more anchor nodes.

Using the knowledge of anchor nodes, a system of linear equations can be obtained as

$$\hat{d}_{ij} = HopSize_i \times (h_{ij} - 1) + \alpha_i \,. \tag{12}$$

The least-squares method is utilized to estimate the $HopSize_i$ and α_i.

Then, the distance between unknown node u and the anchor node I can be obtained by

$$d_{iu} = HopSize_i \times (h_{iu} - 1) + \alpha_i \,. \tag{13}$$

IV. SIMULATION RESULTS

In this section, we discuss two simulations studies: 1) distance estimation; 2) localization accuracy. We simulated DV-Hop algorithm and our algorithm in matlab.

A. Distance Estimation

We randomly distribute n=1000 nodes, there have m=25 anchor nodes.

To evaluate the performance of distance estimation, we adopt the normalized absolute distance estimation error and the normalized distance estimation error. They are defined as

$$e_i = \left| d_i - \hat{d}_i \right| / R \,. \tag{14}$$

$$e_m = \left(d_i - \hat{d}_i \right) / R \,. \tag{15}$$

We carry out 10 independent simulation and take the average of the simulation results.

Fig. 3 shows a comparison of e_i of three different methods and the hop count. It is observed that the distance estimation error of the proposed methods are always smaller than the error of DV-Hop. The error of three methods almost increase when hop count increase.

Fig. 4 shows a comparison of e_i of three different methods and the number of nodes, the number of anchor nodes is equal to 50. It can be observed that the error of proposed methods are always smaller, the differences between the error of proposed methods and the error of DV-Hop increase as the n increase. This result is except, because the difference between 1-hop progress and *h*-hop progress increase as the node density increase as shown in fig. 2, thus our linear approximation model is more accurate than DV-Hop method.

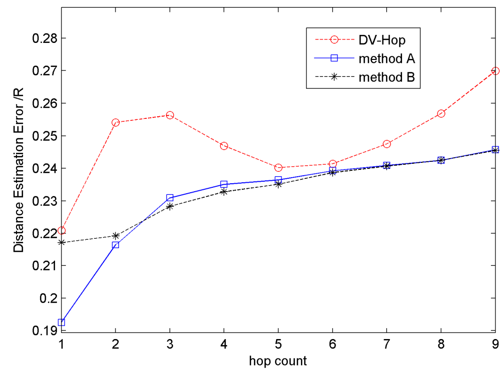

Fig. 3. Distance estimation error for different hop count.

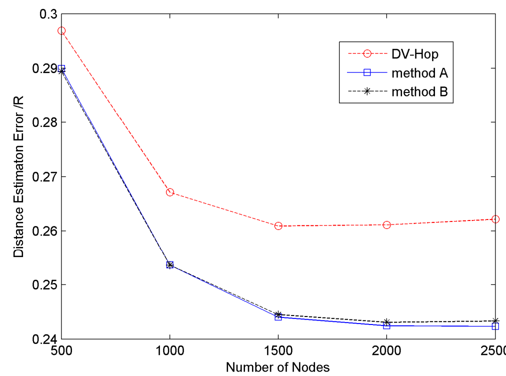

Fig. 4. Distance estimation error for different the number of nodes.

Fig. 5 shows the mean of the estimation errors of different methods. It can be observed that the error mean of DV-Hop method and proposed method B are approximately zero, the error of proposed method A is nonzero.

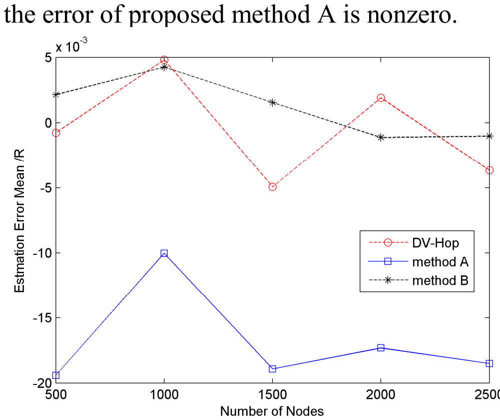

Fig. 5. The mean of the distanceestimation error for different the number of nodes.

B. Localization accuracy

We use the normalized average root mean square error (RMSE) to evaluate the localization performance of proposed methods. The normalized RMSE is calculated as follows:

$$\text{MSE} = \frac{1}{(n-m)\times R} \sum_{i=1}^{m} \left[\sqrt{\left(x_i - \hat{x}_i\right)^2 + \left(y_i - \hat{y}_i\right)^2} \right] \quad (16)$$

First we fix the number of anchor nodes and vary the number of nodes. Fig. 6 shows the normalized RMSE of DV-Hop and the proposed methods for different n. It can be observed that the normalized REMS of three methods decrease when the number of nodes increases. Fig. 7 shows the normalized RMSE for different anchor ratio. It can be observed that the normalized RESM of three methods decrease as the anchor ratio increases. The proposed method B have can obtain more accurate localization result than method A.

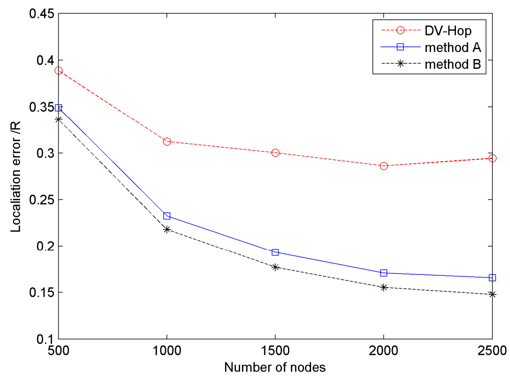

Fig. 6. Localization error for different Number of nodes.

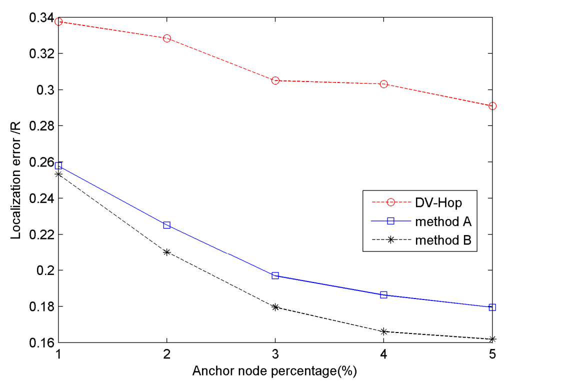

Fig. 7. Localization error for different Anchor node percentage.

V. CONCLUSIONS

We proposed a new linear approximation model of the relationship between hop count and estimation distance, based on this model, we derived two novel estimation distance methods. The proposed methods are shown to outperform DV-Hop method, especially in large node density.

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