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Enhanced Distance Vector Hop Localization Algorithm based on Hop Threshold and Weighted Matrix for Wireless Sensor Networks

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Abstract: Distance Vector Hop (DV-Hop) localization algorithm as the most popular range-free localization scheme that is widely applied in location-based applications for its simple and easy to implement. However, it has poor localization accuracy, especially in complex unevenly distributed network environment. An enhanced DV-Hop localization algorithm based on beacon node hop threshold and weighted matrix is proposed to address this issue, named as TWDV-Hop. First, we build considerable experiments to analyze the distributed law between hop count and average hop size error. Large hop count will be cut out to optimize average hop size based on analysis results, since it is the main reason that lead to large location error for its inaccuracy. Then, weighted matrix is introduced to instead of basic least squares in the third phase to narrow location error brought by non-linear equation. Finally, extensive experiments were conducted for several evaluation metrics, as localization accuracy, energy consumption cost under effected parameters in terms of node density, communication range, total number of nodes. Simulation results demonstrated that our proposed TWDV-Hop had outstanding performance in accuracy and energy consumption. The localization error is decreased more than 60%, when compared with latest new literatures. Especially, it reduced over than 75%, compared to traditional DV-Hop algorithm. Moreover, the average localization error is lower 3.5m, which can meet location-based application requirements at a certain level.

Keywords: Wireless sensor networks (WSNs), DV-Hop localization algorithm, Average hop size, Beacon node

1. Introduction

With the rapid development of embedded technology and artificial intelligence technology, the concept of Internet of Things (IOT) is proposed. Wireless sensor networks (WSNs) as the core technology and fundamental part of IOT, it has become an emerging cross-spot research field. WSNs can be efficiently integrated with internet based on combined information collection, communication, and computing capabilities into one combination, that realize the information transmission and interconnection between people and things, and between things to form the Internet of Things [1]. Node localization technology as most core supporting technologies of WSNs, which can provide location information for sensor nodes and meanwhile afford technical support for geographic location-based protocol and target tracking [2]. In addition, location information is the prerequisite for sensor network monitoring and control, since most monitoring or tracking information need to be accompanied with corresponding location information, otherwise, these data will lost collect meaning [1-2].

One of the easiest ways to obtain location information for unknown nodes is attached global positioning system (GPS). However, it is impossible to equipped it to all sensor nodes, since GPS will largely increase node size, power consumption, and hardware cost, especially, it cannot work in an indoor environment [3]. So, only fewer nodes carried GPS and this type of nodes called as beacon nodes or anchor nodes, the others named as unknown nodes or target nodes. These beacon nodes be utilized to calculate the position of unknown nodes by localization algorithm. Recently, a large numbers of localization algorithms have been proposed. It is broadly divided into two categories range-based scheme and range-free scheme based on whether need to attach additional device to measure distance or angle [5-6]. The range-based localization algorithm has high location accuracy, but its requirements of hardware and cost is high. In addition, it must maintain strict clock synchronization between nodes. The

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representative ranging algorithms are Received Signal Strength Indicator (RSSI) [7], Time of Arrival (ToA) [8], Time Difference of Arrival (TDoA) [8] and Angle of Arrival (AoA) [9], etc. In contrast, range-free technology has no special hardware requirement and is less affected by environment and easy to implement. It conquered most disadvantage of range-based localization algorithm and is more suitable for location-based applications in WSNs, especially for large size and low energy consumption network. Traditional range-free localization scheme includes Amorphous [10], Centroid [11], Approximate Point in Triangle Test (APIT) [12] and Distance Vector-Hop (DV-Hop) [13], etc.

DV-Hop as the most popular range-free localization technology in WSNs. It only utilized beacon nodes broadcast information in network to locate node, which can efficiently save hardware costs and energy consumption. According to the location idea of DV-Hop scheme, it can obtain reasonable average hop size distance and more accuracy position when network nodes are densely and evenly deployed, especially network is isotropic. However, in actual application environment, nodes are often randomly distributed and network topology is easily presented as anisotropy. Hence, DV-Hop localization algorithm has disadvantage of low localization accuracy.

In recent years, a great large number of suitable improvement strategies for basic DV-Hop localization algorithm have been wildly studied. An abounding researcher have proposed enhanced algorithms from different angles. A modified DV-Hop algorithm is proposed in [14], that based on Poisson distribution probability statistical function to select accurate beacon nodes for calculate distance of unknown node. The concept of fractional hop count is introduced to minimize hop error based on RSSI technology in [15]. Then, a correction factor is applied to modify the average hop size. Finally, Differential Evolution (DE) algorithm is explored to solve non-linear equation problem. Simulation results shown HDCDV-Hop algorithm improve accuracy by 10% with low complexity and better efficient. Most of enhanced algorithm improve localization accuracy to a certain stage. Based on above deficiencies, this article mainly focuses on two aspects, enhance average hop size and optimize method to solve non-linear equation.

The structure of rest paper is as follows. Recently advanced literatures research on DV-Hop localization techniques for WSNs are illustrated in Section 2. In Section 3, traditional DV-Hop is introduced. Deeply error analysis of DV-Hop is presented in Section 4. In Section 5, our enhanced DV-hop localization algorithm, TWDV-Hop is comprehensively presented. Experiments outcomes and discussion are elaborated in Section 6. Eventually, conclusions and future work are formulated in Section 7.

2. RELATED WORKS

In recent years, it has been several literatures on DV-Hop localization algorithms for WSNs, which focus on different concern points. A fast, accurate and easy DV-Hop localization algorithm, named IDVLA is introduced in [16]. It computes the average of entire hop distances. In the third phase, a 2-D Hyperbolic location algorithm is employed to solve the nonlinear equation instead of least squares. An upgraded DV-Hop formulated to address big error by enhance one hop count and weight hop size in [17]. One hop count is graded into m levels depended on the number of communicable beacon nodes. RSSI technology is employed to rectify hop value in the light of segmentation hop count. In addition, hop size is modified based on difference error of average hop size. Subsequently, weighted value is employed to recalculate hop size. A fresh metric is presented to rectify hop size in [18], which is depend on whole network beacon node hop distance error. A novel DV-Hop algorithm, PMDV-Hop based on error-compensation is proposed in [19]. To further enhance location accuracy, inequality constraints is utilized to narrow location error by least-square approach. PMDV-Hop shows advanced efficient, remarkable accuracy and fast convergence speed, but with extremely high energy consumption and complex computation. Two new algorithms are proposed in [20], named as Checkout DV-hop and Selective 3-beacon DV-hop, which based on improved protocol to improve the accuracy. The idea of improved algorithm is only using 3 nearest beacons for unknown node instead of using all communicable beacons to compute its location. However, the idea is based on the hypothesis that two sensor nodes have similar connectivity and both must have similar positions. This hypothesis is not always satisfied because the sensor nodes are randomly deployed in the monitoring area.

The concept of proportional parameter is introduced to narrow average hop size error in [21]. Simulation results show that localization accuracy improves 10.2% comparing with traditional DV-Hop. In basic DV-Hop, the average hop size and minimum hop count is estimated, so it will great effect the localization accuracy. In [22], it employed actual distance between beacon node to correct hop size. Then, correction factor is introduced to reevaluate minimum hop count. An improved method is also proposed in [23] to deal with above issue. Firstly, the author introduced a concept of adaptive threshold to re-divided minimum hop count between unknow node and beacon node. Hereafter, average hop size is re-correct by employ weighted normalization. Finally, the experiments are simulated under random and nonrandom environment, which has an obvious better performance in both scenarios. A Half-measure weighted centroid method is proposed in [24], it optimizes optical distance and short paths between beacon nodes.

Most previous work only consider only one performance metric like localization accuracy. A new DV-Hop approach combined weighted centroid localization scheme is introduced in paper [25] that not only consider location error but also energy consumption. In this work, hop counts that is larger than two will be discard, theorical and simulation proved localization accuracy is greatly enhanced, and largely reduced consumption. It compared four typical localization algorithms under same experiment environment in paper [26], one is range-based algorithm, RSSI and other three are range-free algorithm, DV-Hop, APIT and centroid algorithm. Analysis result shown DV-Hop with high stability under even distributed network.

Intelligent algorithms have outstanding advantage in solving complex optimization problems, it had successful applied in DV-Hop localization algorithm. An enhanced adaptive cuckoo search algorithm (HMCS) is introduced to reduce location error for DV-Hop in WSN [27]. In HMCS, the nest population is subdivided into three part based on fitness value to control step size. Furthermore, Lévy Flight is utilized to enhance search ability. In addition, hop counts are corrected by weighted factor that is based on the ideal calculate number. One hop count is evenly divided into three part to minimize estimated distance error gap and area is represented distance for one hop count. A mixed global swarm optimization (GSO) based on chaotic strategy (MC-GSO) is introduced in DV-Hop to instead of least square method, named as MGDV-Hop [28]. The search ability and robustness greatly enhanced by adopt chaos mutation and chaotic inertia weight. It is notable that MGDV-Hop has a superior performance not only under localization accuracy but also under location coverage and energy consumption. Bacterial Foraging Optimization (BFO) was introduced to improve the localization accuracy in the third phrase by correct the estimated coordinate of unknown node [29].

A new improved DV-Hop algorithm for localization based on PSO is proposed in paper [30]. It developed a mathematical model for implementation of meta-heuristic (PSO) approach. It is worth noting that typical PSO is easy to sink into local optimal value and has a limited convergence speed of with fixed learning factor. To address this issue, an advantageous PSO is proposed for DV-Hop in [31]. In this work, two quickening factors in learning factor are introduced to accelerate convergence speed and search ability. Moreover, inertia weighted is updated based on threshold value. Simulation consequents show promoted PSO has a superior performance in convergence speed and localization accuracy. However, it increased the complexity of basic DV-Hop algorithm and positioning time.

All above algorithms have boost localization accuracy to some degree, but most of them at the cost of very high computational complexity and communication overhead. Therefore, we proposed our enhanced DV-Hop localization algorithm, TWDV-Hop to heighten localization accuracy. The traditional DV-Hop localization algorithm is introduced in next Section.

3. Traditional DV-Hop Algorithm

DV-Hop localization scheme was first put forward by Dragons Niculescu and his team [13] for 2D WSNs. The localization process of DV-Hop is consisting of 3 steps.

A. ***Step 1:*** *Calculate Minimum Hop Counts*

Each beacon node broadcasts two parameters, the coordinates of beacon node and minimum number of hop counts. The initial value of minimum hop count is 0. Every communicable neighbor node store received information table, added 1 hop count then forwarded updated information to its neighbor nodes. If received information is from same beacon node and greater than previous hop count, the information will be discarded.

Here, taken Fig. 1 as an example of DV-Hop localization algorithm, A_1, A_2 and A_3 are beacon nodes, and the rest nodes are unknown nodes. It is assumed U_i is the one that need to be located. The minimum hop count of A_1 to A_2, A_2 to A_3 and A_1 to A_3 is 2, 5 and 7, respectively, based on **Step 1**. The minimum hop of U_i to A_1, A_2 and A_3 is 4, 2 and 3, respectively.

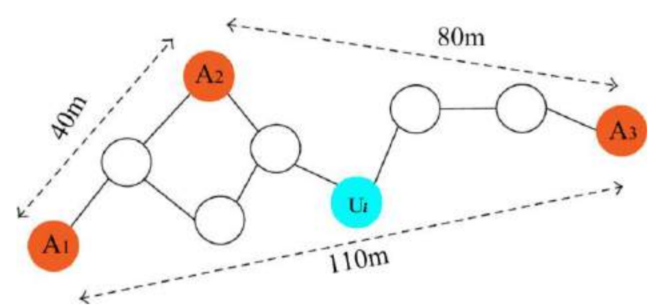

Figure 1. An illustration of DV-Hop localization algorithm

B. ***Step2:*** *Calculate Average Hop Size (AHS)*

After the first step, each beacon node can obtain minimum hop counts to other nodes. The AHS can be obtained by adopted Equation (1) to calculate for each beacon node.

$$AvgHopSize_i = \frac{\Sigma_{i\neq j}^{m}\sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}}{\Sigma_{i\neq j}^{m} H_{ij}} \quad (1)$$

Where (x_i, y_i) and (x_j, y_j) are the coordinate of beacon node i and j, respectively. H_{ij} is the hop count between beacon node i and j. $AvgHopSize_i$ represents the AHS of beacon node i.

Here, we still take Fig. 1 as an illustration. The AHS of A_1, A_2 and A_3 can be estimated as following.

$AvgHopSize\_A_1 = (40 + 110) / (2+7) = 16.67$

$AvgHopSize\_A_2 = (40 + 80) / (2+5) = 17.14$

AvgHopSize_A₃ = (110 + 80) / (7+5) = 15.83

Equation (2) is employed to calculate estimate distance d_{ij} between beacon node i and unknown node U.

$$d_{iu} = AvgHopSize_i \times H_{iu} \quad (2)$$

Since the minimum hop of U_i to A_1, A_2 and A_3 is 4, 2 and 3, so here, it chose *AvgHopSize_A₂* to estimate the distance of U_i to A_1, A_2 and A_3, it can be obtained by Equation (2).

d_ A_1_U_i = 17.14 ×4 = 68.56

d_ A_2_U_i = 17.14 ×2 = 32.48

d_ A_3_U_i = 17.14 ×3 = 51.42

After obtained AHS, each beacon node broadcasts it to whole network. The unknown node only received AHS from the nearest beacon node and forward it to neighbour node.

C. *Step3: Estimate Coordinate of Unknown Node*

The maximum likelihood method or multilateral measurement method be utilized to calculate the coordinate of unknown node.

Let (x_u, y_u) be the coordinates of unknown node U, and d_{iu} is estimate distance between unknown node u and beacon node A_i, $i \in \{1, 2, 3 \ldots n\}$, d_{iu} can be obtained by Equation (2).

$$\begin{aligned} (x_u - x_1)^2 + (y_u - y_1)^2 &= d_{1u}^2 \\ (x_u - x_2)^2 + (y_u - y_2)^2 &= d_{2u}^2 \\ &\vdots \\ (x_u - x_n)^2 + (y_u - y_n)^2 &= d_{nu}^2 \end{aligned} \quad (3)$$

Each equation is subtracted from the last equation of Equation (3), it can be expressed as follow.

$$\begin{aligned} 2(x_n - x_1)x_u + 2(y_n - y_1)y_u &= d_1^2 - d_n^2 - x_1^2 + x_n^2 - y_1^2 + y_n^2 \\ 2(x_n - x_2)x_u + 2(y_n - y_2)y_u &= d_2^2 - d_n^2 - x_2^2 + x_n^2 - y_2^2 + y_n^2 \\ &\vdots \\ 2(x_{n-1} - x_n)x_u + 2(y_{n-1} - y_n)y_u &= d_{n-1}^2 - d_n^2 - x_{n-1}^2 + x_n^2 - y_{n-1}^2 + y_n^2 \end{aligned} \quad (4)$$

Equation (4) can formulated into AX=B, see as follow.

$$A = -2 \times \begin{bmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ & \vdots \\ x_{n-1} - x_n & y_{n-1} - y_n \end{bmatrix} \quad (5)$$

$$X = \begin{bmatrix} x_u \\ y_u \end{bmatrix} \quad (6)$$

$$B = \begin{bmatrix} d_1^2 - d_n^2 - x_1^2 + x_n^2 - y_1^2 + y_n^2 \\ d_2^2 - d_n^2 - x_2^2 + x_n^2 - y_2^2 + y_n^2 \\ \vdots \\ d_{n-1}^2 - d_n^2 - x_{n-1}^2 + x_n^2 - y_{n-1}^2 + y_n^2 \end{bmatrix} \quad (7)$$

The coordinate (x_u, y_u) of unknown node can be estimated by Equation (8).

$$X = (A^T A)^{-1} A^T B \quad (8)$$

4. ERROR ANALYSIS OF DV-HOP LOCALIZATION ALGORITHM

A. *Error analysis of Average Hop Size*

DV-Hop localization algorithm utilized multiple hop size to approximate straight-line distance. Hence, there is inevitable error of the estimate coordinate in unknown node. This can be verified in Fig.2. It can be seen form Fig.2 that the estimated distance of AHS multiple hop count is the sum of all polylines between A and B, which is significantly larger than the linear distance between A and B.

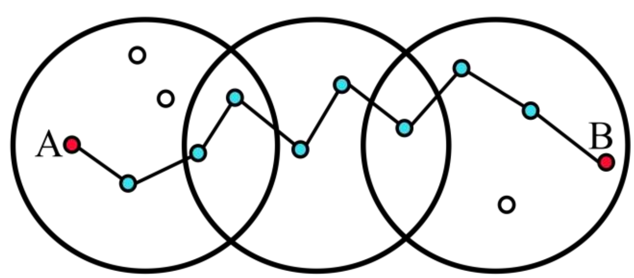

Figure 2. An examlpe of node distribution

Whether estimate AHS is resealable or not that massively determined the localization accuracy of DV-Hop algorithm. In addition, AHS have a close relationship with hop count, aimed at investigating the relationship between AHS error and hop count, following experiment has conducted in this paper. In this experiment, there are 100 sensor nodes are random distributed in 100m ×100m area, including 30 beacon node and communication range is 25m. The distributed law of hop value and AHS error is illustrated in Fig. 3 and Fig.4.

It can be seen from Fig.3 that the relationship between hop value and hop amount is approximate normal distribution. The maximum hop value is 7 and it with least number amount. Hop value 3 with largest amount, that exceeded 220. The amount of hop value 2 and 4 is round 200. It can be observed form Fig.4 that AHS error demonstrated upward trend with hop value increasing. And the conclusion of more hop counts more AHS error can be conducted in Fig.4. Hop value 2 with minimum error less than 2m, the second and third is hop value 1, 2, respectively. The AHS error of hop value 6 is almost 5 times larger than hop value 2. The sum amount of hop value 4, 5, 6, 7 is one-third of the total number. Therefore, it is urgent to optimize AHS cause large hop value with big error. We proposed large hop value be cut out to optimize AHS based on above analysed results.

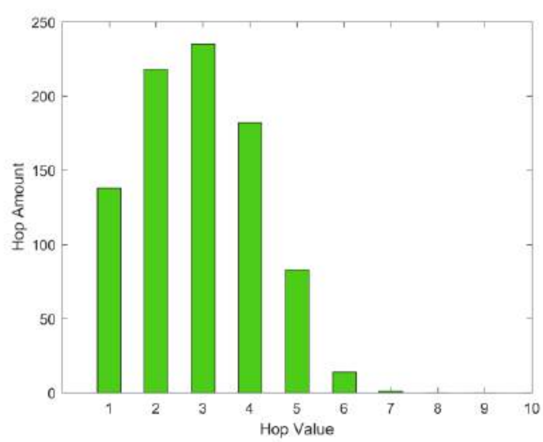

Figure 3. The relationship between hop value and hop amount

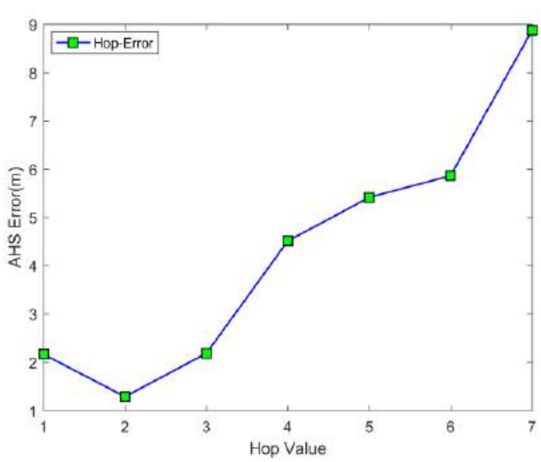

Figure 4. A distribution law between hop value and AHS

B. *Error Analysis of Location Technique*

2D hyperbolic location method is adopted to solve non-liner equation instead of least squares in [16]. It is reported that improved accuracy to a certain degree than that using least squares method in traditional DV-Hop algorithm. But it still has large error in the coordinate of unknown node. To better comprehend above issue, basic 2D hyperbolic location method and error analysis term is illustrated in below section.

- 2D hyperbolic Location Technique.

Let (x_u, y_u) be the coordinate of unknown node U. The estimated distance is calculated using the following equations:

$$\begin{aligned} (x_u - x_1)^2 + (y_u - y_1)^2 + \xi_1 &= d_{1u}^2 \\ (x_u - x_2)^2 + (y_u - y_2)^2 + \xi_2 &= d_{2u}^2 \\ &\vdots \\ (x_u - x_n)^2 + (y_u - y_n)^2 + \xi_n &= d_{nu}^2 \end{aligned} \quad (9)$$

Where, ξ_i is the error between estimate and actual distances, and Equation (9) can be expanded as follows:

$$\begin{aligned} -2x_1x_u - 2y_1y_u + {x_u}^2 + {y_u}^2 + \xi_1 &= \mathrm{d}_{u1}^2 - x_1^2 - \\ -2x_2x_u - 2y_2y_u + {x_u}^2 + {y_u}^2 + \xi_2 &= \mathrm{d}_{u2}^2 - x_2^2 - \\ &\vdots \\ -2x_nx_u - 2y_ny_u + {x_u}^2 + {y_u}^2 + \xi_n &= \mathrm{d}_{un}^2 - x_n^2 - \end{aligned} \quad (10)$$

Let $K = {x_u}^2 + {y_u}^2$, Equation (10) is expressed in linear form:

$$A.c = \mathrm{B} \quad (11)$$

Where, $A = \begin{bmatrix} 1 & -2x_1 & -2y_1 \\ 1 & -2x_2 & -2y_2 \\ & . & . \\ & . & . \\ 1 & -2x_n & -2y_n \end{bmatrix}$, $B = \begin{bmatrix} d_{u1}^2 - x_1^2 - y_1^2 \\ d_{u2}^2 - x_2^2 - y_2^2 \\ . \\ . \\ d_{un}^2 - x_n^2 - y_n^2 \end{bmatrix}$, $\mathrm{c} = \begin{bmatrix} K \\ x_u \\ y_u \end{bmatrix}$

In using the least square method to address Equation (11), unknown node U is obtained as follows:

$$c = (A^T A)^{-1} A^T B \quad (12)$$

The unknown node U is

$$[x_u \; y_u]^T = [c(2) \; c(3)]^T \quad (13)$$

- Error Term Analysis

Let unknown node is U, the closest beacon node is I, and the error between estimated and actual distances is Δd_{ui}. Assume that the projection of the distance between adjacent nodes is on the shortest path, and obeys the Gaussian distribution of zero mean and variance. Therefore, the mean of Δd_{ui} is zero and the variance is proportional to the minimum hop between U and I.

Based on Equation (10), $\xi_i = 2d_{ui} \times d_{ui} + \Delta d_{ui}^2$. Upon neglecting the second term, the following equation is obtained:

$$\xi_i = 2d_{ui} \times d_{ui} \tag{14}$$

As noted from Equation (14), ξ_i has the characteristics of zero mean and heteroscedasticity. Nevertheless, error ξ_i does not satisfy the same variance, and the classic linear regression model does not hold. The least squares estimation also does not satisfy the optimal linear unbiased estimation. Therefore, the heteroscedasticity of error ξ_i needs to be corrected.

5. PROPOSED ALGORITHM (TWDV-HOP)

Our proposed algorithm, TWDV-Hop is mainly focus on two points to optimize basic DV-Hop localization algorithm. AHS is corrected in **Step 1**, which is the first innovation point, see Section 5.1. The second step of proposed algorithm is same as traditional DV-Hop. The other contribution is in **Step 3**, detail information is illustrated in Section 5.2.

A. AHS Correction

As we discussed in Section 4.1, AHS error increased as hop value enlarge. Accordingly, we proposed large hop value be cut out during in the process of broadcast in ***Step 1***. The detail information seen as following.

We adopted information table (ID, X_i, Y_i, Hop_i, *Flag_Hop*) to donate informaion packet from received nodes. Here, we add one new byte *(Flag_Hop)* in information table, compared with traditional DV-Hop algorithm, the other information is same. Flag-Hop is utilized to mark whether hop count is larger than 3 or not. If it is true, *Flag-Hop* is set to be 1, otherwise, it set to be 0. The initial hop count and Flag-Hop are 0.

After network initialization is completed, beacon node will broadcast the information packet contained its location information to the whole network. If the *Flag-Hop* of received packet is 1, discard this packet. Otherwise, compared hop value with previous one. If received hop count is larger or equal than previous one, discard this packet. Else, keep it and update packet information table. Then, hop count added by 1, judge whether hop count is larger or equal to 3. If it is true, *Flag-Hop* is set to be 1 and stop forwarding to neighbor nodes. Otherwise, Flag-Hop is still be 0, and continue to transmit to communicable neighbor nodes.

B. Unknown Node Coordinate Correction

New weighted 2D hyperbolic location technique is proposed to reduce location error in ***Step 3***. The idea of weighted least squares gives smaller weights with larger variances of error terms. Based on Equation (13), the performance index of the weighted least squares estimation is given in the following:

$$\sigma(c) = [b - Ac]^T W [b - Ac]^T \tag{15}$$

Where, σ(c) denotes the sum of squared deviations, while *W* refers to the positive weighted matrix. In order to determine the partial derivative for *c*, the following is applied:

$$\frac{\partial}{\partial c}\sigma(c) = \frac{\partial}{\partial c}[b - Ac]^T W [b - Ac]^T = 2A^T W [b - Ac] \tag{16}$$

When Equation (16) is zero, the coordinates of unknown node are determined by considering the extreme value.

$$c_{LSW} = (A^T W A)^{-1} A^T W b \tag{17}$$

Where, c_{LSW} represents weighted least squares estimation, while the estimated error is given below:

$$E\{[c - c_{LSW}][c - c_{LSW}]^T\} = (A^T W A)^{-1} A^T W R_\xi W H (A^T W A)^{-1} \tag{18}$$

Where, $R_\xi = E\{\xi\xi^T\} = D^T D$, in which D is reversible matrix.

Let $M=A^T D^{-1}$, $N=DWA(A^T WA)^{-1}$. The following equation can be obtained based on Schwarz inequality.

$$N^T N \geq (MN)^T (MM^T)^{-1} (MN) \tag{19}$$

Only one matrix *Q* can satisfy the equation, which is when $N=M^T Q$. Here, Equation (19) can be expressed as follows:

$$(A^T W A)^{-1} A^T W R_\xi W A (A^T W A)^{-1} \geq \left(A^T R_\xi A\right)^{-1} \tag{20}$$

Equation (20) is satisfied only when $W = R_\xi^{-1}$. Based on Equation (13), the error matrix can be expressed as follows:

$$\xi = [\xi_1\ \xi_2\ \cdots \xi_n\ ]^T \tag{21}$$

$$E\{\xi\xi^T\} = diag(E\{\xi_1\xi_1\}\, E\{\xi_2\xi_2\} \cdots\ E\{\xi_n\xi_n\}) + B \tag{22}$$

$$B = \begin{pmatrix} 0 & E\{\xi_1\xi_2\} & E\{\xi_1\xi_n\} \\ E\{\xi_2\xi_1\} & 0 & E\{\xi_2\xi_n\} \\ \vdots & \vdots & \vdots \\ E\{\xi_n\xi_1\} & E\{\xi_n\xi_2\} & 0 \end{pmatrix} \tag{23}$$

In the case of unknown node *U*, and when beacon nodes *I* and *J* are not on the same line, both Δd_{ui} and Δd_{uj} become independent. Hence, $E\{\xi_i\xi_j\} = 0$. This shows that the distance between adjacent two nodes in the direction of the line is independent. In the case of unknown node *U*, and when beacon nodes *I* and *J* are on the same line, its AHS error and variance are the same. The shortest path between $E\{\xi_i\xi_j\}$ is proportional to the same shortest path between beacon nodes *I* and *J*. Considering the network distribution characteristics, the probability of collinearity between *U*, *I*, and *J* is extremely small, hence B is negligible and Equation (24) is given as follows:

$$R_\xi = diag(E\{\xi_1\xi_1\}\ E\{\xi_2\xi_2\} \cdots\ E\{\xi_n\xi_n\}) \quad (24)$$

Based on Equation (14), Equation (25) is obtained, as follows:

$$E\{\xi_i\xi_i\} = 4Hopsize_u{}^2 \times h_{ui}^2 \times E\{\Delta d_{ui} \times \Delta d_{ui}\} \quad (25)$$

It is assumed that the variance distance error between adjacent nodes is σ^2. Therefore,

$$E\{\Delta d_{ui} \times \Delta d_{ui}\} = h_{ui} \times \sigma^2 \quad (26)$$

Equation (24) can be expressed as given below:

$$R_\xi = 4Hopsize_u^2 \times \sigma^2 \times diag({}^1/_{h_{u1}^3}\ \ {}^1/_{h_{u2}^3}\ \cdots {}^1/_{h_{un}^3}) \quad (27)$$

The estimated coordinates can be determined by substituting Equation (27) into Equation (17).

$$\sigma(c) = \sum_{i=1}^{n} w_i \times (d_{ui}^2 - x_i^2 - y_i^2 - K - 2x_i \times x - 2y_i \times y) = \sum_{i=1}^{n} w_i \times \xi_i^2 \quad (28)$$

Where w_i refers to the weighted coefficient of the error term, ξ_i:

$$E\{w_i \times \xi_i^2\} = w_i \times 4Hopsize_u^2 \times h_{ui}^2 \times E\{\Delta d_{ui} \times \Delta d_{ui}\} = 4Hopsize_u^2 \times \sigma^2 \quad (29)$$

Based on Equation (29), after introducing the weighted matrix, the variance and the corresponding weighted coefficient product of error term, ξ_i, become a constant and independent of *i*.

The work flow chart of our proposed algorithm TWDV-Hop is illustrated in Fig. 5.

6. Experimental Results and Discussion

A. *Evaluation Criteria*

Localization accuracy and energy consumption cost metrics are utilized to evaluate the achievement of our proposed TWDV-Hop.

- Accuracy Metrics

(1) Localization Error (LE)

The localization error (LE) is a difference between actual and calculated coordinates of unknown nodes, its expression is shown in Equation (30).

$$LE = \sqrt{(x_u - x_a)^2 + (y_u - y_a)^2} \quad (30)$$

(2) Localization Error Radius (LER)

The LER is the ratio of the average localization error to the communication range, as given in the following:

$$LER = \frac{\sum_{u,a=1}^{n} \sqrt{(x_u - x_a)^2 + (y_u - y_a)^2}}{n \times R} \quad (31)$$

- Energy Consumption Metric

Energy consumption is expressed as the communication cost of algorithms, which is represented by the number of transmitting and receiving packets by sensor nodes in the localization process. The reduction in communication overhead is an important accomplishment of saving energy.

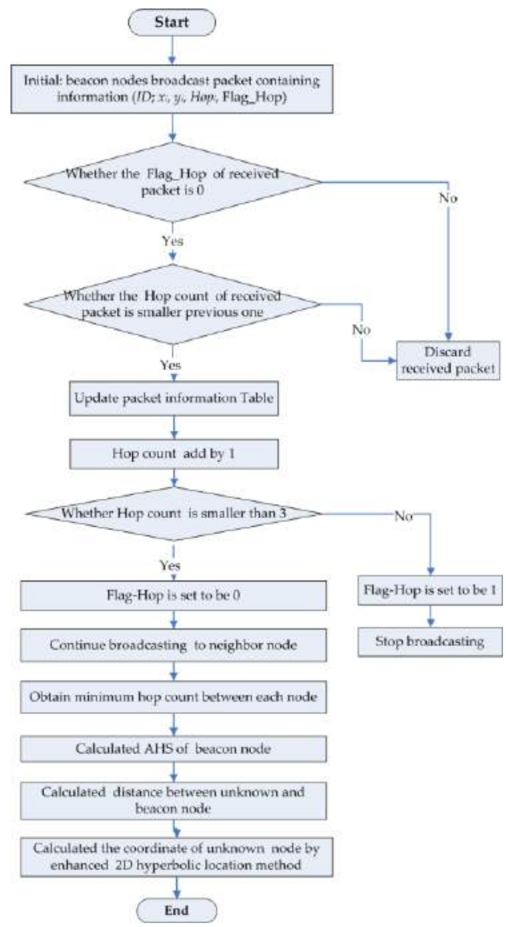

Figure 5. The flow chart of TWDV-Hop

B. *Experimental Environment*

An instance of node deployment in 2D space is illustrated in Fig. 6. A total number of 100 nodes are randomly displayed in the 100 × 100 m^2 area, including 20 beacon nodes denoted by red pentacles. Aiming to testing the performance of TWDV-Hop, comprehensive experiments were conducted in MATLAB 2016a. The experimental outcomes were compared with DV-Hop [13], IDVLA [16], and New-IDV-Hop [18] in same simulated settings. Table 1 illustrates the simulation parameters.

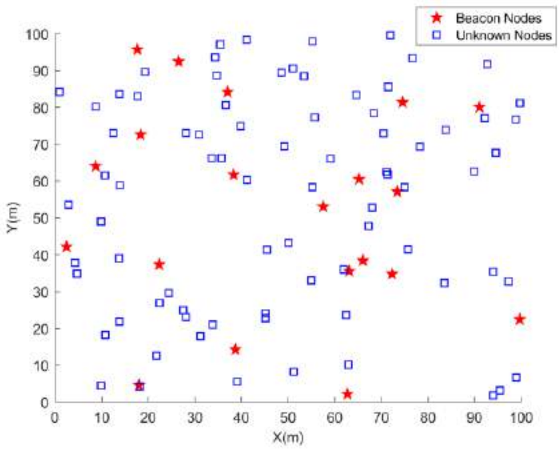

Figure 6. A typical instance of distributed nodes

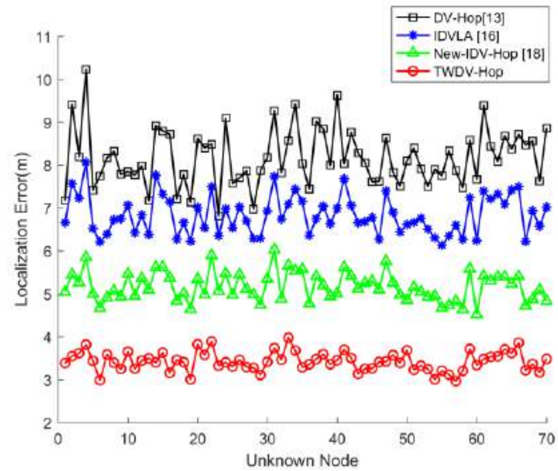

Figure 7. The localization error for each unknown node

TABLE I. SIMULATION PARAMETERS SETTING.

Parameters	Value
Network Size	100m×100m
Total nodes	100
Beacon Nodes	20
Communication Range(m)	25

TABLE II. THE COMPARISONS OF LOCALIZATION ERROR AND STANDARD DEVIATION.

Localization Algorithm	Max. LE(m)	Min. LE(m)	Avg. LE(m)	Std. (LE)
DV-Hop [13]	10.2362	6.8131	8.1779	0.6752
IDV-Hop [16]	8.0688	6.1309	6.8358	0.4554
New-IDV-Hop [18]	6.0286	4.5171	6.0286	0.3348
TWDV-Hop	**3.9753**	**2.9654**	**3.4257**	**0.2229**

C. Experimental Results

To better examine proposed algorithm, all experiments for algorithms were performed as many as 100 times for each result, since sensor nodes are randomly deployed in monitor area. We utilized the average value to evaluate improved algorithm. Here, abbreviations LE and LER are used to represent localization error, localization error radius, respectively.

- LE for Each Unknown Node

This simulation was conducted under the scenario that 100 sensor nodes were irregularly deployed in the area of 100 ×100 m^2 with 20% beacon node. The communication range is 25 m.

Fig. 7 demonstrates the LE for each unknown node under four algorithms in the same environment. Obviously, our proposed algorithm (TWDV-Hop) gave the best outcomes. The LE of basic DV-Hop is around 8m and almost three times larger than TWDV-Hop. Furthermore, it has a steep polyline angle between unknown node. In contrast, all LE of TWDV-Hop are between 3m and 4m, with a flat change trend and almost close to straight line, which means the performance of TWDV-Hop is more stable. The reduction of TWDV-Hop localization error is around at 65%, 45% and 30%, respectively, when came to compared with DV-Hop [13], IDVLA [16], and New-IDV-Hop [18].

Table 2 illustrates the comparisons of LE and its standard deviation under four localization algorithms. Upon comparing with the other three localization algorithms, TWDV-Hop yielded the lowest location error in terms of max, min, and average values. The maximum LE is less than 4m and minimum LE is smaller than 3m. The average LE of TWDV-hop is decreased 59.40%, 49.89% and 33.71, compared with DV-Hop [13], IDVLA [16] and New-IDV-Hop [18], respectively. Besides, the TWDV-Hop also recorded the lowest standard deviation, which indicated that TWDV-Hop had better stability.

- Accuracy Metrics with Variation Factors

Accuracy is most significant evaluate factor for localization algorithm. In this study, LER is adopted to assess the accuracy under effected factor in terms of the effects of total number of nodes, beacon node ratio, and communication range.

(1) Effect of Total Number of Nodes

The total number sensor nodes were evenly increased from 50 to 350, while the communication radius and the proportion of beacon nodes ratio are fixed at 25 m and 10%, respectively. Fig. 8 and Table 3 list the experiential results of LER.

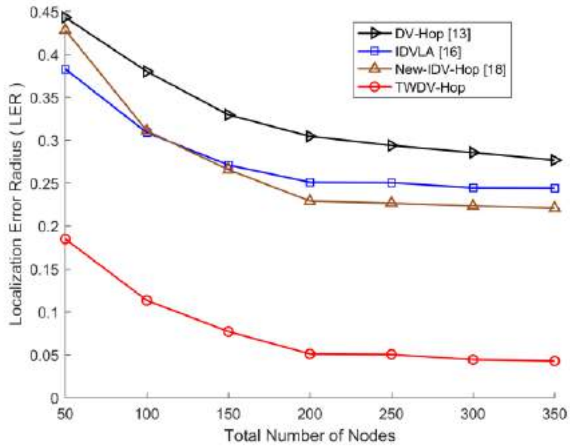

Figure 8. The LER under various total number of nodes.

Fig.8 illustrates the LER under various amounts of sensor nodes. It shows down-ward trend with sensor node increased under four algorithms. The proposed algorithm always scored the lowest error radius under all situations, especially when the nodes exceeded 150. The LER of the proposed algorithm decreased by 75%, 60%, and 70%, when compared with DV-Hop [13], IDVLA [16], and New-IDV-Hop [18], respectively.

TABLE III. COMPARISON LER OF ALGORITHMS WITH VARIOUS TOTAL NUMBER OF NODES.

Localization Algorithm	Localization Error Radius (LER)		
	Max.	**Min.**	**Avg.**
DV-Hop [13]	0.4429	0.2765	0.3303
IDLVA [16]	0.3828	0.2443	0.2789
New-IDV-Hop [18]	0.4282	0.2207	0.2720
TWDV-Hop	**0.1848**	**0.0426**	**0.0804**

Table 3 tabulates LER under different total number of nodes. As depicted in Table 3, TWDV-Hop exerted the best performance under LER. Upon comparing with the proposed algorithm, the LER under average term decreased to 75.66%, 64.87%, and 70.44% for DV-Hop [13], IDLVA [16], and New-IDV-Hop [32], respectively.

(2) Effect of Beacon Node Ratio

In this experiment, the beacon ration is evenly increased from 10% to 40%. At the same time the total number of nodes and communication range were fixed at 100 and 25 m, respectively. Fig.9 and Table 4 present the empirical findings under diverse beacon node ratio.

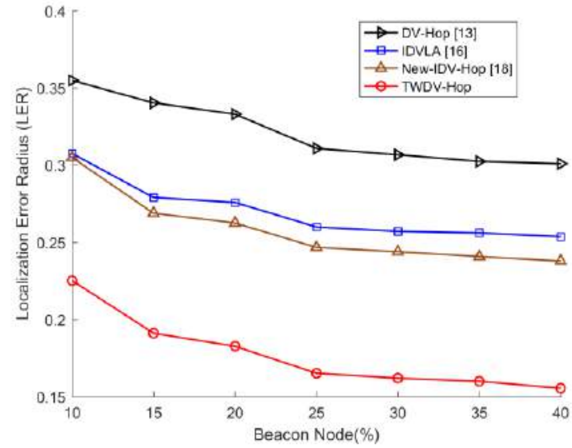

Figure 9. The LER under various beacon nodes ratio

Fig. 9 displays the LER with variation in beacon node ratio. The proposed algorithm always scored the lowest LER under all situations, especially when the beacon node exceeded 32. The LER of the proposed algorithm decreased to 45%, 35%, and 30%, when compared with DV-Hop [13], IDVLA [16], and New-IDV-Hop [18], respectively.

TABLE IV. COMPARISON LER OF VARIOUS ALGORITHMS WITH BEACON NODE RATIO.

Localization Algorithm	Localization Error Radius (LER)		
	Max.	**Min.**	**Avg.**
DV-Hop [13]	0.3588	0.3043	0.3249
IDLVA [16]	0.3110	0.2565	0.2729
New-IDV-Hop [18]	0.3084	0.2405	0.2608
TWDV-Hop	**0.2309**	**0.1594**	**0.1819**

As depicted in Table 4, the proposed algorithm TWDV-Hop outperformed the rest under LER, with the average accuracy reaching up to 85%. The LA, under average term of the proposed algorithm, decreased by 44.01%, 33.35%, and 30.25%, when compared with DV-Hop [13], IDVLA [16], and New-IDV-Hop [32], respectively.

(3) Effect of Communication Range

In this experiment, the communication range is increased from 20 to 36 m, while sensor and beacon nodes were fixed at 100 and 20, respectively. Fig.10 and Table 5 tabulate the empirical outcomes of LER under different communication range.

Fig.10 reflects the LER with variation in communication range. The TWDV-Hop always scored the lowest LER under all situations. The LER of the proposed algorithm TWDV-Hop decreased to 40%, 30%, and 20%, when compared with DV-Hop [13], IDVLA [16], and New-IDV-Hop [18], respectively.

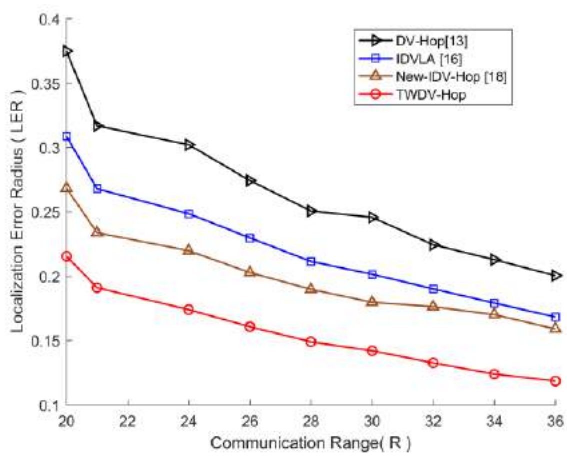

Figure 10. The LER under various communication range

As depicted in Table 5, the proposed algorithm gave the best performance under LER. When compared with the proposed algorithm, the LER, under average term, decreased to 41.42%, 29.85%, and 21.81%, when compared with DV-Hop [10], IDVLA [16], and New-DV-Hop [18], respectively.

TABLE V. COMPARISON LER OF VARIOUS ALGORITHMS WITH COMMUNICATION RANGE.

Localization Algorithm	Localization Error Radius (LER)		
	Max.	**Min.**	**Avg.**
DV-Hop [13]	0.3748	0.2003	0.2668
IDLVA [16]	0.3087	0.2228	0.1682
New-IDV-Hop [18]	0.2683	0.1589	0.1999
TWDV-Hop	**0.2154**	**0.1184**	**0.1563**

- Energy Consumption Cost

Here, we adopted total number of transmitted and received packets (TTRP) to evaluate energy consumption cost, cause more than half of power spent on packet transmission. Table 6 illustrated the TTRP for four algorithms, where N is all total number of sensor nodes, m is the amount of beacon nodes and P is average network connectivity.

TABLE VI. ENERGY COST UNDER ALL ALGORITHMS

Packets		Localization Algorithms			
BP: broadcast packets **RP**: received packets **TP**: Total packets		DV-Hop [13]	IDVLA [16]	New-DV-Hop [18]	TWDV-Hop
Step1	BP	$N\times m$	$N\times m$	$N\times m$	$N\times m$
	RP	$(N-1)\times m\times P_{avg}$	$(N-1)\times m\times P_{avg}$	$(N-1)\times m\times P_{avg}$	$1/3\times(N-1)\times m\times P_{avg}$
	TP	$N\times m+$ $(N-1)\times m\times P_{avg}$	$N\times m+$ $(N-1)\times m\times P_{avg}$	$N\times m+$ $(N-1)\times m\times P_{avg}$	$N\times m+$ $1/3\times(N-1)\times m\times P_{avg}$
Step 2	BP	N	N	N	N
	RP	$N-m$	$N-m$	$N-m$	$N-m$
	TP	$2N-m$	$2N-m$	$2N-m$	$2N-m$
TTRP		$N\times m+$ $(N-1)\times m\times P_{avg}+2N-m$	$N\times m+$ $(N-1)\times m\times P_{avg}+2N-m$	$N\times m+$ $(N-1)\times m\times P_{avg}+2N-m$	$N\times m+$ $1/3\times(N-1)\times m\times P_{avg}+2N-m$

In the first step, each beacon node broadcast packets to all unknow nodes one time to forward its position. DV-Hop [13], IDVLA [16] and New-IDV-Hop [18] are based on flood protocol, hence three of them consumed same energy in **Step 1**. In contrast, TWDV-Hop will cut out the hop value that is larger than 3. In Section 4.1, we conducted the conclusion that it accounts for one third of the total hop amounts. Accordingly, the received packets are reduced one third in **Step 1**. In **Step 2**, each unknown node only forwards the first received AHS, so the communication cost of four algorithms is equal. Overall, it can be revealed that TWDV-Hop achieved fabulous outcomes form Table 6, which consumed less energy than other three algorithms.

7. CONCLUSION

Node location technology is a research hotspot in current wireless sensor networks area. DV-hop as the most popular range-free localization algorithm for its simplicity, no range-based hardware requirement and easy to implement. However, it has lower localization accuracy and inaccuracy AHS. Since AHS is the main reason lead to large location error. We adopted an improved method named as TWDV-Hop to address this issue. Considerable experiments are conducted to analyze the distributed law between hop count and AHS error. If the hop value is larger than three, it will be cut out to optimize AHS based on experiment result. This will greatly save energy consumption since larger hop count is discarded, not continue forward to neighbor node in broadcasting process. Furthermore, weighted matrix is added to rectify error as a result of least squares method. Not only accuracy metric but also energy consumption is taken account into to evaluate the performance proposed TWDV-Hop algorithm with various effected factor in terms of beacon node ratio, communication range etc. Simulation outcomes shown TWDV-Hop has superior advantages in localization accuracy with lesser communication cost. The localization error radius is decreased more 75%, compared with traditional DV-Hop algorithm. Besides, the average localization error is less than 3.5m and minimum value is lower than 3, which can satisfy location-based application at some extent. We are considering extend our work under 3D WSNs in the further.

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