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Improved DV-Hop Localization Algorithm Based on Anchor Weight and Distance Compensation in Wireless Sensor Network

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Abstract

Position information is the foundation of massive applications in Wireless Sensor Network(WSN). Three improved positioning algorithms based on DV-Hop are proposed in order to enhance the positioning accuracy of wireless sensor nodes. First improved algorithm is distance compensation algorithm (DCA) that creates a triangle model to compensate the estimated distance. The second improved algorithm creates a new chain table for all anchor nodes to record and compute the average hop distance. The third improved algorithm is weighting different anchor nodes with anchor nodes' nearest unknown nodes. The second and third improved algorithms are based on the DCA. The simulation results show that the three improved algorithms are better than the original DV-Hop in localization accuracy. Compared to the original DV-Hop algorithm, the simulation results shows that the three improved algorithms proposed in the paper increase the positioning accuracy of the unknown nodes.

Keywords: *Wireless Sensor Network; Positioning Algorithm; Distance Compensation Algorithm; Weight; New Table Chains; DV-Hop*

1. Introduction

It is of vital significance for the wireless sensor nodes to get the position information in the applications of WSN, *e.g.*, the distant medical system, military defense, smart transportation and environmental monitoring [1]. In these applications, the information without nodes' position, which cannot indicate where the events and data occurred, is meaningless. Therefore, position information is very important to wireless sensor nodes.

Generally, according to the required information and hardware, the localization algorithms of the WSN are classified into two categories: Range-based and Range-free. The range-based localization algorithms include Time of Arrival (TOA), Received Signal Strength Indicator (RSSI), Time Difference of Arrival (TDOA), and Angel of Arrival (AOA) [2-3]. These algorithms all require extra hardware to get relevant information, *e.g.*, the signal strength indicators are needed to measure the signal strength in RSSI. Though these algorithms have relative high localization accuracy, inevitably increase the cost when these algorithms are applied in large scale wireless sensor network. The range-based localization algorithms have no special requirements of extra information and hardware, so these alrorithms are more suitable in large scale WSN with lower cost and energy consumptions, these algorithms mainly are: APTI, DV-Distance, MDS-Map, and DV-Hop (Distance Vector-Hop) [4-7].

In [8-10] DV-Hop algorithm was proposed by D. Niculescu and B. Nath. It is simple, robust and has good coverage quality, feasibility as well as facility. Therefore it was widely used in WSN. However, it was faced with two main disadvantages: relatively high power-consumption and inadequate localization accuracy [11-13].

Three improved algorithms were proposed in the paper in order to improve the

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localization accuracy. The DCA is first introduced [14], and the other two were based on the DCA. The second improved algorithm is based on features of DV-Hop and establishes new chain tables to complete the localization. The third improved algorithm is based on the weight evaluated by the amount of nearest unknown sensor nodes. The basic principles and implemental approaches are introduced, and the three localization algorithms are compared through one single simulation platform. Simulation results show their validity and superiority.

The rest of the paper is organized as follows: Section 2 presents the related work about DV-Hop localization algorithm and DCA. Section 3 describes the improved algorithms. The algorithms performances are evaluated in the Section 4. Section 5 draws the conclusions.

2. Related Work

2.1. DV-Hop

The original DV-Hop algorithm employs a distance vector exchange so that all anchor nodes get the distance and hops to the other anchor nodes, and all unknown nodes get hops to the nearest anchor node. Then the anchor nodes estimate the average distance per hop, which is a correction and transmitted to the entire networks. Finally, and the unknown nodes get their locations by multilateral measurement method. Generally, the original DV-Hop algorithm can be divided into three steps.

In the first step, the anchor nodes broadcast their information packages to all other nodes through neighbor nodes. The information packages contains anchor nodes' identifiers, location coordinates and hop count. The hop count is initially set zero, and increase by one when the package passes a node. A node will conclude the minimum hop count to the certain anchor nodes from all the information packages the node received [15]. If a node gets an information packages with different hop count to the same anchor node and the package with lowest hop count will be maintained. The maintained information package will be flooded outward to the entire network. The updates and further broadcasts will continue until all the nodes receive their shortest path. Eventually, every sensor node gets minimal hop count to a certain anchor node.

In the second step, anchor nodes get location coordinate and the minimal hop count to other anchor nodes, and average distance in one hop called average hop distance (AHD), and it is defined as:

$$\mathrm{AHD_i} = \frac{\sum_{j \neq i}^{n} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j \neq i}^{n} hops_{ij}} \bullet \tag{1}$$

In (1) ,(x_i, y_i), (x_j, y_j) are the respectively the coordinate of anchor node i and j, and n is the number of anchor nodes which are able to communicate with the anchor node i, $hops_{ij}$ represents the minimal hop count between anchor node i and anchor node j.

Each anchor node broadcasts its AHD to its neighbors. As the first step describes, the received sensor nodes flooded outward the AHD information. With accepting the AHD information from anchor node, the unknown node computes its distance to the anchor node as:

$$d_{ij} = AHD_j \times hops_i \bullet \tag{2}$$

In (2), $hops_i$ is the hop count of the unknown node to the anchor node, and AHD_j

stands for the AHD information the unknown node accepts.

In the third step, each unknown node calculates its location coordinate with the equation set as:

$$\begin{cases} \sqrt{(x-x_1)^2+(y-y_1)^2}=d_1 \\ \sqrt{(x-x_2)^2+(y-y_2)^2}=d_2 \\ \quad \cdots \\ \sqrt{(x-x_n)^2+(y-y_n)^2}=d_n \end{cases} \tag{3}$$

In (3), (x, y) represents the location coordinate of the unknown nodes, and (x_i, y_i) represents the anchor nodes location coordinates, and d_i is the distance between the anchor nodes and the unknown nodes.

The equation set can be rewritten as $AX = B$, and A, B, X are as:

$$A=\begin{bmatrix} x_1-x_n & y_1-y_n \\ x_i-x_n & y_i-y_n \\ \cdots & \\ x_{n-1}-x_n & y_{n-1}-y_n \end{bmatrix} \tag{4}$$

$$B=\begin{bmatrix} d_1^2-d_n^2-x_1^2+x_n^2-y_1^2+y_n^2 \\ d_i^2-d_n^2-x_i^2+x_n^2-y_i^2+y_n^2 \\ \cdots \\ d_{n-1}^2-d_n^2-x_{n-1}^2+x_n^2-y_{n-1}^2+y_n^2 \end{bmatrix} \tag{5}$$

$$X=\begin{bmatrix} x \\ y \end{bmatrix} \tag{6}$$

The least square solution of $AX = B$ should be:

$$X=(A^TA)^{-1}A^TB \tag{7}$$

3. Improved Algorithms

3.1. Distance Compensation Algorithms

In the classical DV-Hop algorithm, the physical distance is adopted to compute the AHD, and the physical distance is obviously inconsistent with the actual transmission distance as shown in the Figure 1.

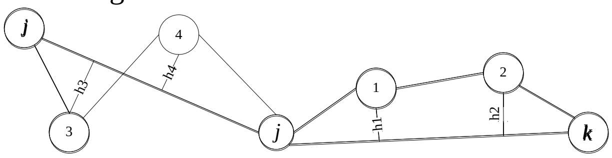

Figure 1. Network Topology

In Figure 1, the information from anchor node i passed through the unknown nodes 3 and 4, and reached at anchor node j. Then it went through the unknown nodes 1 and 2, and finally received by the anchor node k. In the transmission process of the information, the physical distance between the anchor nodes i and k is significantly different from the actual transmission distance. With the increase of hop count as well as irregular distribution of nodes, the localization errors will accumulates in localization process. The critical part of DCA differs from other improved algorithms lies in adopting the transmission distance to calculate the AHD.

3.2. New Chain Tables for Anchor Nodes

In the original DV-Hop algorithm, the information packages containing identifiers, location coordinate and hop count are eventually stored in table chains of the nodes. As described in the first step, each unknown node gets the information of the anchor nodes which are nearest to the unknown node, and the unknown node will uses the AHD and hop count to computes the estimated physical distance. In the sub-section 3.1, this computation method results in certain errors in the localization accuracy, because different anchor nodes of diverse AHD have different impacts on the localization.

Therefore, new chain tables are established to balance the impacts of the AHD diversity and decrease the localization errors. The three steps based on the classical DV-Hop algorithm are given as:

Step 1. The anchor nodes in the network record the information packages in the new chain tables. The packages from the same anchor node, only the one with the smallest hop count will be maintained in the chain tables. The anchor node i has the chain table $list_i$, and received the packages of anchor node j and k. The chain table $list_i$ can be expressed as:

$$\begin{aligned} & list_{ik} = \{ID, hops, AHD_k\}, list_{ik} \subseteq list_i . \\ & ID = anchor\ k, \\ & hops = b, \\ & AHD_k = M. \end{aligned} \tag{13}$$

$$\begin{aligned} & list_{ij} = \{ID, hops, AHD_j\}, list_{ij} \subseteq list_i \\ & ID = anchor\ j, \\ & hops = a, \\ & AHD_j = L. \end{aligned} \tag{14}$$

Step 2. The anchor node i updates its AHD with the information in the chain tables, which can be described as:

$$AHD_{inew} = \frac{aL + bM}{a + b} . \tag{15}$$

In (15), are the updated AHD of the anchor node i, and the anchor node i will flood outward the package with the new AHD, and the transmission path will follow the shortest path in order to save energy.

Step 3. The anchor nodes j and k also will establish new chain tables and update their AHD. When all anchor nodes complete the update, the unknown nodes get the updated AHD to compute the distance and location.

3.3. Weight of Anchor Nodes

According to the original DV-Hop algorithm, the equation is formed to depict the error between each anchor node's AHD and the standard AHD, and is defined as:

$$\sigma(\mathrm{i}) = \sum_{i=1}^{j} \left| AHD_i - AHD_{standard} \right| . \tag{16}$$

In (16), i and j represents the anchor nodes, and the error $\delta(\mathrm{i})$ does not reach its minimum value for the relative invariance of the standard AHD ($AHD_{standard}$). The standard AHD only exists in mathematical theory and makes the overall error minimal.

The formula can be rewritten as:

$$\sigma(\mathrm{i}) = \begin{cases} \sum_{k=1}^{n} (AHD_k - AHD_{standard}) & k \in S_1 \\ \sum_{l=1}^{m} (AHD_{standard} - AHD_l) & l \in S_2 \end{cases} . \tag{17}$$

In (17), S_1 (S_2) represents a set of the anchor nodes whose AHD is less (more) than the standard AHD and n (m) is the number of the set S_1 (S_2). For n and m, the constraint can be draw as:

$$m + n \le AnchorSum . \tag{18}$$

In (15), $AnchorSum$ represents the amount of anchor nodes deployed in the networks and available in communicate with other nodes. Based on (17), the conclusion can be made as:

$$\sigma(\mathrm{i}) = \begin{cases} \sum_{k=1}^{n} AHD_k - mAHD_{standard} & k \in S_1 \\ -\sum_{l=1}^{m} AHD_l + nAHD_{standard} & l \in S_2 \end{cases} . \tag{19}$$

Using x_k and x_l to replace AHD_k and AHD_l , and calculating partial differential of (16) leads to results as:

$$\sigma(x_i) = \begin{cases} \sum_{k=1}^{n} x_k - mAHD_{standard} & k \in S_1 \\ -\sum_{l=1}^{m} x_l + nAHD_{standard} & l \in S_2 \end{cases} . \tag{20}$$

$$\frac{\partial \delta}{\partial x} = \begin{cases} \sum_{k=1}^{n} \frac{1}{x_k} & k \in S_1 \\ \sum_{l=1}^{m} x_l & l \in S_2 \end{cases} . \tag{21}$$

Make the $\frac{\partial \delta}{\partial x} = 0$, two parts of the equation corresponds to different solutions, which are as:

$$X_1 = \max\{S_1\} . \tag{22}$$

$$X_2 = \min\{S_2\} . \tag{23}$$

In the two equations, X_1 (X_2) represent the maximum (minimum) AHD in the set of S_1(S_2). As is known, X_1 and X_2 can't reach the same value in $\frac{\partial \delta}{\partial x} = 0$.

Due to the random employment of nodes, the value of AHD of each anchor node is also relatively random in overall. In order to balance to X_1 and X_2, new AHDs are weighted by the qualified unknown nodes in the network. An algorithm based on the weight of anchor nodes is proposed.

In the third step of original DV-Hop algorithm, all anchor nodes, participating in the localization equations, have more impact to the solutions of the (3), because these nodes are surrounded by unknown nodes in one hop to them, moreover, and the amount of these unknown nodes greatly affect the AHD of the anchor nodes. The anchor node, with more unknown nodes in one hop around, gets the closer AHD to X_1 and X_2 in the entire network. According to (21), the process of weighting on nodes is given as:

1. The anchor nodes record the amount of unknown nodes with n_i (i represents the anchor node number), and these unknown nodes are in one hop to the anchor nodes.

2. All anchor nodes, participating in the location of the unknown nodes, flood outward the n_i to other anchor nodes through these unknown nodes, so the other anchor nodes can receive n_i. The anchor nodes sum all the n_i up in $Sum_j = \sum_i^m n_i$, j represents the unknown nodes number, and the m represents the amount of the anchor nodes communicated with by the unknown node.

3. All the anchor nodes respectively calculate their weight and new AHD as:

$$p_i = n_i / Sum_j = n_i / \sum_i^m n_i \quad . \tag{24}$$

$$\begin{aligned} AHD_{weighted} &= AHD_i \times p_i \\ &= AHD \times n_i / \sum_i^m n_i \quad . \end{aligned} \tag{25}$$

In (21) and (22), i represents the anchor nodes number, $AHD_{weighted}$ represents the weighted AHD, and AHD_i represents the prime AHD that the anchor node i has. The anchor nodes flood outward the updated $AHD_{weighted}$ to the entire network.

4. The unknown nodes receive the weighted AHD and the ID of the anchor nodes, and employ the weighted AHD to compute the distance and locations.

4. Simulation Results

To evaluate the feasibility and validity of the improved algorithms proposed in the paper, simulations of comparison between the improved algorithms and the original DV-Hop algorithm are presented. (DV-Hop), (DV-Hop1), (DV-Hop2) and (DV-Hop3) presents respectively the original DV-Hop algorithm, the algorithm based on the DCA, the algorithm on the basis of new chain table and the algorithm based on the weighted AHD.

One hundred nodes, including 90 unknown nodes and 10anchor nodes, are deployed in the area with both length and width are 100 as is shown in the Figure 4, where the red pots represent the anchor nodes and the blue pot is unknown nodes. Average localization error, under different communication radius and anchor ratios, was selected as the criterion to evaluate the performance of the algorithms.

$$\text{Er}=\frac{\sqrt{(x-x_{est})^2+(y-y_{esst})^2}}{R}. \tag{26}$$

In the equation, (x, y) is the real location coordinate and (x_{est}, y_{esst}) is the estimated location coordinate, R is the corresponding communication radius. The average value was employed as the results by running randomly the simulations of algorithms 100 times.

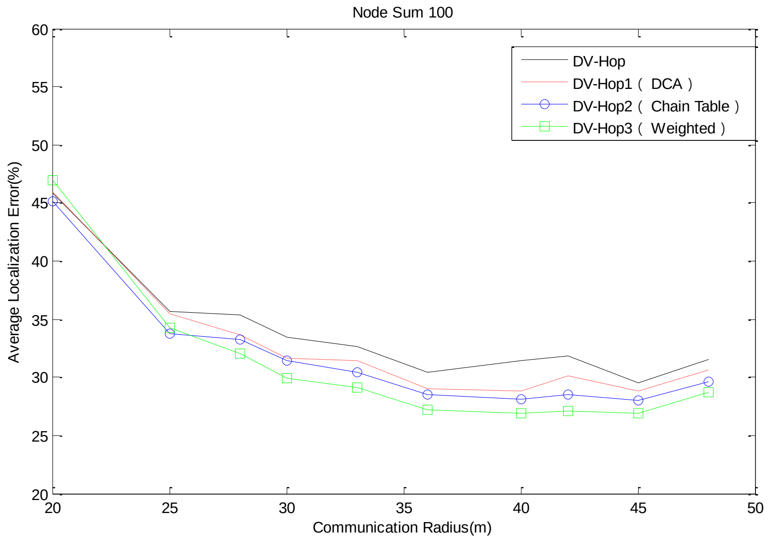

Figure 2. Average Localization Errors with Different Communication Radius

Figure 2, shows the relationship between average localization error and communication radius varying from 23 to 50 with the anchor node ratio 20%. Average localization error is in contradictory relationship to the average localization accuracy. Generally, the average localization error declines with the incensement of the communication radius in one single algorithm. When the communication radius is less about 28, the improved algorithms have better performance in localization accuracy, and the algorithm based on weighted AHD is worse than the algorithm based on the new chain tables for the relatively short communication radius causing the lower weight for the anchor nodes. When communication radius is more than 30, the algorithm based on weighted AHD is better than the algorithm based on new chain tables because of the relatively long communication radius bringing more weight of the anchor nodes which affect the weighted AHD greatly. Overall, the two improved algorithms have better performance in localization accuracy than the DV-Hop algorithm and DCA in different communication radius, undoubtedly, which indicates the validity and optimization of the two algorithms.

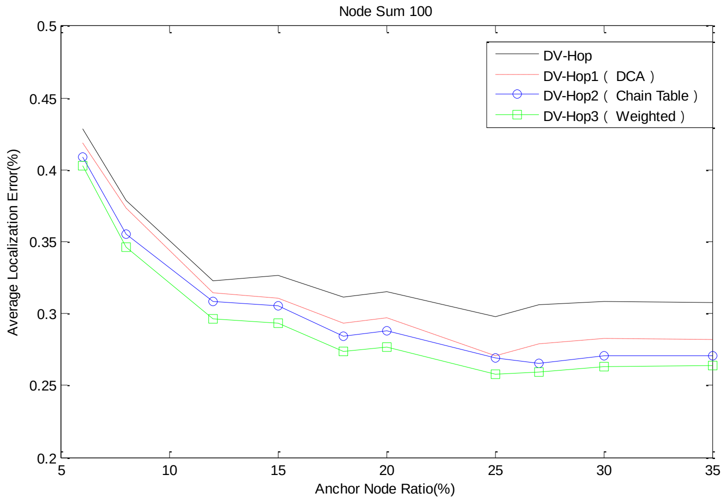

Figure 3. Average Localization Errors with Different Anchor Ratio

Figure 3, shows the relationship between average localization error and anchor nodes ratio varying from 6% to 35% with the communication radius 30. When the anchor nodes ratio is relatively small, the DCA is close to the DV-Hop algorithm, and the algorithm based on weighted AHD is close to the algorithm based on the new chain tables for the low anchor nodes ratio leading to the increasement of the hop count which accumulates the localization error. When the anchor ratio is large enough, The DCA and the two improved algorithms are better than the DV-Hop algorithm, and the more anchor nodes ratio, the lower the average localization error is.

With the change of anchor node ratio, the algorithm based on weighted AHD gets close to the algorithm based on the new chain tables for the high anchor node ratio resulting in the almost same AHD and high coverage. Overall, the two improved algorithms have better performance in localization accuracy than the DV-Hop algorithm and DCA in different anchor ratio, undoubtedly, which indicates the validity and optimization of the two algorithms.

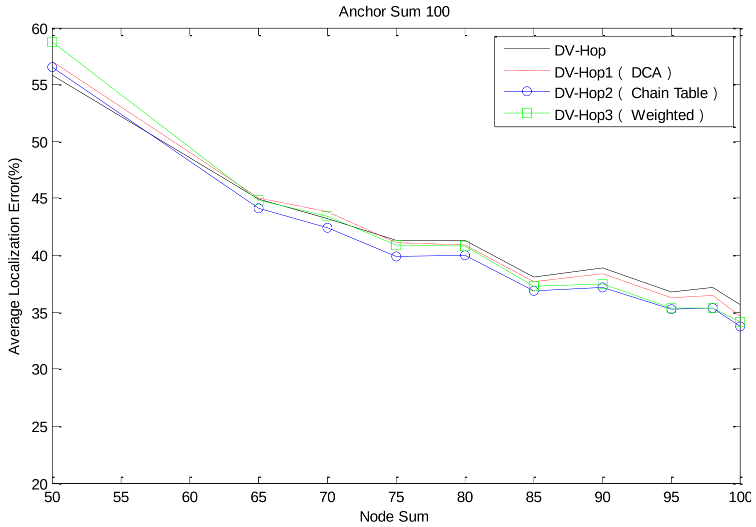

Figure 4. Average Localization Errors with Different Node Sum.

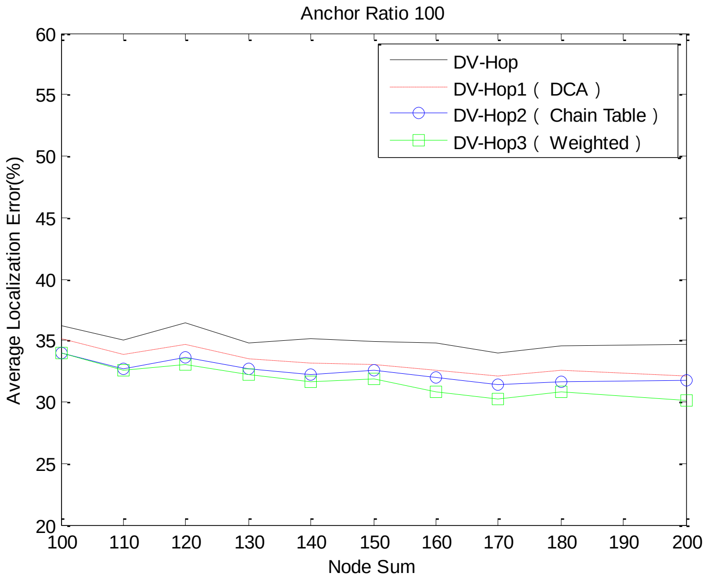

Figure 5. Average Localization Errors with Different Node Sum

Figure 4, shows the relationship between average localization error and node sum varying from 50 to 100 with the communication radius 25 and the anchor ratio 15%. When the node sum is small enough, the improved algorithms approach the DV-Hop in localization error. With the increase of the node sum, the improved algorithms have better performance than the DV-Hop.

Figure 5, shows the relationship between average localization error and node sum varying from 100 to 200 with the communication radius 25 and the anchor ratio 15%. The four algorithms decrease slightly in localization error, and the gap between them is more.

From the two simulation results, the conclusion that the improved algorithms are superior in localization error with different node sum.

5. Conclusion

Localization accuracy, a crucial characteristic of WSN, is a significant factor and considerable research interest. Three improved algorithms are proposed based on the DV-Hop algorithms. In the original DV-Hop algorithm, the physical distance is employed to calculate the AHD, which will inevitably cause localization error. Therefore, The DCA constructed a model to compensate the actual transmission distance based on the physical distance. The improved algorithm based on new chain tables and the improved algorithm based on the weight of anchor nodes, actually, both balance the impacts of the anchor nodes in localization process, and decrease the localization error through different methods to weighting on the anchor nodes. Though the three improved algorithms apply different methods to enhance the localization accuracy, essentially, the three algorithms are the same. The three improved algorithms both change the estimated distance and weight the AHD in different ways, which eventually leads to adjust the AHD to decrease the localization error. On the basis of the simulation results, the three improved algorithms have the same trend with the original algorithm, and the three improved algorithms have better performance than the original algorithm in localization accuracy as well as validity through analysis and comparison.

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