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An Improved DV-HOP Algorithm was Applied for The Farmland Wireless Sensor Network

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Abstract. *To improve the poor performance of distance vector-hop (DV-Hop) algorithm in positioning accuracy caused by the irregularity in the farmland of wireless sensor networks, Firstly, an improvement wireless channel model based on analyzing the signal propagate on characteristics is proposed in wireless channel. Secondly, a refinement method for the irregularity of wireless sensor networks based on node degree is proposed. Simulation results show that the improved DV-Hop algorithm out performs better than the traditional DV-Hop algorithm and these existing improved algorithms in localization accuracy without adding additional hard-ware. So it can better achieve a real-time and accurate management of crops.*
Keywords: DV-Hop; Wireless channel model; Refinement method; Node degree.

1. **Introduction.** Agriculture is the foundation of human survival and nation economy. At present, the agriculture economy development rapidly in china, but it involves a spectacular waste of resources. With the rapid development of wireless sensor network, agriculture gradually realize precision. There are difference in farmland environment and crop conditions in each region of farmland, thus, the calculative precision of pending area of farmland become the key for reduce resources waste, and it can effectively solve the problem by a good location algorithm.

At present, a variety of wireless sensor network localization algorithms has been developed [1, 2]. According to different mechanisms, these algorithms can be divided into two categories: range-based algorithms and range-free algorithms. Range-based algorithms depend on measuring physical attributes of the wireless signals transmitted between antennas such as the received signal strength indication (RSSI) [3], the time of arrival (ToA) [4] and the angle of arrival (AoA) [5] of the signal. These algorithms, however, require adding extra hardware to the sensor nodes, which is expensive and power consuming. On the other hand, range-free algorithms such as distance vector-hop (DV-Hop) algorithm, approximate point-in-triangulation test (APIT) algorithm, centroid algorithm [6] and amorphous algorithm [7] only need the information of network connectivity to complete localization. Therefore, more and more attention has been paid to range-free algorithms. DV-Hop algorithm is one of the widely used localization algorithms in wireless sensor networks because it is simple, robust and does not require extra hardware. However, the main disadvantage of DV-Hop algorithm is that its positioning accuracy is very low, the error is inevitably brought by surrounding environment and irregular network. Although there have been many improvements aimed at improving the positioning accuracy of DV-Hop algorithm [8–10], the result is not very ideal. To overcome these problems, the paper proposes an improved DV-Hop localization algorithm for farmland wireless sensor networks.

The contributions of this paper are stated as follows: (1) We introduce the improvement wireless channel model based on analyzing the signal propagation characteristics in wireless channel. (2) We introduce a method for the irregularity of wireless sensor networks based on node degree, and the partial average hop length in one area is computed by using this mechanism which depends on the selecting of referenced anchor nodes. (3) We use a new method to calculate the distance between the unknown node and anchor node.

2. **An Improvement Wireless Channel Model Based on Analyzing the Signal Propagation Characteristics in Wireless Channel.** Most of the localization algorithms in wireless sensor network is evaluated based on three radio propagation models: Free-space model, two-ray ground reflection model and the log-distance path loss with shadowing. In this paper, we adopt the log-distance path loss with shadowing, the model is shown as follows:

$$PL(d) = PL(d_0) - 10n\lg(d/d_0) + X_\delta \tag{1}$$

Where $PL(d)$ and $PL(d_0)$ represent the received power in dBm at distance d and d_0 respectively. n is the path loss exponent, X_δ represents a Gaussian random variable with zero mean and δ standard deviation.

The model can be simplified as follow:

$$PL(d) = S - 10n\lg(d) \tag{2}$$

$$S = PL(d_0) + X_\delta \tag{3}$$

Then, we can calculated the d value by the following formula:

$$d = 10^{\frac{S-PL(d)}{10n}} \tag{4}$$

Due to the different surroundings in farmland, the algorithm precision can be affected by different path loss exponents. Thus, we calculated the value of each anchor nodes parameters (S, n). There are four anchor nodes distribution conditions in wireless sensor network, which are as follows:

(1) An anchor node i have two neighbor anchor nodes. In this condition, we calculated the parameters (S, n) by the following equation:

$$\begin{cases} PL(d_{i1}) = S_i - 10n_i\lg(d_{i1}) \\ PL(d_{i2}) = S_i - 10n_i\lg(d_{i2}) \end{cases} \tag{5}$$

Then, the result of calculation can be as follows:

$$\begin{cases} n_i = \dfrac{PL(d_{i2}) - PL(d_{i1})}{10\lg(d_{i2}/d_{i1})} \\ S_i = PL(d_{i2}) + \dfrac{PL(d_{i1}) - PL(d_{i2})}{\lg(d_{i2}/d_{i1})}\lg d_{i2} \end{cases} \tag{6}$$

(2) An anchor node i have more than two neighbor anchor nodes. In this condition, we assume that there are M neighbor anchor nodes, then, we can obtain $U(U = C_M^2)$ number of parameters (S, n). Furthermore, we used weighted average method to processed these

values, the result of calculation can be as follows:

$$S_i' = \frac{\dfrac{S_1}{d_{i1}+d_{i2}} + \ldots + \dfrac{S_{M-1}}{d_{i1}+d_{iM}} + \dfrac{S_M}{d_{i2}+d_{i3}} + \ldots + \dfrac{S_{2M-3}}{d_{i2}+d_{iM}} + \ldots + \dfrac{S_U}{d_{i(M-1)}+d_{iM}}}{\dfrac{1}{d_{i1}+d_{i2}} + \ldots + \dfrac{1}{d_{i1}+d_{iM}} + \dfrac{1}{d_{i2}+d_{i3}} + \ldots + \dfrac{1}{d_{i2}+d_{iM}} + \ldots + \dfrac{1}{d_{i(M-1)}+d_{iM}}} \tag{7}$$

$$n_i' = \frac{\dfrac{n_1}{d_{i1}+d_{i2}} + \ldots + \dfrac{n_{M-1}}{d_{i1}+d_{iM}} + \dfrac{n_M}{d_{i2}+d_{i3}} + \ldots + \dfrac{n_{2M-3}}{d_{i2}+d_{iM}} + \ldots + \dfrac{n_U}{d_{i(M-1)}+d_{iM}}}{\dfrac{1}{d_{i1}+d_{i2}} + \ldots + \dfrac{1}{d_{i1}+d_{iM}} + \dfrac{1}{d_{i2}+d_{i3}} + \ldots + \dfrac{1}{d_{i2}+d_{iM}} + \ldots + \dfrac{1}{d_{i(M-1)}+d_{iM}}} \tag{8}$$

(3) An anchor node i only have one neighbor anchor nodes. Note here that a node only can hear from the neighbor nodes with a range of the largest communication radius circle area, and the near-far relationship can be indicated by RSSI value. Thus, when anchor node i received the messages from neighbor nodes, we can obtain a series of RSSI values, then, we assume that the minimum one to be the RSSI value with distance of the largest communication radius R. Finally, we calculated the parameters (S, n) by the following equation:

$$\begin{cases} PL(d_{i1}) = S_i - 10n_i \lg(d_{i1}) \\ PL(R) = S_i - 10n_i \lg(R) \end{cases} \tag{9}$$

Then, the result of calculation can be as follows:

$$\begin{cases} n_i = \dfrac{PL(R) - PL(d_{i1})}{10\lg(R/d_{i1})} \\ S_i = PL(R) + \dfrac{PL(d_{i1}) - PL(R)}{\lg(R/d_{i1})} \lg R \end{cases} \tag{10}$$

(4) An anchor node i does not have one neighbor anchor nodes. We selected one anchor node j from all two hop-count neighbor anchor nodes, which anchor node i, relay node and anchor node j are approximate to collinear, we can obtain the following equation:

$$\begin{cases} PL(d_{ij}) = S_i - 10n_i \lg(d_{ij}) \\ PL(R) = S_i - 10n_i \lg(R) \end{cases} \tag{11}$$

Then, the result of calculation can be as follows:

$$\begin{cases} S_i = \dfrac{PL(R)\lg d_{ij} - PL(d_{ij})\lg(R)}{\lg(d_{ij}/R)} \\ n_i = \dfrac{PL(R) - PL(d_{ij})}{10\lg(d_{ij}/R)} \end{cases} \tag{12}$$

But it should be satisfied one condition. In Figure.1, for example, node A is a relay node, we assume that $PL(d_{iA})$, $PL(d_{Aj})$ and $PL(d_{ij})$ to be x_1, x_2 and x_3, then, the condition can be as follows:

$$\cos\angle iAj = \frac{(\dfrac{S_i - x_1}{10n_i})^2 + (\dfrac{S_i - x_2}{10n_i})^2 - (\dfrac{S_i - x_3}{10n_i})^2}{2\dfrac{(S_i - x_1)(S_i - x_2)}{(10n_i)^2}} = 1 \tag{13}$$

With a similar process, the equation can be deduced as:

$$\frac{(S_i - x_1)^2 + (S_i - x_2)^2 - (S_i - x_3)^2}{2(S_i - x_1)(S_i - x_2)} = 1 \tag{14}$$

And the value can be calculated as:

$$S_i = \frac{2x_3 + \sqrt{8x_3^2 - 8x_1x_2 - 4x_1^2 - 4x_2^2}}{4x_1x_2 + 2x_1^2 + 2x_2^2 - 2x_3^2} \tag{15}$$

Finally, the condition can be as follow:

$$\frac{2x_3 + \sqrt{8x_3^2 - 8x_1x_2 - 4x_1^2 - 4x_2^2}}{4x_1x_2 + 2x_1^2 + 2x_2^2 - 2x_3^2} = \frac{PL(R)\lg d_{ij} - x_3 \lg R}{\lg(d_{ij}/R)} \tag{16}$$

In conclusion, we can calculate the value of each anchor nodes parameters (S, n) by the above method, and using these parameters to calculate the distance between nodes.

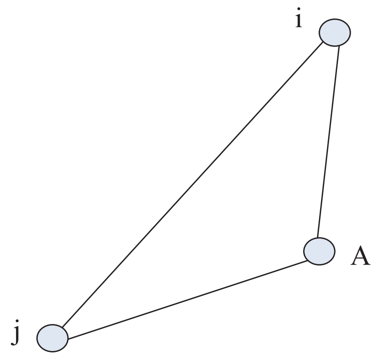


FIGURE 1. The nodes distribution.

3. **A Refinement Method for The Irregularity of Wireless Sensor Networks Based on Node Degree.** Due to nodes were deployed by plane in the farmland, and it could be form an irregular network, which had a different node degree. In Figure.2, for example, S1, S2, S3, S4 and S5 are the anchor nodes; A is the unknown node. The average hop length of anchor node S1 is computed according to the distances and minimum hop counts between it and other four anchors. Since the actual hop length around S3 and S4 is larger than that around S1, the estimated average hop length of anchor node S1 cannot represent the actual hop length. If we use the estimated average hop length to calculate the distance between A and S1, there will be a large error.

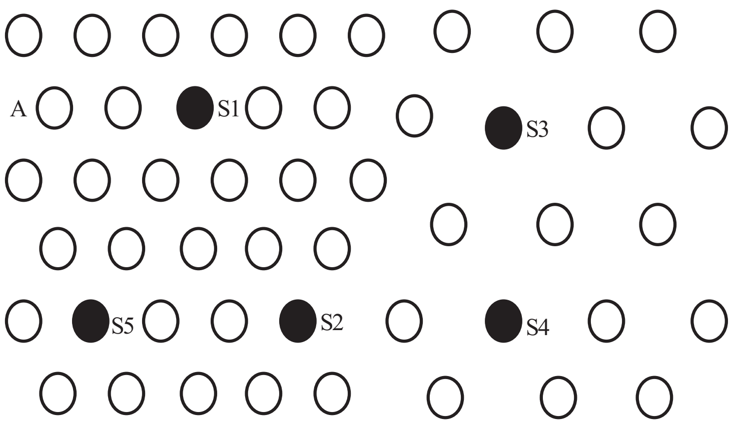


FIGURE 2. The nodes distribution.

To overcome this problem, a refinement method for the irregularity of wireless sensor networks based on node degree is proposed. In this method, we used continuous hop count definition [8] to compute the hop counter between the nodes by RSSI value. For ease of description, some other notations are defined as follows: *HopCount* represent the number of node's hop counter; *NodeCount* represent the number of node's own one-hop neighbors; *a_ID, s_ID, rec_ID* represent the ID number of anchor nodes, sensor nodes and receiving node respectively.

We assume that there are at least two anchor nodes in one area, an anchor node i broadcasts a message including $\{a\_ID_i,\ s\_ID_i,\ Pos,\ HopCount_i\}$, s_ID_i initialized to a_ID_i, and $HopCount_i$ initialized to zero. After a neighbor node receives the message, the a_ID_i and *Pos* remain the same, the receiving node stores the message and set the s_ID_i equal to the rec_ID_j and set s_ID_i equal to s_ID_j before broadcasting it. Indeed, every time a neighbor node receives the message, it first checks the *s_ID*. If the rec_ID_j is not equal to any previous received one, the receiving node stores it and the $NodeCount_j$ adds 1. At same time, the anchor node also can check the rec_ID_j, if the rec_ID_j is not equal to any previous received s_ID_i, then, $NodeCount_i$ adds 1. Finally, each node can obtained the number of one-hop neighbors. Unknown nodes determines which anchor nodes it belongs to according to n_rate_i which is defined by equation (17).

$$n\_rate_j = \frac{|NodeCount_j - NodeCount_i|}{NodeCount_i} \tag{17}$$

From the above equation, we can see that the smaller the n_rate_i is, the less difference the node degree is. If $n\_rate_j < \beta$ (β is a threshold and its value is 0.15 in this paper), then we can assume that these two nodes are located a same area. But some boundary nodes are opposite the rule, then, in this paper, we assume these nodes have a same node degree with anchor nodes, which is nearest node. Unknown nodes store the average hop length *hop_len*, which come from the message broadcast by the anchor node in same area. At this point, we finished dividing the entire wireless sensor network. In the next step, we calculated distance between unknown with anchor nodes.

At first, each anchor node broadcasts a message to the entire network, when a sensor node receives the message, it will check the *hop_len*, if the value is equal to the store one, then, using the following equation to calculate the distance between unknown nodes with the goal anchor node.

$$new\_adis = hoplen_j \times h_{ij} + a\_dis \tag{18}$$

$$h_{ij} = 10^{\frac{S_j - PL(d_{ij})}{10n_j}}/R \tag{19}$$

new_adis represent the distance between one unknown node with the goal anchor node. *a_dis* represent the update value from the last relaying node in the shortest path, and h_{ij} represent the continuous hop count between node i and node j, R represent the node communication radius. Otherwise, using the following equation to calculate the value:

$$new\_adis = hoplen_j \times h_{ij} + a\_dis \tag{20}$$

Where the $hoplen_j$ represent the unknown store value of the average hop length.

Any one unknown node can be used for relaying node, and set the *new_adis* to *a_dis*, and broadcast the update value to the entire network. Finally, we can calculate the distances between the unknown node with all anchor nodes, and using trilateration or maximum likelihood estimation method to compute its location.

4. **Performance Evaluation.** In order to validate the performance of the modified algorithm, we have used MATLAB version 7.0 to simulate the proposed method and compared

it to other localization algorithms such as DV-Hop algorithm and its variation proposed in [8] and [9].

4.1. **Simulation setup and parameters.** In our experiment, 100 nodes are distributed randomly in the 150m × 150m square area. The anchor node positions are known while the locations of all the sensor nodes are unknown. We study the performance of three DV-Hop algorithms with different communication radius, different proportion of anchor nodes and different number of nodes.

One of the most important performance indexes of location algorithm is normalized location error. Assume that (x_i, y_i) and (x_i', y_i') are the coordinates of the real position and the estimated position of sensor node i respectively, the positioning error in one simulation is $\sqrt{(x_i - x_i')^2 + (y_i - y_i')^2}$. If there are N unknown nodes, the average error of all unknown nodes after K times is shown in Equation (21).

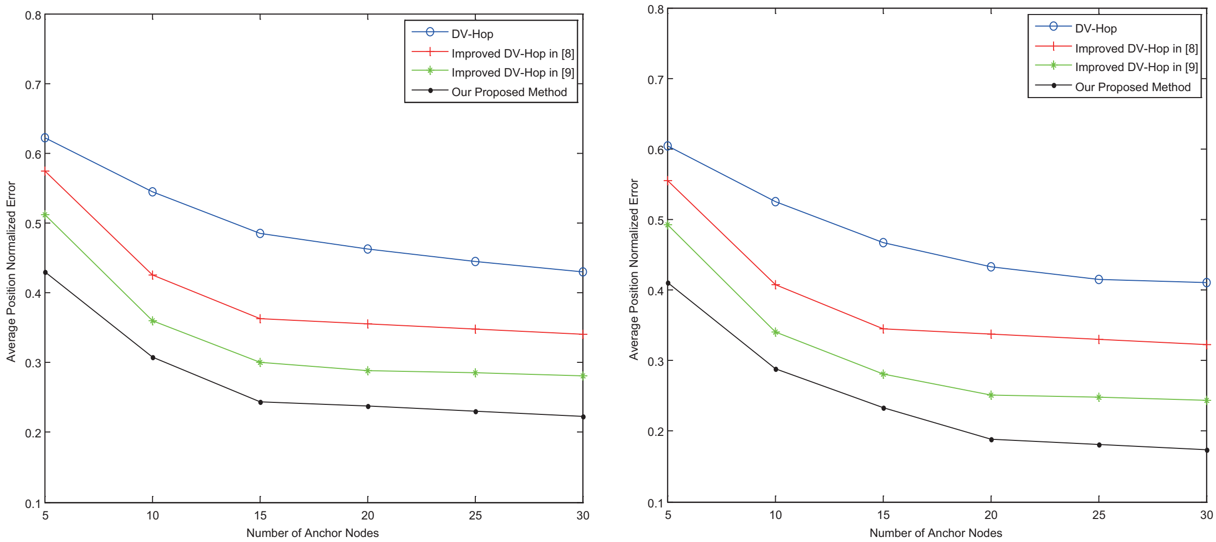
$$average = \frac{\sum_{j=1}^{K}\sum_{i=1}^{N}\sqrt{(x_i - x_i')^2 + (y_i - y_i')^2}}{KN} \tag{21}$$

The normalized location error is:

$$\overline{average} = average/R \tag{22}$$

Where R represent the node communication radius.

4.2. **Simulation result.** Figure 3 (a) and (b) shows the average position errors of three algorithms at varying number of anchor nodes when $R = 20$ and 30 respectively. As the number of anchor nodes gets higher, the average position error of all algorithms starts dropping, and then gradually tends to be stable. The focus of observation is that the average position error of our proposed algorithm is much smaller than the traditional DV-Hop and its variation proposed in [8] and [9]. This is because our proposed method uses the improvement wireless channel model and the partial average hop length which is nearer to the actual distance to calculate the distance between the unknown node and anchor node.



(a) $R = 20$ (b) $R = 30$

FIGURE 3. The average position error at different number of anchor nodes.

In the simulation depicted in Figure 4, we fixed the ratio of anchor nodes to 0.15 and incremented the communication radius from 30 to 60. As is shown in Figure 4, the average position error gets smaller gradually with the increase of the communication radius, and then gradually tends to be stable. We also observe that the average position error and its rate of increase in our proposed algorithm are lower than their counterparts in the traditional DV-Hop and its variation proposed in [8] and [9], which proves the superiority of our algorithm.

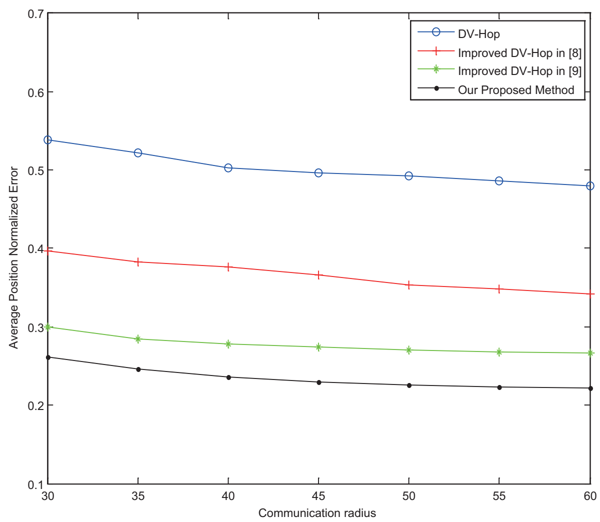


FIGURE 4. The average position error at different communication radius.

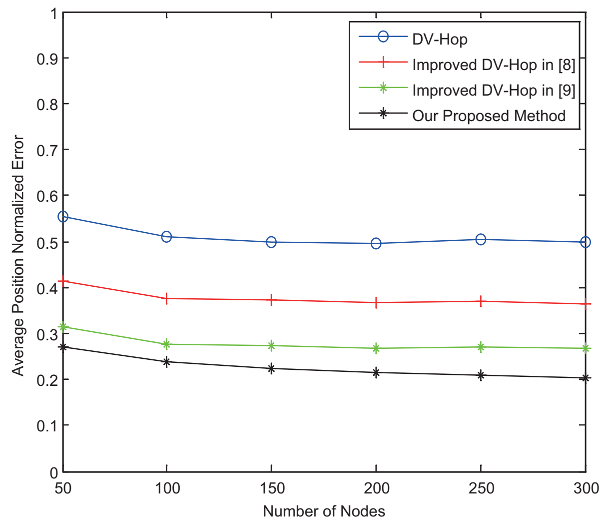


FIGURE 5. The average position error at different number of nodes.

Figure 5 shows the average position error of the three algorithms when the number of nodes changes from 50 to 300. In the simulation, the ratio of anchor nodes is 0.15 and the communication radius is 20m. As is shown in Figure 5, the average position error gets smaller gradually with the increase of the number of nodes, and then gradually tends to be stable. This is because when the number of nodes gets higher, the path between the unknown node and anchor node tends to be a straight line. It means that we can get more precise estimated hop length. Thus the distance from the unknown node to anchor node is also more accurate.

5. **Conclusions and Future Work.** In this paper, we have proposed an improved DV-Hop localization algorithm based on node degree for wireless sensor networks. Our proposed method effectively solves the problem that the irregularity of wireless sensor networks has a great influence on the estimated hop length, and it can have a strong self-adapted ability in farm environment. In order to improve the position precision, firstly, we can calculate the value of each anchor nodes parameters (S, n), and using these parameters to calculate the distance between nodes. Secondly, the entire wireless sensor network is divided into several areas and the partial average hop length in one area instead of the global average hop length is used to calculate the distance between unknown nodes and anchor nodes. Simulation results show that our proposed algorithm is superior to the traditional DV-Hop and its variation. The proposed algorithm is realized in the simulation environment, so how to deploy it on a test network of wireless sensors and study the behavior of the algorithm in a real-life setting will be the direction of further research.

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