An Improved DV-Hop Localization Algorithm Based on Energy-saving Non-ranging Optimization

Li Yamei  
Shandong Management University, Jinan 250357, China  
Email: 1027477719@qq.com

Abstract—In order to reduce energy-consumption and hardware investment in wireless sensor networks, an improved DV-Hop localization algorithm based on energy-saving non-ranging optimization is proposed. In this algorithm, only one anchor node broadcasts its position coordinate information to other node, thus greatly reducing the energy consumption of the node. Non-ranging energy-saving optimization algorithm is first adopted, where the size of the anchor node’s average hop and the distance of average hop between anchor nodes are used to estimate the distance between anchor node and unknown node so as to obtain the location coordinates of unknown node. In order to improve the localization accuracy, the ratio of position is introduced to reduce the localization error after obtaining the estimation of coordinates. Simulation experiment results show that compared with the DV-Hop algorithm based on least squares and the DV-Hop algorithm based on improved particle swarm optimization, our proposed localization algorithm can significantly reduce the localization error and the number of anchor nodes, which has better results in the localization accuracy and the energy-saving performance.

Index Terms—Wireless Sensor Networks; Localization Algorithm; Improved DV-Hop; Non-Ranging Optimization; Localization Accuracy

I. INTRODUCTION

Wireless sensor network (WSN) is composed of a group of multi-hop nodes which have the wireless communication capability with self configuration of the network. The WSN has a very wide application field, such as the target tracking, remote monitoring, regional reconnaissance, resource exploration and environmental monitoring etc. Since the geographic information of the wireless sensors deployment location is very important for the information data collection, the localization technology of wireless sensor network has become a research focus in wireless sensor field. The use of global positioning system (GPS) [1-3] is a simple way to define the node’s location, but these nodes need to have GPS devices which will consume more battery power, so the practicability is not high. Localization technology is generally divided into localization technology based on range and non-ranging localization technology. The localization technology based on range uses the distance and angle information among these nodes, while the non-ranging localization technology is based on the connectivity and hop information. Localization methods based on non-ranging positioning include localization algorithm based on distance vector Hop (DV-Hop) [4-6], localization algorithm based on centroid and approximate triangle localization algorithm. The localization accuracy of these algorithms are better than that of the localization technology based on range, and they need less hardware. In the Non-ranging localization algorithm, DV-Hop algorithm is widely used in localization method and it has better coverage performance and robustness, but its localization accuracy and energy efficiency is not high. Therefore, aiming at solving these problems, this paper proposes an improved DV-Hop localization algorithm.

According to the research of localization algorithm in wireless sensor networks, Researchers [7] proposes an improved DV-Hop algorithm based on coverage relationship between nodes. The algorithm based on the communication rate between two nodes introduces the Hop coefficient so as to reduce the error of hop distance. In addition, the localization error of DV-Hop algorithm is also reduced to some extent. Researchers [8] propose a WSN localization algorithm based on hop-distance, which modifies particle swarm optimization where the data packet structure of anchor node is improved. And these localization errors are weighted and the iterative process of localization is optimized so as to enhance the localization accuracy of wireless sensor network. Researchers [9] propose an improved DV-Hop localization algorithm based on the optimal node communication radius where the distribution features of network node are analyzed so as to obtain the optimal node communication radius, and share the anchor node optimization distribution strategy with minimal impact. The weighted algorithm is adopted to correct unknown node precision so as to improve the node localization performance in wireless sensor networks. Researcher [10] propose an improved localization algorithm based on DV-HOP for wireless sensor networks, where the algorithm adopts a novel algorithm to calculate the distance between unknown node and anchor node, proposes a concept of arbitrary degree for the anchor node, and uses the weighted least squares method to calculate the node coordinates. Experimental results demonstrate that the algorithm improves localization...
accuracy on the premise of reducing the traffic and calculation. Researcher [11] propose an object localization algorithm based on the least square algorithm and DV-Hop algorithm for wireless sensor networks, where the DV-Hop is introduced by mobile beacon nodes and the beacon information is pre-arranged by mobile beacon node. In addition, its location information is continuously broadcast so as to form multiple virtual beacons. The algorithm can reduce network overhead and complexity of localization. Researcher [12] present a node localization algorithm based on improved particle swarm optimization algorithm for wireless sensor network, where the DV-Hop algorithm and the simple particle swarm optimization algorithm (tsPSO) are combined together. The algorithm iteratively searches unknown node so as to restrain the distance estimation error for improving the localization precision, which can achieve higher precision than the DV-Hop algorithm.

II. DV-HOP ALGORITHM

In DV-Hop algorithm, the beacon node broadcasts a beacon to the network and the beacon contains the location information of this beacon node and a hop parameter whose initial value is 1. The beacon is delivered in the network by flooding way and the hop-count increases 1 in every time when the beacon is delivered. The receiver node saves the beacon with the minimum-hop count among all the beacons about a certain beacon node which the receiver node has received and discards the beacons with relative large hop-counts.

In DV-Hop algorithm, locations of unknown nodes are calculated through some anchor nodes (i.e. GPS nodes which know its locations). DV-Hop algorithm includes the following three steps:

Step 1: Every anchor node broadcasts its information of location (coordinate) and values of hop counts, which ensures all anchor nodes can obtain coordinates of anchor nodes and minimum hop-count of every anchor node through the Internet.

Step 2: Calculate the average distance-sum of single-hop node and broadcast it. Unknown node will receive hop-count distance of nearest anchor node.

Step 3: Recalculate the linear form of distance formula and adopt least square method to estimate the locations of unknown nodes.

In DV-Hop algorithm, it is assumed that the routes of minimum hop-count among nodes are similar. If the average distance of every hop-count is used to estimate the distance between anchor node and unknown node, there are some error between the estimated distance and the real one.

In improved DV-Hop algorithm, some methods rectify its estimated distance of hop count through anchor nodes so as to reduce the error in hop-count distance. The unknown nodes adjust the distance of hop-count through the average hop-count of all anchor nodes and the weight of hop-distance. Finally, some unknown nodes are adopted to estimate its location. The localization accuracy of the algorithm is better than that of DV-Hop, but it needs to receive and transmit the beacon packet of anchor node for each unknown node. In addition, the additional communication and calculation are required, which increases the energy-consumption burden.

For some improved DV-Hop algorithm, DV-Hop method is first adopted to locate unknown nodes for anchor nodes, which can obtain the single hop-count distance of the unknown nodes. Then these unknown nodes would also act as anchor nodes to assist in locating other unknown nodes. When unknown nodes and anchor nodes are in multi-hop relationship, the unknown nodes can estimate the distance from the anchor nodes through hop-count and average hop-count distance, and the positions of unknown nodes are estimated through triangulation method. The method can also enhance the localization accuracy, but the costs of communication among nodes will increase. In addition, it also will shorten the communication lifetime of network nodes.

III. NFDV-HOP LOCALIZATION ALGORITHM IN WIRELESS SENSOR NETWORKS

In the DV-Hop algorithm and its improved algorithms, it is necessary to broadcast the data packet twice for all anchor nodes. In the NFDV-Hop algorithm, one communication between anchor node and unknown node is enough. The unknown node improves the hop distance of anchor node and uses the average hop-count of the anchor node so as to estimate the distance between unknown node and anchor node. In order to reduce the transmission error in calculation and improve the localization accuracy, the closest distance equations of anchor nodes are divided and the unknown nodes update the position information using the obtained information from these equations. These steps are shown as follows:

Step 1: In this step, each anchor node broadcasts beacon package and its location (coordinates) and the hop-count value is also initialized as 1. When a node receives its beacon packet, it generates a table \( \{x_i, y_i, n(hop)\} \), which denotes the position coordinates and hop-count information of the received beacon node. If the received data packets in the anchor node contain less hop-count, the hop-count in the table can be replaced with the hop-count of the received packet. If the packet is forwarded in the network, the hop-count will add 1; otherwise the packet will be discarded. Through this mechanism, all the unknown nodes in the network can obtain coordinates and the smallest hop-count from anchor node.

Step 2: After the unknown node obtains the coordinates of the anchor node from step 1, unknown nodes will calculate the size of the hop-count of anchor nodes. Assume that node communication range is \( R \), and \( d(i,j) \) denotes Euclidean distance from node \( i \) to node \( j \). Since the hop-count distance must be less than its communication distance, so the required minimum hop-count from the node to its beacon node is shown as follows:

\[
n_i(hop) = \left[ \frac{d(i,j)}{R} \right]
\]  (1)
After the hop-count is calculated, unknown nodes adopt the information distance between hop-count and anchor node to calculate the hop distance of anchor node. In order to make the hop distance is much closer to actual distance, the unknown node adopts the ratio of the average distance between anchor node and the average hop-count to calculate the hop distance. Therefore, we can get the Equation 2 as follows.

\[
d_{p}(\text{hop}) = \frac{\sum_{i \neq j} d(i, j)}{\sum_{i \neq j} n_p(\text{hop})}
\] (2)

where \(d_p(\text{hop})\) denotes the hop distance, \(n\) denotes the number of anchor node, and \(d(i, j)\) is Euclidean distance.

Therefore, the estimated distance between anchor node \(i\) and anchor node \(j\) is shown as follows:

\[
d_e(i, j) = d_p(\text{hop}) \times n_p(\text{hop})
\] (3)

And the distance error between anchor node \(i\) and anchor node \(j\) is written as follows:

\[
\lambda(d) = \frac{|d_e(i, j) - d(i, j)|}{d(i, j)}
\] (4)

Error produced by each hop of anchor node is related to the hop-count and the distance between anchor node \(i\) and anchor node \(j\), which can be represented as follows:

\[
\lambda(hop) = \frac{|d_e(i, j) - d(i, j)|}{n_p(\text{hop})}
\] (5)

The average hop distance of anchor node is calculated by unknown node, which is shown as follows:

\[
\overline{d}(\text{hop}) = \frac{\sum_{i=1}^{n} d(\text{hop})}{n}
\] (6)

where the hop distance \(d(\text{hop})\) is shown as follows:

\[
d(\text{hop}) = \frac{d(i, j)}{n} - \lambda(\text{hop})d(i, j)
\] (7)

Once the unknown node begins to calculate the number of the average hop-count, the average hop distance and its minimum hop-count of anchor node are adopted to estimate the distance to anchor node. The unknown node will estimate the distance with the \(i\)th anchor nodes, which is shown as follows:

\[
d(k, i) = \overline{d}(\text{hop}) \times n_p(\text{hop})
\] (8)

In order to get closer to the real distance equation of anchor node, it is assumed that the anchor node \(j\) is the closest to the anchor node \(i\) of unknown node. The partition equation of distance is obtained as follows:

\[
\begin{align*}
\frac{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} = d(i, 1)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} = d(i, 2)} & \vdots \\
\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} = d(i, j) & \vdots \\
\frac{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} = d(i, n)}
\end{align*}
\] (9)

The ratio of distance between anchor node \(i\) and anchor node \(j\) of unknown node is shown as follows:

\[
\begin{align*}
\frac{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} = d(i, k)}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} = d(j, k)}
\end{align*}
\] (10)

So we can get the following matrix \(H\):

\[
H = \begin{bmatrix}
x_i d(i, k) & x_j d(i, k) & d(i, 1) d(i, k) & d(i, 1) - d(j, k) \\
x_i d(i, k) & x_j d(i, k) & d(i, 2) d(i, k) & d(i, 2) - d(j, k) \\
\vdots & \vdots & \vdots & \vdots \\
x_i d(i, k) & x_j d(i, k) & d(i, n) d(i, k) & d(i, n) - d(j, k)
\end{bmatrix}
\] (11)

Assume the coordinate of unknown node \(g\) is \((x_g, y_g)\), so the equation of \((x_g, y_g)\) is shown as follows:

\[
(x_g, y_g) = \frac{(x_i, y_i) + (x_j, y_j)}{d(g, i) d(g, j)}
\] (12)

In order to improve the localization accuracy, the unknown node will estimate twice the position estimation, and also introduce ratio \(f = x_g^2 + y_g^2\) to estimate its value. As for the nearest anchor node \(j\), \(s\) can be defined as follows:

\[
s = \sqrt{\frac{f}{x_j^2 + y_j^2} d(g, i) d(g, j)}
\] (13)

The coordinate of unknown node is estimated as follows:

\[
\begin{align*}
x_g' &= s \sqrt{x_j^2 + y_j^2} \\
y_g' &= s \sqrt{x_j^2 + y_j^2}
\end{align*}
\] (14)

Therefore, the coordinate \((x_g', y_g')\) is final location of unknown node.
IV. EXPERIMENT SIMULATION AND ANALYSIS

In the simulation experiment, the localization error and the computational cost are mainly analyzed and discussed. All the algorithms are run on Matlab7.0. In the simulation environment, 100 sensor nodes are randomly deployed. Each node has 50 m communication radius. It is assumed that there are N sensor nodes in a two-dimension wireless sensor network and they are evenly and randomly distributed in a L × L square region without obstacle and interference. A small part of nodes’ coordinates are known (GPS location or manual deployment), which is called Beacon Node. The localization error is defined in the simulation as follows:

\[ \mu = \frac{1}{\sqrt{R}} \times \frac{1}{m} \sum_{i=1}^{m} \sqrt{\left(x_i' - x_i\right)^2 + \left(y_i' - y_i\right)^2} \]  

(15)

where \((x_i', y_i')\) is the estimation coordinate, \((x_i, y_i)\) is the exact coordinate of unknown node, \(m\) is the number of beacon node and \(R\) denotes the communication radius.

In order to verify the performance of our proposed localization algorithm, DV-Hop algorithm based on least square algorithm in literature [13-18] and DV-Hop algorithm based on improved particle swarm optimization in the literature [18-22] are adopted as comparison algorithms in the experiments, and the comparison results are acquired in the simulation as follows:

![Localization error](image1)

Figure 1. Localization error

Localization error is the key strategy to measure localization algorithm performance. In order to verify the localization error of the algorithm, the number of nodes is increased in the experiment from the initial 100 nodes to 300 nodes [22-25]. In addition, the localization error of the algorithm is obtained in the process of the increased node. We can see from Figure 1 that the more the number of nodes, the smaller the localization error, which is because our proposed algorithm holds higher prediction accuracy. Comparing with DV-Hop algorithm based on least square algorithm in literature [13-18] and DV-Hop algorithm based on improved particle swarm optimization, we can see that our localization error has at about 27.5% and below. The worst case of localization error is only 5.7%, while that of comparison algorithms are 17.8% and 14.7%, respectively.

In order to verify the energy-saving performance of our proposed algorithm, the average energy consumption of network nodes can be obtained by gradually increasing the amount of nodes. The average node energy consumption is much less than the comparison algorithms, where the highest node energy consumption is only 0.768J, and the lowest is 0.529J (see Figure. 2). The lowest average node energy-consumption of two comparison algorithms is 0.754J and 0.696J. Therefore, the energy-saving performance of our proposed algorithm is much better.

![Energy consumption](image2)

Figure 2. Energy consumption

The proportion of the anchor nodes in the total nodes is increased, which means that the amount of the anchor nodes, used as a distance measure, also will increase. That is to say that the localization accuracy will be improved. The simulation experiment verifies the localization error of our proposed algorithm will decrease with the increase of the proportion of the anchor nodes. The localization errors of the three algorithms will decrease with the increase of the percentage of the anchor nodes. Thus, the localization accuracy will be improved (see Fig. 3). Viewed from the distribution of the curves, the improved DV-Hop localization algorithm based on energy-saving non-ranging optimization has the lowest localization error, which is followed by the improved particle swarm optimized DV-Hop algorithm, while the localization error of the DV-Hop algorithm based on least square method is the highest.

Figure 4 is the average node energy-consumption when the proportion of the anchor nodes in the total nodes increases. Since the anchor node needs to broadcast its position only once, the proportion of the anchor node shows the total communication cost of the nodes will decrease. That is to say that the average node energy-consumption will decrease. Therefore, when the proportion of the anchor nodes increases, the decreasing trend of the average energy-consumption is obvious,
while the energy-consumption of the other two algorithms does not decrease much. When the proportion of the anchor nodes is 30%, the average energy-consumption is 0.706J, while the other two algorithms are 0.842J and 0.805J, respectively.

2D Graph 3

Figure 4. Average energy-consumption

V. CONCLUSION

The node localization technology is one of the important support technologies for wireless sensor networks. The node localization is to get the position information by using location information. This paper primarily investigates an improved DV-Hop localization algorithm based on energy-saving non-ranging optimization. Only one anchor node broadcasts its position coordinate information to the other node, so as to obtain the location coordinates of unknown node. In order to improve the localization accuracy, the ratio of position is introduced to reduce the localization error after obtaining the estimation of coordinates. Simulation experiment results show that compared with the DV-Hop algorithm based on least squares and the DV-Hop algorithm based on improved particle swarm optimization, our proposed algorithm has better results in the localization accuracy and the energy-saving performance, which can effectively carry out the network localization.

REFERENCES


