An Improved WC-RDV Localization Algorithm for WSNs

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2 authors:

Guozhi Song
Tianjin Polytechnic University

Dayuan Tan
University of Maryland, Baltimore County

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Guozhi Song and Dayuan Tam
School of Computer Science and Software Engineer
Tianjin Polytechnic University
Tianjin, China
{guozhi.song, dayuan.tam} @gmail.com

***Abstract*—As a classic localization algorithm for WSNs (Wireless Sensor Networks), DV-hop is widely used due to its simplicity but its accuracy is less satisfying. In this paper, we have delved deeply into the algorithm details of the original DV-hop and investigated the reasons behind its high error rate. We then proposed an Improved Weighted Centroid RDV-hop (Improved WC-RDV) algorithm, which combines the Improved Weighted Centroid algorithm and Improved RDV-hop algorithm. Simulations also have been conducted and the results confirm that our Improved WC-RDV performs much better than several other DV-hop localization algorithms.**

Keywords-Wireless Sensor Networks, Localization, DV-hop, Centroid.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are currently used in a wide range of military, environment, civil, health-care applications and so on. A WSN is composed of a collection of sensor nodes deployed in a field, each of which collects data and relays them to the sink node where data can be best-analyzed and used. Finding the location of the sensor where the event occurred is an intrinsic and integral part of any WSN application and represents a major challenge because without finding the position of the sensor that is reporting the sensed data, the latter will not be useful [1].

There are already kinds of algorithms and schemes to solve the node's positioning problem, and they are roughly classified as the range-based algorithms and range-free algorithms [2]. Range-based protocols calculate the location using the point-to-point distance (or angle) estimates, and can be only applied when nodes are equipped with sophisticated hardware [3]. These algorithms can be implemented by using the following physical measurement techniques: received signal strength indicator (RSSI) [4], time of arriving signal (TOA) [5], time difference of arrival (TDOA) [6], and angle of arriving signal (AOA) [7], etc.

In contrast, range-free solutions do not rely on the availability of range (or angle) estimates, so they need no expensive hardware, which makes them more cost-effective and simpler alternative to range-base algorithms. Although range-free algorithms provide less accurate results compared with range-based algorithms, which is due to ranging errors, they satisfy many applications' requirements [2]. What's more, lots of optimizing algorithms can be used to improve the accuracy. Many range-free algorithms have been proposed for several years, such as centroid algorithm [8], DV-hop [9, 10], amorphous [11], APIT [12], MDS-MAP [13, 14], etc.

Among many of range-free localization algorithms, DV-hop is a neat scheme which is worth further investigation [15]. Since Niculescu and Nath proposed DV-hop algorithm in 2001 [4, 5], it has become popular very quickly for its simplicity, cost effectiveness, robustness, and a lot of researchers continue to work on its improvement.

In [16], a refined DV-hop (RDV) is proposed. The reason leading to error in original DV-hop has been analysed. The authors calculate the average of all average HopSize of all nodes, instead of taking the average HopSize of nearest node as the average HopSize of UnknowNodes. The ML localization in DV-hop is also replaced by Hyperbolic localization algorithm.

There are also some researchers working on centroid localization algorithm. A Weight Centroid Localization algorithm (WCDV) for WSNs was proposed by Bingjiao Zhang et al. coming from Shanghai University [17]. They set a weight for anchors when calculating estimation to improve the precision.

In this paper, investigation on the DV-hop algorithm and other refined algorithms based on it has been done and the reasons behind their high error rate have been analyzed. Based on detailed preparatory work, we proposed our Improved Weighted Centroid RDV-hop Localization Algorithm (Improved WC-RDV) localization algorithm, which combines the Improved weighted Centroid algorithm and Improved RDV-hop algorithm. We also realized two of other algorithms by programming with MATLAB so that we can compare our proposed algorithms with them from lots of aspects.

The rest of this paper is organized as follows. In section 2, some theoretical background, including original DV-hop localization algorithm and centroid algorithm, is briefly introduced. In section 3, we describe our new Improved WC-RDV algorithm. The simulation results, and performance comparisons will be introduced in section 4. Finally, we present our conclusion in section 5.

II. THEORETICAL BACKGROUND

In this section we will introduce some algorithms which are the basis of the following parts of this paper.

A. DV-hop localization algorithm

The traditional DV-hop algorithm was developed by Niculescu and Nath [4, 5]. It can be summarized as the following three steps.

1) *Finding the minimum HopCount.*

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Firstly, all BeaconNodes broadcast beacon messages to other nodes. After a period of time, all nodes in the network will have the minimum HopCount to other nodes.

2) Calculation of the distance between BeaconNodes and UnknownNodes.

The BeaconNodes can calculate its distance with other BeaconNodes easily, and divide it by minimum HopCount so that we can get the size per hop (HopSize). Then the average HopSize can be calculated by Eq. (1). The i'th BeaconNode's average HopSize can be obtained by

$$HopSize_i = \frac{\sum_{j=1,j\neq i}^{N} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j=1,j\neq i}^{N} h_{ij}} \quad (1)$$

Where (x_i, y_j) and (x_j, y_i) are coordinates of BeaconNode i and j, h_{ij} is the minimum HopCount value between BeaconNode i and j, N presents the quantity of BeaconNode. Every BeaconNode broadcasts its average HopSize to the whole network before UnknownNode use its nearest BeaconNode's average HopSize as its own average HopSize. In the end, we can calculate the distance of every UnknownNode to BeaconNode by

$$d_{ij} = HopSize_i * HopCount_{ij} \quad (2)$$

Where d_{ij} is the distance of the i'th UnknownNode to j'th BeaconNode and $HopCount_{ij}$ indicates the minimum HopCount of the i'th UnknownNode to j'th BeaconNode.

3) Calculation of estimated location

The UnknownNode can calculate their locations by maximum likelihood estimation (ML) [18].

B. Centroid localization algorithm

Centroid algorithm is one of the most basic and classical schemes, UnknownNode using the centroid of BeaconNodes which are around it as its own coordinates. A threshold is also often used to select BeaconNodes.

Suppose that there are five BeaconNodes $\mathrm{A}(x_1, y_1)$, $\mathrm{B}(x_2, y_2)$, $\mathrm{C}(x_3, y_3)$, $D(x_4, y_4)$, $\mathrm{E}(x_5, y_5)$ distributed around the UnknownNode S ({$\mathrm{S}(x, y)$}). Thus the position of UnknownNode S can be calculated using Eq. (3).

$$(\mathrm{x}, \mathrm{y}) = \left(\frac{x_1 + x_2 + x_3 + x_4 + x_5}{5}, \frac{y_1 + y_2 + y_3 + y_4 + y_5}{5}\right) \quad (3)$$

The general algorithm can be summarized using Eq. (4).

$$x_{est} = \frac{\sum_{i=1}^{n} x_i}{n}, y_{est} = \frac{\sum_{i=1}^{n} y_i}{n} \quad (4)$$

III. IMPROVED WC-RDV LOCALIZATION ALGORITHM

After a thorough study of the principle of original DV-hop localization algorithm, we found that the errors of original DV-hop algorithm are caused by the UnknownNodes' average HopSize in the second step and the calculating algorithm in the third step of DV-hop. RDV-hop in [16] has solved these two problem. In [16], the authors choose the average of all BeaconNodes' average HopSize, instead of the average HopSize of the nearest BeaconNode, as the average HopSize of UnknownNode. The ML localization in DV-hop is also replaced by Hyperbolic localization algorithm.

Based on RDV-hop algorithm, we have done further investigation on DV-hop and RDV-hop, and more reasons leading to errors have been found out and further improvement has been done.

1) Further analyses of the reason for error---about UnknownNodes' average HopSize

We have introduced RDV-hop algorithm in above section. But the improvement of accuracy is still limited. After further analyzing the DV-hop and RDV-hop algorithm, we found that error can be further reduced by adopting a new method.

In the second step of the original DV-hop, as also RDV-hop, UnknownNode uses Eq. (2) to calculate the distance between itself and BeaconNodes. The distance can also be calculated by multiplying BeaconNodes's HopSize by HopCount from another perspective. In other words, the HopSize of UnknownNodes are not necessary anymore. That means we can cut out one little step from the second step of DV-hop.

2) Refinement on the second step of RDV-hop

The HopSize of UnknownNode is not needed anymore and the step to calculate the HopSize of UnknownNode is cut out. The $HopSize_i$ can be replaced by $HopSize_j$, then the distance between UnknownNode i and BeaconNode j can be obtained by

$$d_{ij} = HopSize_j * HopCount_{ij} \quad (5)$$

Since we have known the HopSize of every BeaconNode and the HopCount between every nodes, it is easy to get the distance between every UnknownNode and each BeaconNode. As we all know, the computation complexity will be less and the calculation result will be more precise with less steps of calculations. So the accuracy will be Improved as the number of the steps of localization has been decreased.

3) Further analyses of the reason for error---about calculating algorithm in third step

In original DV-hop algorithm, ML algorithm is chosen as its calculating algorithm, and in RDV-hop, ML is replaced by Hyperbolic which has better performance. In our Improved WC-RDV algorithm, Improved Weighted Centroid algorithm takes place of Hyperbolic algorithm and simulation experience proved that we gain a great improvement on accuracy.

In classical Centroid algorithm, UnknownNode using the centroid of BeaconNodes which are around it as its own coordinates. A threshold is also often be used to select BeaconNodes. But the data collected by BeaconNodes is exiguous and precious so it is better to make full use of all BeaconNodes. And Centroid algorithm cannot reflect the influence of the distance between BeaconNodes and UnknownNodes when calculating the centroid. In fact, the

BeaconNode closer to the UnknownNode will have a greater impact on the UnknownNode. Different BeaconNodes have different effect on the UnknownNode, considering the different distance between them, which has also been proved in [17]. But the Centroid algorithm treats them as the same kind of node. In order to reflect the effect of BeaconNodes on the centroid calculation, our Improved weighted Centroid algorithm is proposed.

4) Refinement on the calculating algorithm in third step--- Improved Weighted Centroid algorithm

As what Eq. 2 and Eq. 5 have showed, distance between BeaconNodes and UnknownNodes have a direct correlation with HopCounts. So the effect of distance on accuracy can be replaced by HopCounts. Then we can calculate the location of UnknownNodes by

$$x_{est} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}, y_{est} = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i} \quad (6)$$

(x_{est}, y_{est}) is the coordinates of the UnknownNode. And we suppose it has received n BeaconNodes' messages $(\{(x_1, y_1), (x_2, y_2) \ \dots \ (x_n, y_n)\})$. w_i is the weight of BeaconNode i, and its value can be obtained by

$$w_i = \frac{\sum_{i=1}^{n} hop_i}{\mathrm{n} hop_i} \quad (7)$$

hop_i is the HopCount between the UnknownNode and the BeaconNode i. These weights determine relatively importance of each BeaconNode when calculating the centroid which later is the UnknownNode's coordinates. That is to say, if the weight w_i is larger than the other weights, the BeaconNode i plays a more important role on the calculation of centroid. This scheme ensures that the closest BeaconNode will have the greatest effect upon the localization result.

IV. SIMULATION AND PERFORMANCE COMPARISON

We realized the other two algorithms by programming using MATLAB, i.e. RDV-hop proposed in [16] and WCDV proposed in [17]. What's more, the original DV-hop algorithm and classical Centroid algorithm are also included into the comparison.

Error ratio is a widely accepted metric in the analyses of accuracy of WSNs localization. It represents the ratio of the distance between real coordinates and estimated coordinates of UnknownNodes and the communication radius. We can get it by

$$Error\ Ratio\ (s) = \frac{\sum_{j=1}^{n} \sqrt{(x_{real_j} - x_{est\_j})^2 + (y_{real_j} - y_{est\_j})^2}}{R} \quad (8)$$

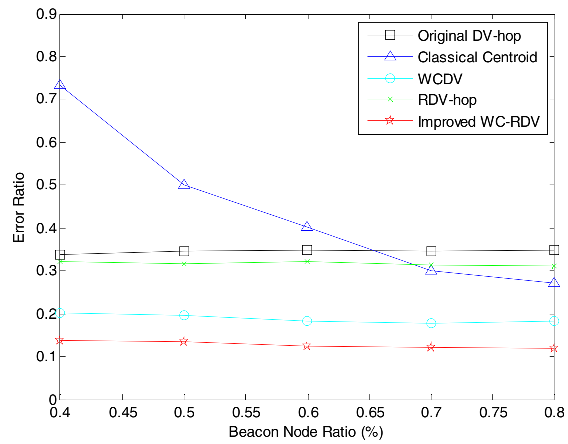

Figure 1. Comparison with different BeaconNode Ratios

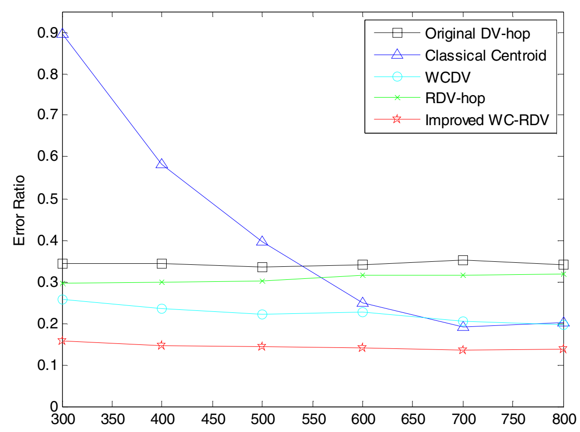

Figure 2. Comparison with different Node Number

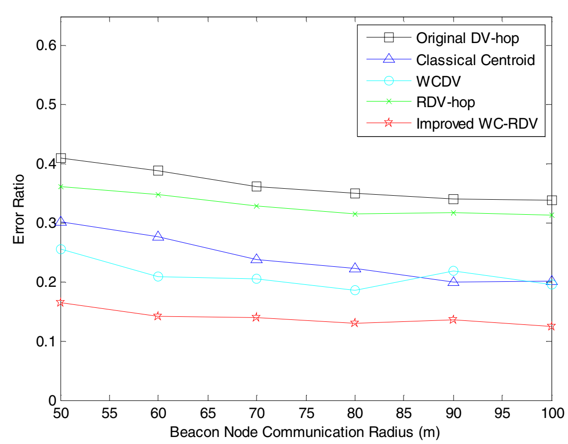

Figure 3. Comparison with different Communication Radius

Error Ratio (s) means the error ratio of one simulation, and s means the simulation time. (x_{real_j}, y_{real_j}) and (x_{est_j}, y_{est_j}) respectively present the real coordinates and estimated coordinates of UnknownNode j. R is the communication radius.

Suppose the WSN is a static network, all the nodes are randomly deployed in a $500m \times 500m$ area. Each simulation experiment with same parameter will be conducted 100times and the average of 100 results will be treated as the final result. The performance comparison is simulated using MATLAB R2013a.

We compare the performance of five algorithms with different parameters from three different perspectives. Firstly we set the BeaconNode Ratio as the variable and increase it from 0.4 to 0.8 gradually. Meanwhile the node number is 800 and the communication radius is 100m. The result is showed in Fig. 1. Secondly we vary the node number from 300 to 800 while the BeaconNode Ratio is 0.5 and communication is 100m, which is illustrated in Fig. 2. Fig. 3. shows the third series of simulation experience. The communication radius is varied from 50m to 100m gradually while BeaconNode Ratio is 0.5 and node number is 800.

As what above figures have illustrated, there is no doubt that our Improved WC-RDV algorithm has a much better performance than other four localization algorithms. Furthermore, not only its estimating precision is much better, but also the Improved WC-RDV performs much more steadily. No matter how the parameters change, the error ratio of Improved WC-RDV algorithm always stays between 0.13 and 0.16 with considerable less fluctuation. By contrast, the other three algorithms' Error Ratio fluctuate remarkably, especially the Classical Centroid algorithm.

V. CONCLUSIONS

Localization problem is one of the most important and difficult problems for WSNs. Range-free localization algorithms are considered as more appropriate solution for WSNs for they need no expensive hardware, which makes them more cost-effective and simpler over range-base algorithms. We Improved DV-hop algorithm and Centroid algorithm and obtained Improved RDV-hop and Improved Weighted Centroid algorithm. Then they were combined together to construct Improved WC-RDV algorithm. Compared to the original DV-hop algorithm, the accuracy is Improved on a large scale. In addition, comparing to other localization algorithms for WSNs or other refined algorithms based on DV-hop, our Improved WC-RDV still performs excellently. According to our simulations, our Improved WC-RDV algorithm not only has much better accuracy but also performs much more steadily no matter how the parameters change.

In the future, we will be interested in studying on 3D localization algorithms. Some test-bed can also be constructed to allow us to compare real results with those simulation results.

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