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Conference Paper · December 2014

DOI: 10.1049/cp.2014.1558

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RDV-Hop Localization Algorithm for Randomly Deployed Wireless Sensor Networks

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

Abstract

Accurate location estimation is very important in WSNs, for a number of applications' requirement. Due to the hardware limitation in WSN devices, range-free schemes are more appropriate for WSNs than rage-based schemes. A novel localization algorithm, RDV-hop localization algorithm, is proposed in this paper. The reason leading to error in original DV-hop has been analyzed and the refinement has been done. We also replace the ML localization algorithm with Hyperbolic location algorithm with better performance results. Simulations have been conducted to prove that RDV-hop performs more accurately than DV-hop, and the accuracy is improved by 24.9% on average.

1 Introduction

Wireless Sensor Networks (WSNs) have attracted worldwide research and industrial interest, because they can be applied in various areas such as earthquake monitoring, target tracking and surveillance etc. These new applications require deployment of large number of sensor nodes over large geometrical areas, and their utility are dependent on the automatic and accurate location estimation of those nodes. In addition, accurate location estimation could also be helpful in sensor network services such as routing, information processing, tasking and querying [1, 2]. In wireless sensor networks, localization has become a very important research area.

The localization problem has received considerable attention in the past. Undoubtedly, the Global Positioning System (GPS) is the most well-known location service in use today. The approach taken by GPS, however, is unsuitable for low-cost, ad-hoc sensor networks since GPS is based on extensive infrastructure. Likewise solutions develop in the area of robotic [3, 4, 5] and ubiquitous computing [2] are generally not applicable for sensor networks as they require too much processing power and energy.

Localization systems are of two main types: range-based and range-free. In general, range-based schemes such as Received Signal Strength Indicator (RSSI) [6], Time of Arrival (TOA) [7], Time Difference of Arrival (TDOA) [8], and Angle of Arrival (AOA) [9] etc. have better location accuracy than range-free schemes, with two disadvantages that can't be neglected.

Range-free schemes are much more cost-effective than range-based schemes, because they don't need any additional range hardware. Many range-free algorithms have been proposed the last few years, such as centroid algorithm [10], DV-hop [11, 2], amorphous [12], APIT [13], MDS-MAP [14, 15], etc.

WSN devices have a hardware limitation so that range-free schemes are more appropriate. However the existing algorithms haven't provided sufficient accuracy. In this paper, we proposed a localization algorithm based on DV-hop algorithm, RDV-hop localization algorithm, to improve localization accuracy.

The rest of this paper is organized as follows. In section 2, we briefly review other researchers' study on DV-Hop's improvement. In section 3, Original DV-hop localization algorithm is briefly introduced. In section 4, we introduce how we refine DV-hop, the simulation results, and performance comparison. Finally, we present our conclusion in section 5.

2 Related works

After Niculescu and Nath proposed DV-hop algorithm in 2001 [11, 2], it become popular immediately for its simplicity, cost-effective, robust, and a lot of researchers works focusing on it.

In [16], Stefan et al. discussed the influence of the underlying random topology, and based on that they derived distance estimations function of the number of hops two nodes are separated by, and characterized the precision of these estimations. And they obtained the improvement of roughly 26% for DV-hop localization algorithm in the position accuracy.

BinWei et al. applied his improved centroid localization algorithm in WSN in [17]. They proposed a centroid algorithm with selected anchor node localization algorithm (SA-Centroid) for WSNs. The triangle centroid and polygon centroid were used and the method of selecting nearest anchor node was adopted.

JianLi et al. proposed a weighted DV-hop localization scheme in [18]. They derived their algorithm from DV-hop algorithm and used weight of anchors to improve localization accuracy.

Checkout DV-hop algorithm and Selective 3-Anchor DV-hop algorithm were proposed by L.Gui et al. A calculation step, called checkout step, was added to DV-hop in Checkout DV-hop [19]. A group of candidates were generated in Selective 3-Anchor DV-hop algorithm, then one of the candidates was chosen based on its connectivity vector from its pool [20].

DV-hop+Lastdist algorithm was proposed by Zhang Hong et al. in [21]. A distance variable of final hop was added to the DV-hop communication message, the distance from the node to the anchor node can properly reduce the error distance caused by the final hop .

WD-DVhop was proposed by Zhigui Lin et al. in [22]. The centralized and distributed calculation method is replaced by a weighted calculation method. The distance be-tween unknown nodes and anchor nodes is calculated by a method, which the aver-age one-hop distance of each anchor node multiplies by hops count between un-known nodes and anchor node .

But we found those improvements are still not good enough, so our research is to improve its accuracy.

3 DV-hop localization algorithm

In this paper, we focus on static networks, where nodes do not move, since this is already a challenging condition for distributed localization. We assume that some anchor nodes, named BeaconNode, have a priori knowledge of their own. Note that anchor nodes have the same capabilities (processing, communication, energy consumption, etc.) as all other sensor nodes with unknown positions, which are named UnKnownNode.

The traditional DV-hop algorithm was developed by Niculescu and Nath [11, 2]. It can be summarized in the following three steps:

3.1 Finding the minimum HopCount.

All BeaconNodes broadcast beacon messages to other nodes. The format of the beacon message is {id, x_i, y_i, HopCount}. The initial value of HopCount is 0. Each Receiving Node maintains a BeaconNode information table and keeps the minimum HopCount value from other nodes. After a period of time, all nodes in the network will have the minimum HopCount to other nodes.

3.2 Calculation of the distance between BeaconNodes and UnknownNodes.

In the second step, the BeaconNodes get minimum HopCount value to other BeaconNodes according to the result in the first step. Then it can estimate average Hop-Size to other BeaconNodes on the basis of the minimum HopCount and the distance between BeaconNodes. 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. Each UnknownNode receives all BeaconNode's average HopSize and selects the HopSize of a BeaconNode, which has the minimum HopCount value to this UnknownNode, as its 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 $HopCount_{ij}$ indicate the minimum HopCount of the i'th UnknownNode to j'th BeaconNode.

3.3 Calculation of estimated location.

The UnknownNode can calculate their locations using maximum likelihood estimation [23] or trilateration.

4 RDV-hop localization algorithm

4.1 Improvement of DV-Hop localization algorithm

Though analyzing the principle of original DV-hop localization algorithm, we found that the errors of original DV-hop localization algorithm come from HopCounts, averaging HopSizes and localization algorithm. So we refined it by focusing on the second step, the way to calculate distance between BeaconNode and UnKnownNode, and the third step, the localization algorithm.

4.1.1 Refinement on second step---distance estimation.

As what we have introduced above, UnknownNodes, in original DV-hop algorithm, take the average HopSize of its nearest BeaconNode as its own average HopSize. But the nodes in the WSN are disposed stochastically, which means the path between nodes may not be straight. Therefore the average HopSizes are always bigger than the actual value.
When the distance between UnknownNodes and BeaconNodes is calculated using the average HopSize, the error is always large. The nearest BeaconNode is unique and can't be used to represent the whole BeaconNodes. Since ML in the third step will make use of the distance between UnknownNodes and every BeaconNode, it is a good way to take the average HopSize of all BeaconNodes to replace that of the nearest BeaconNode for UnknownNodes.

So we calculate the average HopSizes of all BeaconNodes with eq. (3):

$$HopSize_i = \frac{\sum_{i \neq j} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{i \neq j} h_{ij}} \quad (3)$$

Then calculate the average of the average HopSize of BeaconNodes, and take this as the average HopSize of every UnknownNode---$HopSize_{UN}$:

$$HopSize_{UN} = HopSize_{avg} = \frac{\sum HopSize_i}{n} \quad (4)$$

4.1.2 Refinement on third step---location algorithm.

In the original DV-hop algorithm, ML or trilateration is used for physical distances estimations. In this paper, we use Hyperbolic location algorithm [24] [25] to replace ML.
We derive the following expression:

$$X_N^2 + Y_N^2 - 2X_N X_i - 2Y_N Y_i + {X_i}^2 + {Y_i}^2 = d_{iN}^2$$

$$\Rightarrow$$

$$d_{iN}^2 - E_N = -2X_N X_i - 2Y_N Y_i + K \quad (5)$$

Where $E_N = X_N^2 + Y_N^2$, $K = {X_i}^2 + {Y_i}^2$.
Set

$$P_c = [X_i, Y_i, K]^T \quad (6)$$

$$M_c = \begin{bmatrix} -2X_1 & -2Y_1 & 1 \\ -2X_2 & -2Y_2 & 1 \\ \vdots & \vdots & \vdots \\ -2X_N & -2Y_N & 1 \end{bmatrix} \quad (7)$$

$$h_c = \begin{bmatrix} d_1^2 - E_1 \\ d_2^2 - E_2 \\ \vdots \\ d_N^2 - E_N \end{bmatrix} \quad (8)$$

We can derive from (5) that

$$M_c S_c = h_c \quad (9)$$

Using Least Square algorithm [25], from (9) we can get

$$P_c = (M_c^T M_c)^{-1} M_c^T h_c \quad (10)$$

Then, the position of i'th UnknownNode should be

$$(P_c(1), P_c(2)). \quad (11)$$

4.2 Simulation and Performance Comparison between RDV-hop and DV-hop

In order to describe the localization accuracy more objectively and accurately, we need to introduce two new concepts, i.e. N-order relatively error ratio, succeeded localization ratio. N-order relatively error ratio equals n/100 of the distance between measured location and actual location of the UnknownNodes. For example, if the N-order relatively error ratio is 5, that means the distance between measured location and actual location of UnknownNode is 5m when the network area is within the size of 100m*100m.

Succeeded localization ratio means the ratio of how much the nodes which are successfully localized during the whole nodes. Combined the actual conditions, we came to the conclusion that the succeeded localization ratio should be at least larger than 80%.

4.2.1 Comparison with different BeaconNode ratio.

We suppose the network is set in an area of 100m * 100m, while the communication radius is 50m, the total number of nodes is 500, beacon node ratio varies from 5% to 30%. This supposition can make sure the succeeded localization ratio is up to 80%.

At first we set the beacon ratio as 5% and do the simulations 50 times. Then we calculate the average of results of 50 simulations and set the average as the N-order relatively error ratio in current situation. Then we increase the ratio of beacon node, and get the different results in different situations.

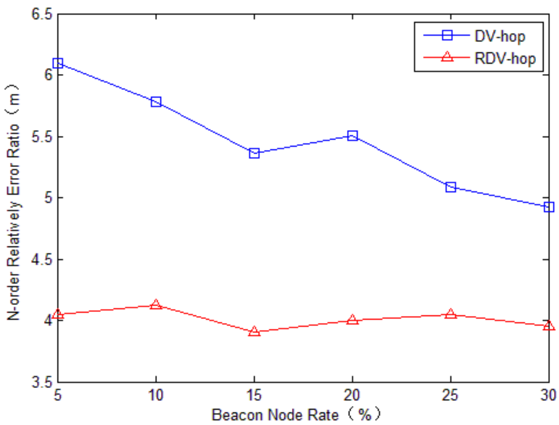

Fig. 1. Error ratio varies with the change of beacon node rate

Fig. 1 illustrates the contrast between DV-hop localization algorithm and RDV-hop localization algorithm with different beacon node ratio conditions. The upper line shows the N-order relatively error ratio of DV-hop localization algorithm varies with the change of beacon node ratio, while the lower line shows the N-order relatively ratio of RDV-hop localization algorithm varies with the change of beacon node ratio. We can observe that the N-order relatively error ratios of RDV-hop localization algorithm are always smaller than that of DV-hop localization algorithm, no matter how much the beacon node ratio is. The accuracy has been increased by 26% on average. So it can be concluded that the accuracy of RDV-hop is better than that of DV-hop localization algorithm.

4.2.2 Comparison with different number of the nodes.

In this section we set the number of nodes as variation to compare the difference between DV-hop and RDV-hop localization algorithm in the situation of different number of nodes. We still suppose the wireless sensor network is set in an area of 100m * 100m, communication radius of beacon nodes is 50m, beacon nodes ratio is 20%, the total number of nodes varies from 500 to 1000.

Firstly we set the number of nodes as 500, then run the simulation 50 times, calculate the average of results of 50 simulations and set the average as N-order relatively error ratio in current situation. We then increase the number of nodes to 1000 gradually, so we can get the N-order relatively error ratios in different situations with different number of nodes.

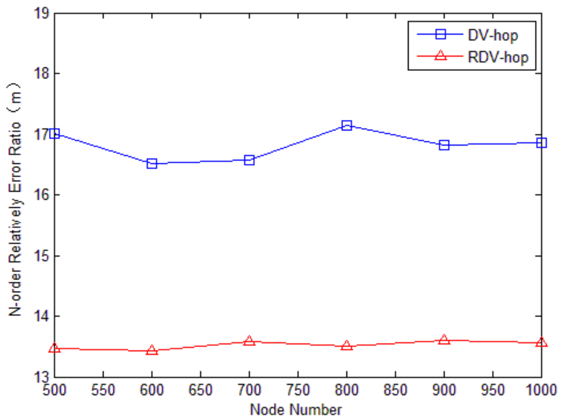

Fig. 2. Error ratio varies with node number

Fig. 2 shows the contrast between DV-hop localization algorithm and RDV-hop localization algorithm with different number of nodes. The upper line shows the N-order relatively error ratio of DV-hop localization algorithm varies with the change of node number, while the lower line shows the N-order relatively ratio of RDV-hop localization algorithm varies with the change of node number. We can obtain the result from Fig. 2 that the N-order relatively error ratios of RDV-hop localization algorithm are always smaller than that of DV-hop localization algorithm, no matter how many nodes there are.. An average increase of accuracy by 24% can be obtained. So we can conclude that the accuracy of RDV-hop is always better than that of DV-hop localization algorithm.

4.2.3 Comparison with other improved DV-hop algorithms.

Now we set the communication radius as variation to compare the different between DV-hop and RDV-hop localization algorithm in the situation of different communication radius. We still suppose the wireless sensor network is set in an area of 100m * 100m, the number of nodes is 500, beacon node ratio is 20%, and communication radius of beacon node varies from 10 to 100.

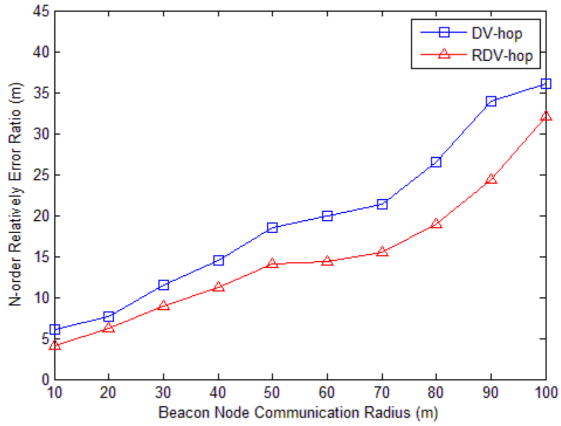

Fig. 3. Error radio varies communication radius

Fig. 3 shows the contrast between DV-hop localization algorithm and RDV-hop localization algorithm with different communication radius. The upper line shows the N-order relatively error ratio of DV-hop localization algorithm varies with the change of communication radius, while the lower line shows the N-order relatively ratio of RDV-hop localization algorithm varies with the change of communication radius. We can get the result from Figure 3 that the N-order relatively error ratios of RDV-hop localization algorithm are always smaller than that of DV-hop localization algorithm, no matter how much the communication radius is. The accuracy has been promoted by 24% on average. So we can conclude that the accuracy of RDV-hop is always better than that of DV-hop localization algorithm.

It is interesting to find that the N-order relatively error ratio become bigger with the growth of beacon node's communication radius, we also have analyzed this, and we think it is more likely to become more circuitous for communicate route with the increase of communication radius. So the average HopSize is bigger, that is why the error ratio is bigger.

4.2.4 Comparison with other improved DV-hop algorithms.

Stefan obtained the improvement of roughly 26% for DV-hop localization algorithm in the position accuracy [16]. Compared with stefan's method, the refinement in this paper has a minor improvement in accuracy but is much easier to be implemented, for Stefan improved his algorithm by adding a step after the original DV-hop algorithm.

According to [17], BinWei's localization algorithm has improved the accuracy by about 11%. And JianLi's scheme improved the accuracy by about 19% [28].

L.Gui proposed Checkout DV-hop algorithm and Selective 3-Anchor DV-hop algorithm. The accuracy improvement of Checkout DV-hop over DV-hop is between 20%~25%. The improvement of Selective 3-Anchor DV-hop ranges from 18%~30%. As what L.Gui analyzed, Checkout DV-hop algorithm and Selective 3-Anchor DV-hop algorithm differ on computational complexity. The Checkout DV-hop and original DV-hop algorithms have the same complexity, while the Selective 3-Anchor DV-hop algorithm has higher complexity. [26]

Zhang Hong proposed DV-hop+Lastdist algorithm and improved the accuracy by about 12.5% [21]. WD-DVhop was proposed by Zhigui Lin in [22] and the accuracy was improved by 13.63%~24.35% [22].

So it is obvious that our RDV-hop algorithm works best.

5 Conclusions

In the context of low-cost wireless sensor network, the range-free localization scheme is not only more cost-effective than range-base scheme, but also more robust. DV-hop is one of the most famous and classical localization algorithms. Focusing on DV-hop algorithm, we analyze every step of DV-hop localization algorithm carefully and the reason for error, which is average HopSize. So we change the way to calculate the average HopSize. Instead of taking the average HopSize of the nearest node as the average HopSize of UnknownNodes, we calculate the average of all average HopSize of all nodes. We also replace the ML localization algorithm with Hyperbolic location algorithm, which has better performance. Then we conduct simulation experiments to validate the performance superiority of our localization algorithm. The results of simulations show as predicted that RDV-hop is much better than the original DV-hop localization algorithm with accuracy increase by 24.9% on average, and beating several other improved DV-hop algorithms.

In the future, we will be interested in implementing our algorithms on a test-bed. This will allow us to compare real results with those simulation results.

Acknowledgements

This work is supported by National Training Program of Innovation and Entrepreneurship for Undergraduates (201410058046) and Tianjin Higher Education Fund for Science and Technology Development under Grant No.20110808.

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