Research status of improvement based on DV-Hop non-range positioning algorithm

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Abstract. In order to solve the problem of poor positioning of the DV-Hop algorithm, it is a current research hotspot. In view of the three aspects of error distribution, the research plan for effective improvement is listed. In the field of the minimum number of hops, the RSSI-based weighting correction and the use of deviation factor improvement; in the average distance of hops, the calculation of distance error improvement and the use of angle value weighting processing; in the calculation of unknown nodes, the weighting of the least square method and the triangle centroid method two. This correction is estimated. Relevant scholars of the above methods can solve the problem of poor positioning of the classic DV-Hop algorithm through simulation experiments.

1. Introduction
Wireless sensor network is a distributed sensor network, which is formed by deploying many sensor nodes in the detection area[1]. In the positioning technology, there are many shortcomings, and WSNs positioning technology can effectively solve. WSNs positioning technology has range-based and range-free [2-3] positioning algorithms.

Although the ranging positioning algorithm has high positioning accuracy, it will generate a lot of unnecessary overhead for the problem of more hardware requirements. In contrast, non-range positioning algorithms such as centroid algorithm [4] and convex algorithm [5] have the advantages of low energy consumption and no need for hardware support, but there is a problem of poor positioning accuracy due to the lack of accurately measured node coordinates.

Dragos N[6] et al. first proposed the DV-Hop (Distance Vector-Hop) algorithm in 2003. It has the advantage that it does not need to rely on the ranging method in the positioning process, so that the positioning coverage is larger. The algorithm is divided into the following three processes. The first process is to estimate the minimum number of hops between the positioning node and each beacon node. The second process is to estimate the actual average distance of hops between the beacon node and the unknown node. The third process is to use the minimum number of hops and the average distance of hops obtained in the first two processes to calculate the position of the unknown node itself, so the least square method is commonly used.

In 2004, Tian S[7] and others first proposed to combine RSSI (Received Signal Strength Indicator) with DV-Hop, which initially improved the positioning accuracy. In recent years, many scholars have proposed using different methods to optimize the algorithm from three different aspects, so this article summarizes the research results of these scholars.
2. Improvement status of minimum hops

2.1. RSSI weighted correction minimum number of hops

RSSI is the received signal strength indicator, it is a positioning technology, converted from RSS (Received Signal Strength), and calculates the distance between the receiving point and the receiving point by measuring the strength of the received signal, literature [8] also uses RSS performs node ranging. However, due to fluctuations in signal power, it is impossible to maintain accurate ranging. So Song Ling et al. [9] scholars use RSSI method as an auxiliary tool to refine the minimum number of hops.

Literature [10] introduced the Log-Normal (logarithmic-normal distribution) signal model on this basis to express the correlation between RSSI distances. According to the Log-Normal signal model[11], use the RSSI-d conversion equation to convert the RSSI value of the unknown node to the beacon node into the distance, refer to Equation (1).

\[
\text{RSSI} (d) = A - 10n \log d + x_n
\]  

Among them, the RSSI(d) and A environmental parameters are the RSSI values of the signal absorbing node and the transmitting node, respectively, d is usually 1 meter, and Gaussian noise can be ignored. The RSSI value of the neighbor node is used as the comparison reference, and the first hop count is 1, and the RSSI reference value is added to the information packet distributed by the beacon node. When receiving, the neighbor node compares the RSSI value with its own value, and uses the ratio between the two as a weighted hop count. At the same time, sum the last hop count and the weighted value as the optimal value of this node, and the weighted minimum hop count can refer to Equation (2).

\[
\text{Hops}_i = \text{Hops}_{i-1} + W_i = \text{Hops}_{i-1} + \frac{\text{RSSI}_i}{\text{RSSI}_R} = 1 + \frac{\text{RSSI}_1 + \text{RSSI}_2 + \ldots + \text{RSSI}_i}{\text{RSSI}_R}
\]

Among them, \( \text{Hops}_i \) indicates the weighted minimum number of hops of the \( i \) (\( i > 1 \)) node after the improvement, \( \text{RSSI}_i \) represents the signal strength value of the \( i \) node, and \( \text{RSSI}_R \) represents when the communication radius of the beacon node is \( R \), that is For the RSSI benchmark value, refer to Figure 1 for an example.

In the above figure, in a communication cycle with a beacon node O as a radius \( R \), the hop distance with the neighboring node B is recorded as 1. B sends a packet containing the hop count and RSSI to C, according to C’s The weight of the hop count can calculate the minimum hop count of C as \( \text{Hop}_c = 1 + W_c \), thus the minimum hop count of node D. In traditional DV-Hop, the jump between two adjacent nodes is always fixed at 1 hop. But in this algorithm, the number of hops fixed at 1 can be modified accordingly according to the distance, so that the hops fixed at 1 become a continuous value without exceeding 1, which is closer to the actual value.
2.2. Deviation factor to improve the minimum number of hops

Literature [12] uses $H$ to define the ratio of the distance between two neighboring nodes to the communication radius as the ideal number of hops, then the distance between neighboring nodes is denoted by $d$, and the communication radius is denoted by $R$. The algorithm estimates the ratio of the number of hops $h$ to the ideal number of hops as the deviation factor $\delta$, refer to Equations (3) and (4).

\[
H = \frac{d}{R} \tag{3}
\]

\[
\delta = \frac{h - H}{h} \tag{4}
\]

The deviation factor reflects the deviation of the estimate from the ideal number of hops. According to the above equation, the deviation between the estimated and actual number of hops has a certain relationship with the deviation coefficient. Therefore, when the value of the deviation factor is higher, the deviation between the estimated and the actual number of hops is greater, and the error is also greater. Therefore, the hop number correction factor $\xi$ is represented by, refer to Equation (5), and use the correction factor to correct the number of hops between neighboring nodes, refer to Equation (6).

\[
\xi = 1 - \delta^2 \tag{5}
\]

\[
h' = \xi h \tag{6}
\]

Finally, the deviation between the corrected hop count and the ideal hop count can refer to Equation (7).

\[
h' - H = (1 - \delta^2)h - H = h - \frac{(h - H)^2}{h} - H = H \left(1 - \frac{H}{h}\right) \tag{7}
\]

Because $h$ is always greater than 1 and greater than $H$, the value of $H/h$ is less than 1, and the corrected value is closer to the true value.

3. Improvement status of the average distance hops

3.1. Calculate the distance error to improve the average distance of hops

Through the average distance of hops of the second process of the DV-Hop algorithm, $h_{ij}$ is the minimum number of hops between beacon nodes $i$ and $j$ ($i \neq j$), and $\text{HopSize}_i$ is the average distance of hops of beacon node $i$. Refer to Equation (8).

\[
\text{HopSize}_i = \frac{\sum_{j \neq i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j \neq i} h_{ij}} \tag{8}
\]

Literature [14] uses Equation (9), $m$ represents the number of beacon nodes, and finds the average distance of hops of all beacon nodes, which reduces the larger average distance of hops and compensates for the smaller average distance of hops.

\[
\text{AveHopSize} = \frac{\sum_{i=1}^{m} \text{HopSize}_i}{m} \tag{9}
\]

Referring to Figure 9, Because calculating the true distance between two beacon nodes and the distance error of the calculated distance and the minimum jump value (no double calculation), it is necessary to calculate the difference between $A$ and $B$, $A$ and $C$, and $B$ and $C$. The estimated distance between the two, the true distance and the minimum jump value.
Figure 2. Example of improvement in average distance per hop

Refer to Equation (10) to calculate the distance error of the entire WSN jump. Refer to Figure 2, the value of the distance error $\text{ErrHop}$ of the entire WSN for one hop is equal to $\left( |R_{AB} - E_{AB}| + |R_{AC} - E_{AC}| + |R_{BC} - E_{BC}| \right) / \left( h_{AB} + h_{AC} + h_{BC} \right)$. Among them, R and E are the true distance and calculated distance between the two nodes, and $h_{ij}$ is the minimum hop value between the two nodes.

$$\text{ErrHop} = \frac{\sum_{i=1}^{m} \sum_{j=i+1}^{m} |R_{ij} - E_{ij}|}{\sum_{i=1}^{m} \sum_{j=i+1}^{m} h_{ij}}$$  (10)

Finally, refer to Equation (11) to calculate the updated the average distance of hops of the entire wireless sensor network, which is represented by $\text{NewAveHopSize}$, and estimate the average distance of hops of each $i$ after the update, refer to the Equation (12), which is represented by $\text{NewHopSize}_i$.

$$\text{NewAveHopSize} = \text{AveHopSize} + \frac{\text{ErrHop}}{2}$$  (11)

$$\text{NewHopSize}_i = \frac{\text{HopSize}_i + \text{NewAveHopSize}}{2}$$  (12)

3.2. Angle value weighted processing the average distance of hops

The minimum routing path and direct distance calculated by each beacon node can calculate the actual error, and determine the weight according to the angle value between the nodes, so as to correct the average distance of hops of each beacon node. [13] The calculated routing distance between beacon nodes is not equal to the actual distance, so the average distance of hops error refers to Equation (13), $\varepsilon_i$ is the average distance of hops error of beacon node $i$, HopNum is the minimum hop, $C_m^2$ is the total routing distance between any two nodes participating in the calculation of unknown nodes.

$$\varepsilon_i = \frac{\sum_{i=x}^{m} |d'_{ij} - d_{ij}|}{\text{HopNum} \times C_m^2}$$  (13)

$t_i$ represents the angle of beacon node $i$. The average distance of hops error of beacon node $i$ is inversely proportional to the angle value. Refer to Equation (14) to indicate that the larger the angle value, the smaller the error, so refer to Equation (15) for the ratio of the angle Modify the average distance of hops of beacon node $i$ as the weight.

$$t_i = \frac{\text{Sum}_i \alpha_i}{\text{Sum}_i \alpha_i}$$  (14)

$$\text{AveHopDis}'_i = \text{AveHopDis}_i + \sum_{i=1}^{m} t_i \varepsilon_i$$  (15)

After the unknown node receives the average distance of hops of all beacon nodes, construct the weight value $w_i$ referring to Equation (16).

$$w_i = \frac{1}{\sum_{j=1}^{m} \frac{1}{\text{HopNum}_j}}$$  (16)
U is the average distance of hops of the unknown node, using each beacon node, refer to the modified Equation (17).

\[
\text{AveHopDis}_u = \sum_{i=1}^{m} w_i \times \text{AveHopDis}_i
\]  

Therefore, Reference Equation (18) represents the distance between i and U, where \(\text{HopNum}_{u_i}\) represents the minimum number of hops U and the i.

\[
W = \begin{bmatrix} w_{k,1} & 0 & \cdots & 0 \\ 0 & w_{k,2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & w_{k,n-1} \end{bmatrix}
\]  

4. Improvement status of calculation method

4.1. Weighted estimated coordinates based on least square method

The error analysis of the DV-Hop algorithm shows that the positioning of the algorithm is not high. Therefore, literature [15] proposes a weighted least squares method. A weighting matrix W is introduced. For the unknown node k, refer to Equation (19), which shows the weighted matrix of the minimum number of hops with the beacon node.

\[
\text{Dis}_{ui} = \text{AveHopDis}_u \times \text{HopNum}_{ui}
\]  

When \(w_{k,i}\) represents the weight of unknown node k and beacon node i, \(h_{ki}\) represents the minimum number of hops between k and i. Refer to Equation (20) to express.

\[
W_{k,i} = \frac{1}{h_{ki}}
\]  

Then, the reference Equation (21) is calculated according to the least square method. Among them, \((x, y)\) are the position of the unknown node, \((x_i, y_i)\) \((i = 1, 2, \ldots, n)\) are the position of the beacon node, and the estimated distance between the unknown node and i is denoted by \(d_i\).

\[
A = \begin{bmatrix} x_1 - x_n & y_1 - y_n \\ \vdots & \vdots \\ x_{n-1} - x_n & y_{n-1} - y_n \\ x_i^2 - x_n^2 + y_i^2 - y_n^2 + d_i^2 - d_n^2 \\ \vdots & \vdots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 + d_{n-1}^2 - d_n^2 \end{bmatrix}
\]

\[
B = \begin{bmatrix} x_1 \\ \vdots \\ x_{n-1} \\ x_i \\ \vdots \\ x_{n-1} \end{bmatrix}
\]

Finally, according to the position coordinates estimated by weighted least squares, refer to Equation (22).

\[
X = (A^T W^T W A)^{-1} A^T W^T W B.
\]  

4.2. Triangular centroid method twice corrected estimated coordinates

After using the least square method to estimate the position of the unknown node, the literature [16] proposes to use the triangle centroid method to make a second correction to obtain relatively more accurate coordinates.

If the position of the unknown node N coordinate \((x_i, y_i)\), select the beacon node A. Because the hop distance between A and the unknown node is the smallest, and record its coordinate position as \((x_j, y_j)\). Draw a circle with N and A as the center and \(R_i\) and \(R_j\) as the radius, as shown in the reference Equation (23) and Figure 3.
\[ R_i = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, R_j = HS_i \times hop_{ij} \] (23)

Figure 3. Correct the coordinate position of the unknown node

Among them, \( \epsilon \) denotes the beacon node; \( p \) denotes the estimated position of DV-Hop; \( l \) denotes the position of the triangle centroid correction; \( \star \) denotes the true position. Find the intersection of two circles \( S_1(x_{1l}, y_{1l}), S_2(x_{2l}, y_{2l}) \). The centroid of the triangle formed by two nodes is the coordinate position of the unknown node. The centroid of the triangle formed by two nodes is the position of the unknown node. The position of the last unknown node is calculated using Equation (24).

\[ X_l(x_t, y_t) = \left( \frac{x_{1l} + x_{1l} + x_{2l}}{3}, \frac{y_{1l} + y_{1l} + y_{2l}}{3} \right). \] (24)

5. Conclusions

How to improve the positioning accuracy of the classic DV-Hop algorithm is still a hot research direction. The different methods to improve the accuracy listed in this article are just the tip of the iceberg. Because the three different aspects can use different methods to optimize the problem of poor accuracy, scholars have obtained better performance indicators through comparative experiments with classic algorithms, especially those obtained from the simultaneous optimization of the three aspects of error. The improvement in accuracy is the most significant, so many optimization schemes have been proposed. Even so, how to improve the positioning accuracy more efficiently is still a hot spot for future research.

The future development direction of wireless sensor networks will be to realize the omnipotent network of information between the earth and the outer space, form the interface between the real world and the simulated world, and participate in all aspects of human life, thereby changing the relationship between humans and nature [1]. Therefore, improving the accuracy of non-ranging positioning algorithms has an important influence. With its advantages of low energy consumption and no hardware support, it can create many contributions to the society and the world's wireless sensor network.

References

[1] Zhihong Qian, Yijun Wang, (2013) Overview of Wireless Sensor Networks Oriented to the Internet of Things.EI, 35(01):215-227.

[2] Bulusu N, Heidemann J, Estrin (2000).D.GPS-less low cost outdoor localization for very small devices .IEEE Personal Com- munications Magazine,7(5):28 -34.
[3] Niculescu D, Nath B. (2001) Ad-hoc positioning system(APS). In: IEEE GLOGECOM. San Antonio, pp.2926-2931.

[4] CuevasU-Martinez JC, Yuste-Delgado AJ, Leon-Sanchez AJ, et al. (2019) A New Centralized Clustering Algorithm for Wireless Sensor Networks. Sensors (Basel, Switzerland). 19(20):4391

[5] Liu Wu Sun Donghong, Ping, ren, et al. (2013) Co-SRL: A Convex Optimization Algorithm for Anchor Localization in Wireless Sensor Networks. AASRI Procedia, 5:62-66

[6] Dragos N, Badri (2003) NDV based positioning in Ad Hoc networks. In: Telecommunication Systems, 22(1-4):267-280.

[7] Tian S, Zhang XM, Liu PX, et al. (2007) A RSSI-based DV-Hop algorithm for wireless sensor networks. In: International Conference on Wireless Communications, pp.2555-2558.

[8] Elnahrawy Eiman, Li Xiaoyan, Martin Richard P. (2004) The limits of localization using signal strength: a comparative study. In: First Annual IEEE Conference on Sensor and Ad-hoc Communications and Networks, Santa Clara, CA, United States, pp.406-414.

[9] Ling Song, Dasheng Huang. (2021) An improved DV-Hop positioning algorithm based on wolf pack optimization. CSCD, 43(07):1210-1218.

[10] Hui Wang. (2020) Research and Improvement of DV-Hop Location Algorithm in Wireless Sensor Network. Nanjing University of Posts and Telecommunications, 40-43.

[11] Qiyue Li, Wei Li, Wei Sun, Jianping Wang, Jie Li. (2016) Wi-Fi indoor positioning method based on RSSI and auxiliary node cooperation. CSCD, 30(05):794-802.

[12] Zesheng Su. (2019) Research and improvement of wireless sensor network positioning algorithm. Tiangong University, 38-41.

[13] Juan Ye. (2019) Research on Non-Ranging Positioning Algorithms in Wireless Sensor Networks. Guangxi Normal University, 30-32.

[14] Ying Chou, Xiaojun Ni. (2020) Improved DV-Hop positioning algorithm based on Newton iteration method. In: Computer Era, pp.29-33

[15] Min Zhu, Haolin Liu, Zhihong Zhang, Zongrui Yi. (2012) An improved wireless sensor network positioning algorithm based on DV-HOP. EI, 93-98.

[16] Wanti Zhang, Qixiang song. (2020) Research on Improvement of Node Location Algorithm Based on DV-Hop. In: Journal of Ningxia Normal University, pp.53-57.