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Signal Hunting Algorithm Based on Difference Grouping Mechanism in Sensor Network

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Abstract

In order to solve such problems as the difficult realization of accurate positioning and multidimensional dynamic elastic range measurement and the poor reading of positioning data caches during the range measurement process in wireless sensor network, a wireless sensor network positioning algorithm based on neighbor spin-hop iteration mechanism. Firstly, the neighbor clustering process is executed for the nodes in the wireless sensor network, namely: the first-order neighbor nodes and the second-order neighbor nodes are taken as the network neighborhood. Secondly, other network nodes are positioned according to the rejection and attraction conditions of the neighborhood radius, and meanwhile the iteration mechanism is adopted to realize error minimization so as to obtain the accurate position coordinate of the node. The simulation result shows: compared with currently widely applied two-dimensional non-iterative accurate positioning algorithms, such as RSLM algorithm and SOCP algorithm, the new algorithm is provided with clustering mechanism for accurate positioning and the error correction method based on iteration mechanism, thus to not only effectively reduce the node position error and improve positioning accuracy during multidimensional range measurement, but also improve network packet delivery ratio and reduce network control overhead.

Keywords*: Wireless sensor network (WSN); Neighbor spin-hop; Neighbor clustering; Node positioning; Multidimensional range measurement; Network packet delivery ratio*

1. Introduction

Along with the continuous development of integrated circuit technology and chip manufacturing industry, the data processing capacity and the working stability of WSN nodes are also continuously improved. Existing WSN sensors can not only realize basic data collection and aggregation, but also measure, locate and trace some surrounding objects [1]. Generally speaking, such functions can be realized through installing such positioning chips as GPS chips and Beidou navigation chips on the wireless sensor nodes [2]. However, due to such problems as limited node power of WSN sensor nodes and power supply replacement difficulty, it is difficult for the navigation chips to fully cover the nodes under existing technology and cost conditions [3]. Therefore, the practical deployment usually also depends on the network characteristics for positioning [4]. On this basis, a WSN positioning algorithm based on neighbor spin-hop iteration mechanism is proposed in this paper. Specifically, the neighbor thought is introduced therein to divide the network nodes and the surrounding nodes into the first-order node and the second-order node

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according to the hop number; then, the preliminary positioning is realized according to the relationship between the order of the neighbor node and the order of the node to be positioned; then, the iteration mechanism is introduced to accurately locate the node to be positioned, thus to not only improve the network positioning performance and the network data grouping delivery ratio, but also effectively reduce network control overhead. Meanwhile, the simulation experiment has verified the network performance of the algorithm.

2. Multidimensional Positioning of WSN Node and Positioning Error Analysis

2.1. Multidimensional Positioning Analysis of WSN Nodes

Multidimensional positioning of WSN node is an emerging technology gradually developed in recent years for positioning and range measurement in WSN. This technology is mainly developed from some programming algorithms and aims at finding the optimum position solution through certain nonlinear programming processes. Specifically, the datum node set is $\overline{N}$, the datum position after network initialization is a_k , the actual position in the network is b_k , node i is the node to be positioned and the measured position thereof is c_i , and the measurement accuracy is Δi [10]. Obviously, the error of the whole positioning process can be expressed as follows:

$$\min \sum_{i,j\in i} \left(\left|c_i - c_j\right| - l_{i->j}\right)^2 + \sum_{k\in \overline{N}} \left|a_k - b_k\right| \tag{1}$$

wherein:
$$\left|a_k - b_k\right| \le \Delta i, k \in \overline{N} \tag{2}$$

In the above formula, i is the node to be positioned, j is the first-order neighbor node of i , and $l_{i->j}$ is the measured distance from i to j .

If the deviation among the positions of all datum nodes is greatly less than Δi 11], then Formula (1) can be written as follows:

$$\min \sum_{i,j\in i} \left(\left|c_i - c_j\right| - l_{i->j}\right)^2 \tag{3}$$

Formula (1) is namely the accurate measurement error in the multidimensional positioning of WSN node.

2.2. Positioning Error Analysis

According to section 2.1, the error of the accurate positioning of the network nodes is mainly composed of the following two parts:

$$Error\_1 = \sum_{i,j\in i} \left(\left|c_i - c_j\right| - l_{i->j}\right)^2 \tag{4}$$

$$Error\_2 = \sum_{k\in \overline{N}} \left|a_k - b_k\right| \tag{5}$$

In the above formulae, $Error\_1$ is mainly determined by the error between node i to be positioned and the surrounding first-order neighbor node, and this error is called as the first-order solitary neighborhood error. $Error\_2$ is the positioning error caused by the accurate positioning failure of the datum node itself, and this error is called as datum error.

For any node a to be positioned, if there is only one first-order neighbor node, since no second first-order neighbor node can be taken as the reference, then significant measurement error will be generated. As shown in Figure 1, only one node b exists in the first-order neighborhood of node a to be positioned, a third node cannot be found for the angle calculation of node a and other node within the first-order neighborhood of node b, such as node c, is beyond the communication capability of node a, so large measurement error will be caused to the position measurement of node a. Moreover, if there are many nodes with the status as the same as that of node a, then the measurement error will have accumulative effect.

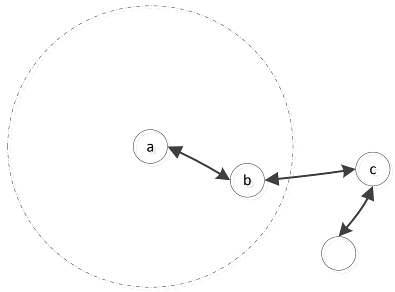

Figure 1. First-order Solitary Neighborhood Error

The unique approach for reducing such error is to adopt high-order neighborhood to calculate the specific position of the node to be positioned. For example, as shown in Figure 1, if node c is the first-order neighbor node of node b and is located within the communication range of node a to be positioned, then the above approach can be used to calculate the position of node a. However, WSN has large connectivity, and when the network node distribution can meet mutual independence condition, such situation that node a to be positioned only has one first-order neighbor node as shown in Figure 1 is very rare. In practical application, the connectivity of a WSN is usually above 10, and the probability for an optional network node to have only one first-order neighbor node is 0.008‰ and can be completely ignored. Once a node is detected to only have one first-order neighbor node, this node will directly send the position information previously recorded thereby to its first-order neighbor node and meanwhile aggregate and upload such information. In this way, the first-order solitary neighborhood error can be effectively avoided.

3. The Proposed WSN Positioning Algorithm

3.1. Triggering Condition of Accurate Positioning

According to the above analysis, for WSN node positioning, the positioning accuracy of nodes is actually inconsistent with the hop number of the nodes. Obviously, in order to accurately position node i, the positioning accuracy of node i shall be controlled at least within the communication range R of the node. If the two nodes are the second-order neighbor nodes of each other, then the positioning accuracy between the two nodes is certainly within in the range of $(R, 2R)$. If the positioning accuracy between the node to be positioned and the first-order neighbor node thereof is beyond R or the positioning accuracy between the node to be positioned and the second-order neighbor node thereof is within R, then it is indicated that the positioning data of node i to be positioned have certain error. During the positioning process, it is necessary to ensure the minimization of $Error\_i$, wherein the analytical expression of $Error\_i$ is as follows:

$$Error\_i = \min \sum_{j \in M_{i1}} \left(\left| c_i - c_j \right| - R \right)^2 + \sum_{j \in M_{i2}} \left(\left| c_i - c_j \right| - R \right)^2 + \sum_{j \in M_{i2}} \left(\left| c_i - c_j \right| - 2R \right)^2 \qquad (6)$$

In the above formula, M_{i2} is the second-order neighbor node set of node i, and M_{i1} is the first-order neighbor node set of node i.

For an optional node i to be positioned, if this node is regarded as a neighborhood, then this node has mutual attraction relationship with the first-order neighbor node thereof but has mutual rejection relationship with the second-order neighbor node thereof[12-13].

According to Formula (3), under the condition of not considering the first-order solitary neighbor node, the positioning error $E_i(k)$ of an optional node i can meet the following formula:

$$E_i(k) = \sum_{j \in M_{i1}} A_{i->j}(k) + \sum_{j \in M_{i2}} B_{i->j}(k) \qquad (7)$$

In the above formula, $A_{i->j}(k)$ and $B_{i->j}(k)$ are defined as follows:

$$A_{i->j}(k) = \begin{cases} L, \left| c_i(k) - c_j(k) \right| > R \\ 0, other \end{cases} \qquad (8)$$

$$B_{i->j}(k) = \begin{cases} L, \left| c_i(k) - c_j(k) \right| < R \\ 0, other \end{cases} \qquad (9)$$

In the above formulae, $c_i(k)$ is the position of node i after being positioned for k times, wherein if $k = 0$ is true, then the initial position of node i is $c_i(0)$; L is the minimum error accuracy which is usually defined as half of the communication range R, namely $L = 0.5R$.

Formula (4) can be adopted to determine whether a certain node needs to be accurately positioned. In case of large $E_i(k)$, the node shall be accurately positioned. Generally speaking, in order to realize the accurate positioning of a certain node, it is necessary to find two or more first-order neighbor nodes with accurate positions. In this section, the number of nodes able to meet Formula (5) after node i is positioned for k times is assumed as $N_i(k)$ and the total number of the first-order neighbor nodes thereof is assumed as $M_i(k)$. If the following formula can be met, then node i shall be accurately positioned again.

$$M_i(k) - N_i(k) \geq 2 \qquad (10)$$

$$N_c = \frac{N_i(k)}{M_i(k)} \qquad (11)$$

N_c is the judgment threshold value for the accurate positioning of node i after this node is positioned for k times. On the basis of combining Formula (7), the following formula can be obtained:

$$N_c = 1 - \frac{2}{M_i(k)}, M_i(k) \geq 2 \qquad (12)$$

3.2. Algorithm Steps

In conclusion, WSN positioning algorithm based on neighbor spin-hop iteration mechanism includes the following steps:

Step 1: Firstly, confirm the first-order neighbor node of node i to be positioned, judge whether this node has two or more first-order neighbor nodes, and turn to Step 2;

Step 2: Calculate the error level according to Formula (4), and turn to Step 3;

Step3： Execute iterative calculation and error calculation according to Formulae (15), (16), (17) and (18) to find two nodes a_1 and a_2 with minimum error, then calculate the distances $l_{i->a_1}$ and $l_{i->a_2}$ from a_1 and a_2 respectively to node i , then respectively take a_1 and a_2 as the communication neighborhoods and take $l_{i->a_1}$ and $l_{i->a_2}$ as the scanning radiuses, then confirm that the node to be positioned is located within the radius range, and then turn to Step 4;

Step 4: Respectively record the two intersection points of scanning radiuses a_1 and a_2 as d_{a_1} and d_{a_2} , then respectively calculate the absolute error according to Formula (12), then select the intersection point with smaller absolute error as the preliminary position, and then turn to Step 5;

Step 5: After taking the intersection point with smaller absolute error as the preliminary position, calculate the absolute deviation and iteration error according to Formulae (16) and (17) and meanwhile update the node position data according to Formulae (20) and (21);

Step 6: End the algorithm.

4. Simulation Result and Analysis

Since WSN nodes have limited energy, the energy consumption of the network nodes will be significantly increased after frequent positioning operations. Additionally, the control data messages in the network will be also continuously increased during the frequent positioning process, thus causing certain network congestion. Therefore, the simulation experiment is carried out in this paper from the aspects of positioning accuracy, energy consumption and network congestion. In order to verify the performance of the proposed algorithm, the node positioning algorithm based on RSLM mechanism [14] and the network node positioning algorithm based on SOCP[15] are taken as the control group. NS2 is adopted for this experiment. The specific simulation parameters are as shown in the following table:

Table 1. Simulation Parameters Table

Parameter	Numerical Value
Area of Region	2400m×1600m
Data Simulation Time (min)	7200
Sub-region Quantity	9
Node Distribution Mode	Random Distribution
Node Distribution Density (PCS/ m2) of Sub-region	0.2/m2、0.4/m2、0.5/m2
Node Signal Communication Radius (m)	20m
Node Cache (KB) (S)	512KB
Node Radio-frequency Signal Emission Period (S)	60
Node Power (J)	4~12

4.1. Number of Error Nodes

Under high network node density, the number of the error nodes of the proposed algorithm and RSLM algorithm, SOCP algorithm is as shown in Figure 2. According to the figure, along with the continuous increase of the network node density, the number of the error network nodes of the proposed algorithm is gradually reduced while that of RSLM algorithm and SOCP algorithm is continuously increased. Because the first-order neighbor node used for accurate positioning is introduced in the proposed algorithm, when the network node density is continuously increased, the first-order neighbor node density of an optional node is also increased, thus reducing the absolute deviation and iteration error of the positioning process.

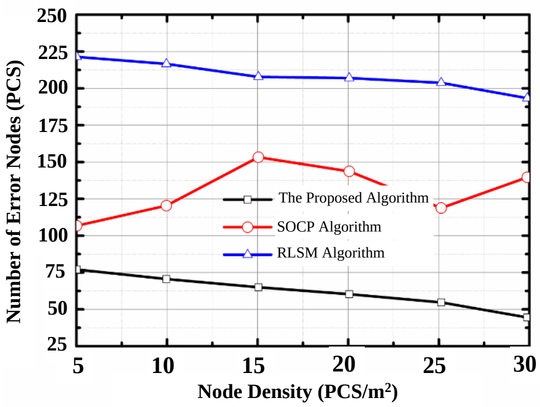

Figure 2. Number of the Error Nodes of the Positioning Algorithm Under High Node Density

Under low network node density, the number of the error nodes of the proposed algorithm and RSLM algorithm, SOCP algorithm is as shown in Figure 3. According to the figure, along with the increase of network node density, the number of the error network nodes of the proposed algorithm is not obviously increased and is even reduced more or less, but the number of the error network nodes of RSLM algorithm and SOCP algorithm is continuously increased. Because the network under low network node density has less nodes available for positioning than the network under high node density has, thus the probability of the error nodes in such network is higher than that in the network under high node density and the number of the error network nodes of RSLM algorithm and SOCP algorithm is increased along with the increase of the node density. However, the neighbor spin-hop iteration mechanism is adopted for the proposed algorithm, and when the network has low node density, the proposed algorithm can realize error correction according to the continuous iteration of the positioning error and accordingly reduce the occurrence frequency of the error nodes.

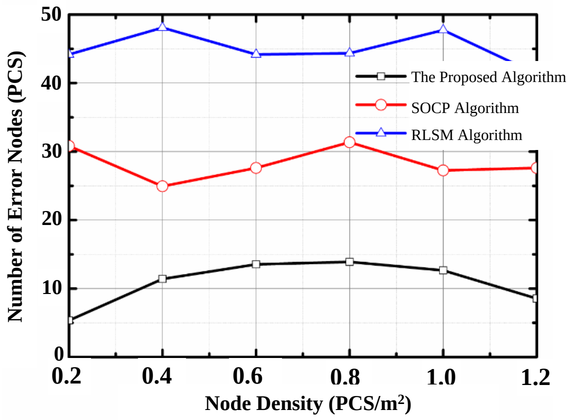

Figure 3. Number of Error Nodes of Various Algorithms Under Low Node Density

4.2. Comparison of Network Packet Delivery Ratio

Under high network node density, the comparison of the network packet delivery ratios of the proposed algorithm and RSLM algorithm, SOCP algorithm is as shown in Figure 4. According to the figure, under high network node density, the network packet delivery ratio of the proposed algorithm is continuously increased while that of RSLM algorithm and SOCP algorithm is continuously reduced, because the proposed algorithm can better position the nodes under high network node density. Especially, the introduction of the neighbor spin-hop iteration mechanism can reduce the broken links caused by the node searching failure during the network data transmission process. The performances of RSLM algorithm and SOCP algorithm are not significantly improved under high network node density, so the number of error nodes is continuously increased and meanwhile the broken links are also continuously increased due to the node searching failure during the data transmission process, thus reducing the network packet delivery ratio.

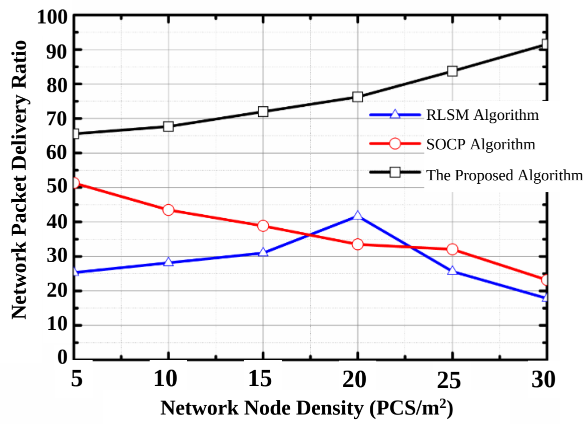

Figure 4. Network Packet Delivery Ratio under High Node Density

Under low network node density, the comparison of the network packet delivery ratios of the proposed algorithm and RSLM algorithm, SOCP algorithm is as shown in Figure 5. According to the figure, under low network node density, the network packet delivery ratio of the proposed algorithm is stably kept along with the continuous increase of the network node density while that of RSLM algorithm and

SOCP algorithm is significantly fluctuated. Under low network node density, the nodes are sparsely distributed and the positioning information acquired from the nodes during the positioning process is usually instable, so the network is caused to have serious link joggle and finally the network packet delivery ratios of RSLM algorithm and SOCP algorithm are significantly fluctuated. Since the neighbor spin-hop iteration mechanism is adopted for the proposed algorithm and the proposed algorithm can continuously correct the errors according to several finite positioning nodes under low network node density, thus the network has a small probability to have link joggle and the network packet delivery ratio can be kept in a stable state.

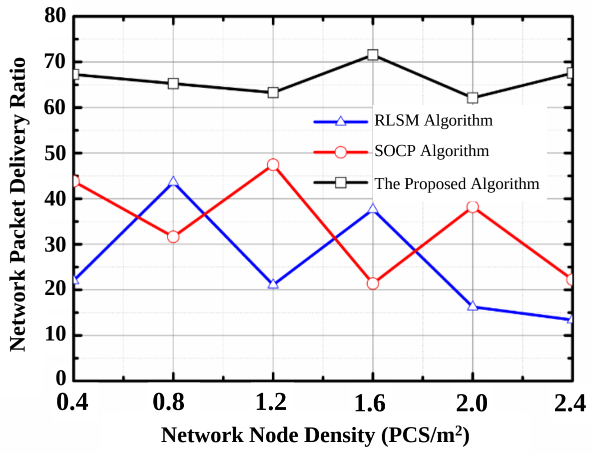

Figure 5. Network packet delivery Ratio Under Low Node Density

4.3. Network Control Overhead

Under the continuous increase of the network node power, the comparison of the network control overheads of the proposed algorithm and RSLM algorithm, SOCP algorithm is as shown in Figure 6. According to the figure, along with the continuous increase of the network node power, the proposed algorithm has a relatively low network control overhead. The neighbor spin-hop iteration mechanism adopted in this paper can realize the accurate positioning of the network nodes and meanwhile control the positioning error, so the network link has high stability and the network correspondingly has less data messages used for maintaining the network overhead, thus reducing the network control overhead. However, RSLM algorithm and SOCP algorithm fail to realize the accurate positioning and the error control of the network nodes, thus causing the network to have serious link joggle and significantly increasing the data messages used for maintaining the network control overhead, namely, increasing the network control overhead.

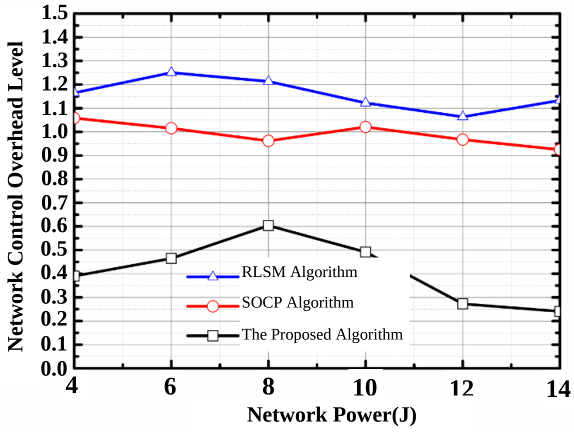

Figure 6. Network Overhead Levels of different Algorithms

5. Conclusion

A WSN positioning algorithm based on neighbor spin-hop iteration mechanism is proposed in this paper. Specifically, the neighborhood thought is introduced in this algorithm to compare the position difference between the node to be positioned and the first-order neighbor node, the second-order neighbor node thereof; then, the iteration mechanism is continuously adopted to iteratively calculate the node positions between the node to be positioned and its several first-order neighbor nodes and second-order neighbor nodes; finally, the updating mechanism is adopted to realize the accurate acquisition of the node positioning information. The experiment result shows that the proposed algorithm can effectively reduce the number of the error nodes and improve the network performance and the network packet delivery ratio as well as reduce the network control overhead.

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