



Artificial Intelligence-Based Wireless Sensor Network Radio Frequency Signal Positioning Method

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Abstract. Aiming at the problem of low positioning accuracy of existing wireless sensor network node positioning methods, a distributed node positioning method based on radio frequency interference is proposed. Analyze the structure of the wireless sensor network, use two anchor nodes to form a radio frequency interference field, and use the movement of one of the anchor nodes to generate the Doppler effect, so that each node can obtain the instantaneous frequency indicated by its low frequency received signal field strength the angle information with the mobile anchor node, combined with the geographic location of the anchor node, the node merges multiple sets of positioning angle information to obtain the optimal position estimate. The simulation results show that, compared with other localization methods, the positioning accuracy of this method is significantly improved, and the localization time of radio frequency signal in wireless sensor networks is shortened.

Keywords: Artificial intelligence · Wireless sensor network · Radio frequency signal · Doppler effect · Node location

1 Introduction

In recent years, wireless sensor networks have received more and more attention. With the rapid development of microelectromechanical technology, the node terminals of wireless sensor networks are more intelligent, lightweight, and low energy consumption, and have the functions of measuring, sensing, and collecting external environmental information. Wireless sensor network has great practical value in the fields of national defense technology, smart home, sharing economy, fire disaster relief and other fields. It is considered as one of the most important technologies in the 21st century after the Internet [1].

In wireless sensor network (WSN), data without geographic location information is often meaningless, so wireless sensor node positioning plays an active role in data routing. There are many types of conventional positioning algorithms, but they are generally divided into two categories: one is based on non-ranging (Range-free) algorithms, such as the centroid method, the DV-Hop algorithm, and the APIT algorithm. These algorithms use inter-node Information exchange obtains information such as packet hops and distance per hop to estimate the location of the node to be measured.

The required equipment is simple, but the positioning accuracy is poor; the other is a range-based algorithm, such as RSSI Algorithm 5), AOA algorithm, TOA algorithm, TDOA, etc., this type of algorithm uses the characteristics of radio signal phase information or radio signal strength (RSSI) with distance attenuation to perform ranging positioning. However, the positioning accuracy is poor, and the algorithm using phase has better accuracy, but there is often phase ambiguity, so it is necessary to introduce complex number to correct the algorithm. In addition, when ultrasonic signal and infrared signal are used for positioning, additional measurement equipment is needed, which will increase the complexity of the system, high energy consumption and short propagation distance [2].

In view of the problems of the above methods, this paper proposes a distributed node positioning method based on radio frequency interference. The node can obtain the angle information with the mobile anchor node by measuring the Doppler frequency deviation of the radio frequency interference signal, and then estimate the position. Compared with the RIPS method, this method has the following advantages: the node can complete the positioning only by performing signal reception measurement, and does not require centralized processing. It is a distributed location method. The nodes measure the signal frequency, and there is no phase ambiguity. The complexity of positioning is greatly reduced.

2 Radio Frequency Signal Location Method in Wireless Sensor Network

Wireless sensor network (WSN) is a self-organized network composed of a large number of sensor nodes deployed in the monitoring area through wireless communication technology. The emergence of wireless sensor network has profound social background and technical conditions, which not only comes from the actual needs, but also is the inevitable result of technological development. At present, information collection and acquisition methods have fallen far behind the development of computer computing speed, storage capacity and network bandwidth, so a wireless sensor network that combines sensor technology, network communication technology and information processing technology with information collection as the main purpose is ready And was born [3].

In the application of sensor network, it is almost useless to collect data without location information. It is a very important problem to determine the location of the event after detecting the event. For example, in the application of environmental monitoring, it is necessary to know the corresponding position of environmental data sensed by sensor nodes; for emergencies such as forest fire, it is necessary to know the specific location of fire. For these applications, sensor nodes must first know their geographic location, which is also an inherent requirement of wireless sensor networks [2].

This paper proposes a node positioning method combining RF interference and Doppler frequency offset measurement. A fixed anchor node and a mobile anchor node (such as an aircraft) are used to form an RF interference field. The mobile anchor node moves horizontally and uniformly to produce the Doppler effect. The frequency of the

RF signal transmitted by the two transmitting nodes is very close, and the superimposed signal received by the receiving node has a low frequency envelope; at the same time, due to the presence of the Doppler effect, the frequency of the low frequency envelope signal will change with the movement of the mobile anchor node [4]. Each node can obtain the relative position information of the unknown node and the flight path by measuring the change law of the instantaneous frequency of its own low-frequency RSSI (received signal field strength indication) signal. By moving the cross movement of the anchor node and fusing multiple relative position information, the unknown node can obtain its own absolute position information.

2.1 Wireless Sensor Network Structure

First, the network structure of the positioning system is introduced. The positioning system consists of a fixed error node, a mobile shop node and a large number of unknown nodes. The fixed anchor node and the mobile anchor node transmit single-frequency signals with similar frequencies, and the signal strength is sufficient to cover the entire network. The mobile anchor node is equipped with GPS equipment and broadcasts its own GPS information in real time. Mobile anchor nodes (such as helicopters or drones) do low-altitude intersections and fly straight in the positioning area. The network structure is shown in Fig. 1.

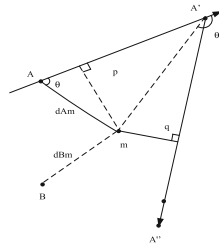


Fig. 1. Network structure of positioning system.

In Fig. 1, A is a mobile shop node, B is a fixed anchor node, and m is a wireless sensor node to be located. AA', A'A'' are the two flight paths of the mobile anchor node, and the arrow points to the direction of movement [5]. P and q are the vertical feet of the vertical line made by the crossing point m on the flight path, the mobile anchor node Movement distance is long enough.

The positioning method adopted here is two-dimensional positioning, and the following parts are the mapping of flight path and unknown nodes to two-dimensional plane analysis. The unknown node receives the radio frequency interference signal, because the mobile anchor node moves, the frequency of the radio frequency interference signal measured at the unknown node contains Doppler frequency shift, so it is the core content of this algorithm to analyze the frequency change, so as to realize the positioning.

2.2 Doppler Effect

Doppler effect refers to that if there is relative movement between the wave source and the observer, the receiving frequency of the observer will be different from that of the vibration source. When the wave source moves to the observer, the receiving frequency will be higher, while when the wave source is far away from the observer, the receiving frequency will be lower [6], as shown in Fig. 2.

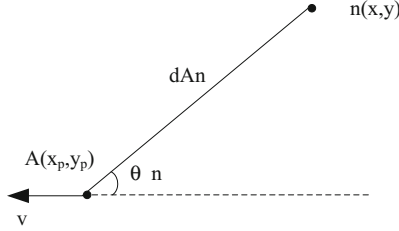


Fig. 2. Schematic diagram of the Peller effect

In Fig. 2, the mobile anchor node A transmits the tone signal $\exp[j(2\pi f_A t) + H_A]$, and moves at the instant (x_p, y_p) at the instantaneous velocity v along the negative direction of the x axis, where H_A comprehensively considers the response of the A local oscillator initial phase and the transmission channel. In a line-of-sight (LOS) environment, the received baseband complex signal of node n can be expressed as $\exp\left[j(2\pi(f_A - f_n)t) + H_A - \frac{2\pi dAn}{\lambda - s_n}\right]$, where f_n is the local oscillator frequency of n, λ is the wavelength of the RF signal, and s_n comprehensively considers the initial phase of n local oscillator and the receive channel. In response, dAn is the distance between the sending and receiving nodes.

We call the angle θ_n between the node and the anchor node A and the negative direction of A movement at a certain moment as the node's Doppler angle at that moment. According to the simple geometric relationship, the instantaneous change rate $v \cos \theta_n$ of the distance dAn between the node and the anchor node A at this moment can be obtained. Due to the influence of the Doppler effect, the baseband complex signal of the node generates a Doppler frequency offset, so the instantaneous frequency of the received signal at this moment is $(f_A - f_n) - \frac{v \cos \theta_n}{\lambda}$, where $-\frac{v \cos \theta_n}{\lambda}$ is the Doppler frequency offset.

If the Doppler frequency offset can be accurately measured, the nodes can get the estimation of the Doppler angle at that time. However, for general communication systems, it is almost impossible to accurately measure the small frequency change caused by Doppler effect based on the local frequency deviation of transmitter and receiver nodes, and the local frequency drift will seriously affect the instantaneous frequency change. The above-mentioned problems that can not accurately measure the Doppler frequency deviation can be solved by using the radio frequency interference signal. In the RF interference field formed by the two transmitting anchor nodes, the mobile anchor node generates a Doppler effect, which makes the low-frequency RSSI

signal of each node produce a Doppler frequency offset that is easy to measure. Due to the influence of vibration drift, the node can obtain accurate measurement of its own Doppler frequency deviation under low complexity [7, 8].

2.3 RF Interference

The mobile anchor node A and the stationary anchor node B respectively emit single-frequency signals $\cos(2\pi f_A t + H_A)$ and $\cos(2\pi f_B t + H_B)$ with similar frequencies (for example, a difference of about 1 kHz). Suppose that at some point in the LOS environment, the initial distance between unknown node m and A and B is dAm and dBm , respectively. The radio frequency interference signal received by node m can be expressed as:

$$G_n(t) = a_A \cos\left(2\pi f_A \left(t - \frac{dAm(t)}{c}\right) + H_A\right) + a_B \cos\left(2\pi f_B \left(t - \frac{dBm(t)}{c}\right) + H_B\right) \quad (1)$$

The baseband complex signal obtained by down converting the RF interference signal is as follows:

$$r_n(t) = a_A \cos\left(2\pi(f_A - f_n)t - \left(2\pi(f_A - f_n)\frac{dAm(t)}{c} - H_A\right)\right) + a_B \cos\left(2\pi(f_B - f_n)t - \left(2\pi(f_B - f_n)\frac{dBm(t)}{c} - H_B\right)\right) \quad (2)$$

In the formula, a_A and a_B are the amplitude of the transmitted signal of the anchor node to reach node n; c is the speed of light; H_A and H_B comprehensively consider the initial phase of the anchor node local oscillator and the response of the transmission channel.

Therefore, the received field strength indication (RSSI) signal obtained by node M can be expressed as:

$$2\pi(f_A - f_n)t + H_A - H_B + 2\pi f_B \frac{dBm(t)}{c} - 2\pi f_A \frac{dAm(t)}{c} \quad (3)$$

From Eq. (3), we can see that the frequency of the RSSI signal is $\|f_A - f_B\|$, f_A and f_B are very close (such as a difference of 1kHz), the node can use its own simple equipment to achieve the measurement of the low-frequency interference signal frequency. The advantage of this method is that many chips have RSSI output, the use of low-speed AD can solve the problem of RSSI signal acquisition, without the need to use additional transceiver equipment [9, 10].

2.4 Puhler's Angle Estimation

At a certain moment t , the anchor node A moves at the instantaneous velocity at the (x_p, y_p) axis in the negative direction of the z axis. At this time, the Doppler angle of the node row is the angle θ_n between the line connecting the bamboo and A and the

positive direction of the z axis. Due to the influence of the Doppler effect, the node's RSSI signal produces a Doppler frequency offset. At this moment, the instantaneous frequency of the RSSI signal is $f_{RSSI,n}$. This instantaneous frequency is derived from the interference between anchor nodes A and B on the one hand, It is due to the movement of the anchor node A. The former is the same at each receiving node in the whole network, while the latter is proportional to the cosine of the Doppler angle of the node. The schematic diagram of the Doppler angle of the node is shown in Fig. 3.

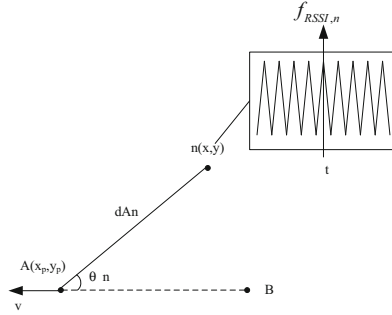


Fig. 3. Doppler included angle diagram

If the frequency of the interference signal at this time and the instantaneous moving speed of the anchor node A are known, then the Doppler angle estimation $\cos \theta_n$ at this time can be obtained by measuring the instantaneous frequency of the RSSI signal. However, because the interference signals formed by the anchor nodes A and B have a certain frequency drift, and the instantaneous movement speed of A has a large instability, the node cannot directly obtain its own Doppler angle by the above formula, which requires additional Two monitoring anchor nodes C and D are added to assist the Doppler angle estimation of the node [11, 12]. At time t, anchor nodes C and D respectively measure the instantaneous frequency of their RSSI signals as

$$f_{RSSI,C} = (f_A - f_B) - \frac{v \cos \theta_C}{\lambda} \tag{4}$$

$$f_{RSSI,D} = (f_A - f_B) - \frac{v \cos \theta_D}{\lambda} \tag{5}$$

Since the positions of the anchor nodes C and D are known, their respective Doppler angles θ_C and θ_D can also be calculated at this time. Therefore, combining the instantaneous frequencies of the RSSI signals of the anchor nodes C and D, an estimate of the interference frequency and the instantaneous moving speed of the anchor node can be obtained.

$$f_A - f_B = \frac{f_{RSSI,C} \cos \theta_D - f_{RSSI,D} \cos \theta_C}{\cos \theta_D - \cos \theta_C} \quad (6)$$

$$v = \frac{\lambda(f_{RSSI,C} - f_{RSSI,D})}{\cos \theta_D - \cos \theta_C} \quad (7)$$

Substituting $f_A - f_B$ and v in the above formulas (4) to (7) into the formula for estimating the angle of the node Doppler can be obtained:

$$\cos \theta_n = \frac{\cos \theta_D (f_{RSSI,C} - f_{RSSI,D}) - \cos \theta_C (f_{RSSI,D} - f_{RSSI,C})}{(f_{RSSI,C} - f_{RSSI,D})} \quad (8)$$

To sum up, with the help of anchor nodes C and D, each node can estimate its Doppler angle by measuring the instantaneous frequency of RSSI signal.

2.5 Node Positioning

Since the unknown node receives the GPS broadcast information of the mobile anchor node in real time, the CPS information at the vertical foot (P, Q in Fig. 1) of the mobile path and the vertical line of the unknown node and the moving direction of the mobile node can be obtained. The mobile anchor node moves along the route shown in Fig. 1. The GPS information of perpendicular P and Q can be obtained by the method introduced in part 3. The intersection of two perpendicular lines is the position of unknown node. Let the unknown node coordinates (x, y) , P-point coordinates (P_x, p_y) , q-point coordinates (Q_x, Q_y) , M1 and M2 be the slopes of the two flight paths respectively, and then we can get formula (9), and then we can get the node position by solving formula (9).

$$\begin{bmatrix} 1 & m1 \\ 1 & m2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} m1p_y, p_x \\ m2q_y, q_x \end{bmatrix} \rightarrow a \times D = b \quad (9)$$

In the formula, a and b are called positioning matrix.

In order to improve the positioning accuracy of the network, the least squares method can be used to estimate the multiple results after making multiple intersections and movements in the unknown node area. $A = [a_1 \dots a_n \dots a_N]^T$ and $B = [b_1 \dots b_n \dots b_N]^T$ are the positioning matrices determined by the intersection and movement. This method uses interference to measure frequency, and the nodes only need to measure low-frequency interference signal, which reduces the complexity of the equipment hardware; through the difference of the received frequency, it can simply and effectively eliminate the influence of frequency offset; and it uses multiple flight positioning to improve the accuracy of positioning. In the whole positioning process, the unknown node only receives the high-power broadcast signal of the anchor node from a long distance without sending, and the energy consumption is low, which is suitable for positioning in a large-scale network.

3 Experimental Analysis

3.1 Experimental Environment

Due to the lack of experimental conditions in real sensor network environment, this paper chooses to use simulation software to simulate the node positioning process. The experimental environment is MATLAB, version 7.0. Matlab is an integrated experimental environment developed by Math Works of the United States for conceptual design, algorithm development, modeling and simulation and other purposes. It has a wide range of applications, including aerospace, medicine, finance, education and other fields. It has become the first choice for scientific computing, modeling and simulation, and information engineering system design and development.

3.2 Node Distribution and Initialization

Matlab environment can produce a random distribution topology in a specific area. In this paper, we specify a square with boundary value of 100. The nodes are randomly distributed in this square area. We can regard this area and the nodes in it as the practical application environment of wireless sensor network. For each node, it needs to be initialized. This information is indispensable for positioning using the CDLI algorithm. Because the randomly generated nodes themselves have coordinates, these coordinates need to be stored and correspond to the serial numbers of the nodes. This experiment uses a Sxy matrix to store this information. The coordinates of beacon nodes and unknown nodes need to be distinguished when the algorithm is implemented, so the coordinates of these two types of nodes are stored in two different matrices respectively. Of course, the coordinates of unknown nodes are not allowed to be used except for calculating the positioning error in the last step. Because the nodes are generated by MATLAB in the experiment, the coordinates of unknown nodes can be obtained, but In the practical application environment, we need to determine the coordinates of unknown nodes, which are unknown in advance. In the experiment, the final use of the coordinates of unknown nodes is to verify the positioning accuracy of the algorithm. When calculating the average distance per hop of the beacon node, the algorithm needs to use the distance information between the beacon nodes. Because the position of the beacon node has been determined, the distance can also be calculated accurately. Distance information. In addition, because matlab does not have the function to describe the communication signal transmission, the hop number is used to measure the distance between nodes, and the matrix is used to store the hop information between nodes. In the initial calculation of the hop number, the node coordinate information stored in the front, including the unknown node coordinates, needs to be used. In practical application, the sending and arriving of the communication signal can be segmented in the MATLAB experiment, the judgment is based on the distance between the unknown node and other nodes. If the distance is less than the communication radius, the corresponding node is in the range of the unknown node. After initialization, the shortest path algorithm is needed to calculate the number of hops between nodes.

3.3 Storage of Node Information

According to the characteristics of MATLAB experimental environment, node information is stored by matrix, and the data operation of node information is also based on matrix. The key of storage is to change the row and column labels of matrix correctly according to the specific requirements. For example, for a matrix storing the distance between beacon nodes, assuming that the number of beacon nodes is the number of beacons, the number of rows and columns of the matrix is scalar; for the matrix that stores the coordinates of beacon nodes, the number of rows and columns is 2 And Beacon Amount.

3.4 Upgrading Secondary Beacons of Unknown Nodes

In the location algorithm, the unknown nodes that have been located are regarded as beacon nodes, and continue to participate in the location of other unknown nodes, which are called secondary beacon nodes. In the experiment in this paper, a matrix Beacon1 is set, which initially stores the coordinates of all beacon nodes. As the positioning progresses, some unknown nodes determine their own coordinates. These coordinates are added to the Beacon1 matrix. The centroid algorithm is used for positioning The beacon node in this matrix, of course, includes the original beacon node and the secondary beacon node. The unknown nodes upgrading to secondary beacons need to broadcast packets with their own location information to other unknown nodes, which will consume a certain amount of energy. However, the cost of common nodes is far lower than that of beacon nodes, and this paper focuses on the energy saving of beacon nodes, so the increase of energy consumption of common nodes is acceptable.

3.5 Evaluation Performance Index of Positioning Algorithm

The location accuracy is an important performance index for evaluating the location algorithm. The high location accuracy of an algorithm determines that the algorithm has at least some practical application value. As for whether it can be put into use on a large scale, it is necessary to analyze the network characteristics and other performance of the algorithm. However, if the positioning accuracy of a positioning algorithm is not satisfactory, then no matter how good the other performance is, it is impossible to apply it to actual positioning alone. Generally speaking, when investigating a positioning algorithm, we should first pay attention to its positioning accuracy. Only when the positioning accuracy is guaranteed, will we evaluate other performance indicators of this algorithm, and then consider applying it to practice.

The positioning accuracy is judged by the positioning error. The smaller the positioning error is, the higher the positioning accuracy is. The calculation formula of positioning error of unknown node i is as follows:

$$E(i) = \frac{\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}}{R} \quad (10)$$

Among them, (x_1, y_1) is the actual position of node i ; (x_2, y_2) is the estimated position of node i ; R is the communication radius of node i .

Assuming that there are M nodes in the network, N of which are anchor nodes ($i = 1$ to $i = N$ are anchor nodes and $i = N + 1$ to $i = M$ are unknown nodes), then the average positioning error of all unknown nodes is as follows:

$$E' = \frac{\sum_{i=N+1}^M E(i)}{M - N} \quad (11)$$

The following is a comparison of the performance of the DV-Hop algorithm, AOA algorithm, and the algorithm in this paper from the perspective of positioning accuracy and network coverage.

3.6 Result Analysis

200 nodes randomly distributed in a $100 \text{ m} \times 100 \text{ m} \times 100 \text{ m}$ cube network are used for simulation experiments, of which 20 nodes are anchor nodes and the rest are unknown nodes. The positioning results are shown in Table 1.

Table 1. Location result analysis ($r = 15$).

Positioning error	Number of nodes
≤ 0.1	15
0.1–0.5	20
0.5–1.0	25
1.0–1.5	30
≥ 1.5	40

It can be seen from Table 1 that the algorithm in this paper has high positioning accuracy, all unknown nodes can be located and the positioning error is small, so the algorithm has ideal effect in optimizing positioning.

(1) Positioning accuracy under different number of anchor nodes.

As shown in Table 2, when the node communication radius $R = 16$, and the number of anchor nodes N gradually increases from 1 to 50, the positioning accuracy

Table 2. Average positioning error under different number of anchor nodes.

Project	Number of anchor nodes 20	Number of anchor nodes 30	Number of anchor nodes 50
Algorithm in this paper	0.465	0.431	0.237
DV hop algorithm	0.604	0.442	0.324
AOA algorithm	0.623	0.601	0.452

of the three algorithms is improved. As the number of reference nodes and the number of test triangular pyramids increase, the estimation range of unknown node positioning is reduced, and the positioning accuracy is naturally improved. In addition, anchor nodes have a direct impact on the possibility of node location. When the number of anchor nodes is small, the positioning accuracy of this algorithm is obviously better than DV hop algorithm and AOA algorithm. This algorithm improves the division of positioning modules, reduces the estimation range of positioning, and speeds up the positioning speed. The estimated range of positioning can be reduced to half of other algorithms. More importantly, the algorithm in this paper can solve the situation where it cannot be located, so the positioning accuracy has been greatly improved.

Table 3. Average positioning error under different communication radius

Project	Communication radius 10	Communication radius 20	Communication radius 30
Algorithm	0.812	0.475	0.263
DV-Hop algorithm	1.402	0.604	0.512
AOA algorithm	1.493	0.925	0.553

(2) Positioning accuracy under different communication radius.

As shown in Table 3, when the number of anchor nodes $n = 18$, and the communication radius r of nodes gradually increases from 1 to 30, the average positioning errors of the three algorithms are rapidly reduced. This is because the increase in R allows unknown nodes to communicate with more anchor nodes, so the number of test pyramids continues to increase and the estimated range of nodes gradually decreases. As the size of the communication radius of the node has a significant impact on the positioning accuracy, it can be concluded that the positioning accuracy of this algorithm is significantly better than DV hop algorithm and AOA algorithm. With the increase of R , the number of anchor nodes within the one-hop communication range will also be greater, and the number of test pyramids obtained by the algorithm in this paper will also be greater.

In order to further verify the effectiveness of the method in this paper, the positioning time of radio frequency signal of wireless sensor network based on the proposed method and the traditional method is compared and analyzed. The comparison results are shown in Fig. 4.

According to Fig. 4, the positioning time of radio frequency signal in wireless sensor network of this method is within 30 s, while that of traditional method is within 60 s, which shows that the positioning time of radio frequency signal in wireless sensor network can be shortened by using this method.

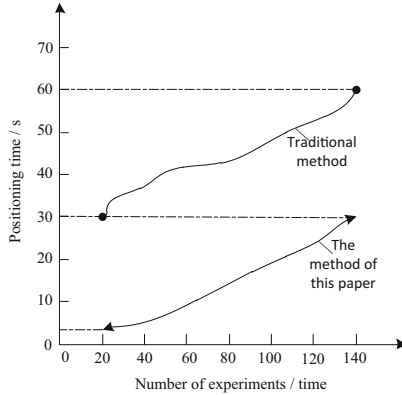


Fig. 4. Positioning time comparison results

4 Conclusion

In summary, this article elaborated on the principles and methods of interferometric positioning, and simulated and analyzed the interferometric positioning algorithm to verify the feasibility of the algorithm and analyze the factors that affect the accuracy. The location method of WSN based on interference effect can realize distributed location only by measuring the received signal phase at each receiving node. It has the advantages of simple equipment, high positioning accuracy and low power consumption. It is a better method. Of course, compared with other positioning algorithms, this algorithm has higher time complexity and increased network energy consumption. Future research directions should focus on reducing the energy consumption required for positioning while improving positioning accuracy and network coverage.

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