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MEC-MS: A Novel Optimized Coverage Algorithm with Mobile Edge Computing of Migration Strategy in WSNs

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Abstract. The traditional network coverage mode with the cost of deploying a large number of sensor nodes has poor coverage effect. Aiming at this problem, this paper proposes a Novel Optimized Coverage Algorithm with Mobile Edge Computing of Migration Strategy (MEC-MS). First, the algorithm uses the network coverage model to give the expression method of the distance measurement and the judgment conditions of the best and worst paths. Secondly, it analyzes the necessary conditions for improving the coverage quality and the prerequisite for the existence of redundant coverage for adjacent the redundant coverage nodes by the theory of probability. Thirdly, using the precondition of redundant coverage, we give the calculation process of the sensor nodes own redundant coverage and the calculation method of the redundant node coverage expectation. Finally, the algorithm compares the number of working sensor nodes with the other two algorithms under different parameters. The experimental results show that the average number of working sensor nodes in the MEC-MS algorithm is 9.74% lower than that of the other two algorithms, and the average value of network coverage is 9.92% higher than that of the other two algorithms, which verify the effectiveness of the algorithm in this paper.

Keywords: wireless sensor networks, mobile edge computing, migration strategy, optimization coverage,networks lifetime.

1. Introduction

Wireless sensor network is a large self-organizing network that organically integrates the physical and information world, and is also an important carrier for human society to perceive the physical world and the information world [1-5]. Wireless sensor networks have been widely used as the underlying perception system of the Internet of Things, and their applications are mainly concentrated in the fields of military and national defense, safety production, intelligent industry, environmental monitoring, emergency rescue and

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medical and health. Optimizing coverage is a key issue in the research field of wireless sensor networks. The quality of coverage directly affects the quality of other performance indicators of wireless sensor networks, such as random deployment, route backup, and target tracking [6-9]. In the process of optimizing coverage, the solution to the coverage problem is mainly focused on the following fields.

Firstly, how to use the least number of sensor nodes to cover the largest monitoring area under a random deployment environment. Secondly, how to effectively improve the coverage under the premise of meeting a certain connectivity coverage effective coverage of the target nodes of interest. Thirdly, how to resist the energy consumption of sensor nodes under the premise of ensuring transmission quality to extend the network life time. Fourth, in the monitoring area, when a large number of working sensor nodes are covered at the same time, how to avoid the emergence of redundant nodes to improve the coverage of the target nodes of interest [10-13]. Therefore, as a basic problem in wireless sensor network research, the coverage problem has attracted the attention of many scholars at home and abroad.

The traditional coverage mode in the sensor network is mainly with the underlying coverage based on the perception layer. The sensor nodes are static, and the basic state information of the target node is obtained through the perception ability. The main shortcomings areas follows. (1) The lack of control nodes in the network makes it impossible to effectively control and manage other sensor nodes. (2) Due to the lack of unified coordination capabilities, there will often be a large number of redundant nodes, thus forming a communication link congestion. (3) There is a phenomenon that a large number of nodes cover the target node at the same time, which speeds up the energy consumption of the node and reduces the accuracy of the effective coverage rate. (4) In the process of data transmission, due to the number of hops from the sensor node to the base station, The network responds slowly to data transmission, which leads to longer data delays and frequent data packet loss. Compared with traditional coverage methods, the advantages of the proposed MS-MEC algorithm in this paper are mainly reflected in the following. Firstly, other nodes can be effectively controlled, organized and managed through controllable nodes, thereby reducing redundant nodes, improving work efficiency and enhances the robustness of the network. Secondly, the state of sensor nodes is effectively scheduled through the node scheduling algorithm. Under the condition of no need to work, shut down some sensor nodes, suppress node energy consumption, and extend the network life time [14-16]. Thirdly, under the premise of meeting a certain effective coverage rate, the sensor nodes in the sensing coverage area can be reasonably scheduled to focus on the target in the process of data transmission, the MS-MEC algorithm in this paper can effectively reduce the number of data transmission link hops, suppress the generation of delay, reduce data packet loss, and improve data transmission effectiveness [17-19]. In general, the coverage problem is based on the coverage model, and the coverage accuracy are improved through a certain calculation method to achieve the purpose of extending the network life time. In terms of the entire monitoring area, we do not need to effectively cover the entire monitoring area, but to effectively cover the target node of interest to improve the accuracy of the coverage rate. In order to better study the problem of optimized coverage, this article puts forward the Optimized Coverage Algorithm with Mobile Edge Computing of Migration Strategy in WSNs (MEC-MS) which is based on the research background of mobile edge computing and node migration strategy. The main contributions of this article include the following aspects.

(1) Chapter Two, this article mainly analyzes and studies related work, and gives the advantages and disadvantages of different documents. Solutions and measures are proposed for the deficiencies of related documents.

(2) In Chapter Three, this article gives relevant hypotheses and basic definitions, and then, establishes and analyzes the coverage model, and gives the analysis process at the same time. And also introduces relevant parameters to optimize the coverage model.

(3) In Chapter four, the process of sensor node coverage is calculated and reasoned by the change of related parameters and the implementation and analysis process of the MS-MEC algorithm are also presented.

(4) In Chapter five, the characteristics of the sensor network is compared by simulation experiments, and the comparison experiment process and analysis process are given, so as to further illustrate the effectiveness and stability of the MS-MEC algorithm in this paper.

(5) Chapter six summarizes the full text and points out the key tasks in the future.

2. Related Works

As an important subject in the field of sensor network research, the coverage problem has attracted the attention of many scholars at home and abroad, and a series of related studies have been carried out, and some very important results have also been achieved. With the rapid development of theoretical knowledge and practical applications of sensor networks, higher requirements are put forward for sensor network coverage [20-21]. Such as, how to quickly and accurately cover the moving target node, how to achieve unified control of heterogeneous sensor networks and effective coverage of local locations in the monitoring area, etc. In the process of collecting data, sensor nodes are forced to make a large number of rapid responses to deal with various situations due to the diversity of data and some irresistible factors in the process of data transmission. Only by effectively covering the target node can we provide accurate data for our next research.

2.1. Linear Coverage Problem

Literature [22] uses the sensor nodes perception ability to directly cover the target node. When the target node moves at random time, the sensor node wakes up its neighbor nodes through perception control to complete the continuous coverage of the target node. Literature [23] proposed an Event-driven Mechanism Coverage Algorithm Based on Sensing-cloud-computing in Heterogeneous Sensor Networks (EMC-SC). Firstly, the algorithm uses the network coverage model to calculate the boundary relationship between the peer square and the sensor node coverage area. Secondly, the authors analyze the coverage performance of randomly deployed sensor nodes through the Poisson distribution model, and further calculate the probability of effective coverage of the monitored area. Thirdly, the coverage rate of the target node is determined according to the distance relationship between neighbor nodes and sensor nodes and the energy of the remaining sensor nodes. Literature [25] uses the neighboring nodes perception ability to linearly cover the target node, and uses a geometric-based calculation method to complete the monitoring area coverage, and at the same time, the solving process for the required minimum number of sensor nodes is present. Literature [26] uses a virtual grid division method to effectively divide the monitoring area and uses time series to periodically cycle the coverage period of sensor nodes. The purpose of this algorithm is to find the best matching position information in each time sequence to achieve effective coverage of the target node. After N cycles, the algorithm uses an adaptive function to adjust the optimal distance between the sensor node and the target node to achieve accurate coverage, thereby it improves the adaptive capability and coverage efficiency of WSN. Literature [27] adjusts the sensing range by adjusting the transmit power of sensor nodes to achieve coverage. The algorithm first judges the distance relationship between the sensor node and the target node. If the distance between the sensor node and the target node is more than twice the sensing radius, the sensor nodes transmitting power is increased, and vice versa. When the transmit power is greater than or equal to the threshold, and the target node still cannot be covered, the sensor node is turned off to save energy. Literature [28] divides the monitoring area into multiple equilateral triangle areas while discussing effective coverage, so that any sensor node is at the apex of the equilateral triangle and gives the proof process of the relevant maximum coverage theorem. Literature [29] proposed a division method that divides the monitoring area into multiple concentric circles and squares. Through the parameter relationship between the sensing radius and the communication radius, the connected coverage ratio function is given and proved, and the maximum coverage rate of the monitoring area is finally obtained. Literature [30] proposed a diamond-shaped coverage model in which each sensor node is placed on the vertex of the diamond to ensure the monitoring of the diamond-shaped coverage area. The sensor nodes perception and communication capabilities can achieve effective coverage of the diamond-shaped coverage area. For the entire area, iterating the above process will complete the effective coverage of the entire area. Literature [31] discussed a maximum coverage algorithm based on the dominating set under the premise of satisfying the connected coverage rate. The algorithm completes the effective coverage of the monitoring area by means of adjacent nodes forming an adjacency graph, and combines the characteristics of random deployment to give the network topology of the mobile sink node in the data collection process. Literature [32] proposed a data-centric coverage control algorithm. The algorithm uses the idea of data center based on the multiple relationship of the step length of the perception radius, gradually expands to the periphery, and finally achieves effective coverage of the whole world through the collaborative work of adjacent nodes. Literature [33] studied the energy conversion mechanism under the premise of satisfying the coverage rate. The energy conversion process and algorithm realization process of sensor nodes in the coverage process are given. This model successfully completes the energy conversion of sensor nodes and prolongs the network life time.

2.2. Non-linear Coverage Problem

Literature [34] discussed the continuous coverage of target nodes along a certain trajectory. The proposed algorithm proves the constraint condition of the continuous coverage of sensor nodes, and to a certain extent ensures the local effective coverage of the entire monitoring area. Literature [35] gives a centralized k-degree coverage model. The model proves the solution process of the minimum number of sensor nodes required for k under different value ranges, and proves that the functional relationship between the communication radius and the sensing radius when the monitoring area is effectively covered, and the expected value of the number of sensor nodes is formulated by using the sensor node density. Literature [36] takes the network life time as the research background and proposes a discrete coverage algorithm based on k degree. The algorithm sets the conditions for the existence of the upper and lower limits of the discrete coverage rate. In terms of network energy consumption, the algorithm uses the state transition mechanism of sensor nodes to schedule sensor nodes in different states to complete effective coverage of target nodes. Literature [37] completed the effective coverage of the target node with integer programming method. The algorithm is based on a heuristic algorithm and studies the collective membership of the sensor node set and the target node to realize the heuristic coverage algorithm. At the same time, the high-density sensor node is used to construct a coverage set to complete the coverage of the moving target node. Literature [38] uses artificial bee colony and particle swarm algorithm to convert different states of sensor nodes, thereby completing the uninterrupted conversion of sensor node states and realizing the process of covering moving targets. The algorithm also gives the best plan for deploying sensor nodes. Literature [39] proposes an efficient and energy-saving connectivity coverage routing algorithm. The algorithm divides the monitoring area twice, uses the knowledge of probability theory to calculate the network coverage, and finally achieves effective coverage of the moving target node. Literature [40] uses ant colony algorithm to optimize the deployment of sensor nodes. Through the ant colony algorithm, the entire network is continuously traversed and searched. And then the partial optimization of the entire monitoring area is realized, thereby expanding to the entire network monitoring area.

3. Related Definitions and Network Models

In order to better study the network coverage problem and simplify the complexity of calculation, this paper makes the following assumptions.

(1) All sensor nodes have a unique identification ID and show a disc shape.

(2) In the monitoring area, the sensor node density is large enough and boundary effects are ignored.

(3) The length of the boundary of the monitoring area is much longer than the sensor nodes sensing radius.

(4) The location information of all sensor nodes is acquired through a certain positioning algorithm, Such as: RSSI positioning algorithm.

Definition 1:(Sensing neighbor set) The set formed by the distance between any two sensor nodes less than or equal to the sum of the sensing radius.

$$S\left(n\right)=\left\{\left(i,j\right)\left|d\left(i,j\right)\leq r_i+r_j,i\neq j\right.\right\} \tag{1}$$

where $S(n)$ is the set of perceptual neighbors, $d(i,j)$ is the distance between any two sensor nodes, r_i and r_j are the sensing radius of sensor node *i* and sensor node *j*, respectively.
Definition 2: (Joint Coverage Ratio) In the monitoring area, the ratio of the coverage area of all sensor nodes to the area of the monitoring area.

$$p\left(s,A\right)=\sum_{i=1}^{n}s_i\bigg/S\left(A\right) \tag{2}$$

where s_i is the area covered by any sensor node, n is the number of sensor nodes; $S(A)$ represents the area of the monitoring area.

Definition 3: (Effective coverage area) In the monitoring area, the difference between the area of any sensor node and the coverage area of adjacent sensor nodes.

$$S_{ec}=\sum_{i=1,j=1}^{n}\left(\left(s_i\cup s_j\right)-\left(s_i\cap s_j\right)\right) \tag{3}$$

where s_i and s_j respectively represent the area covered by any sensor node i and sensor node *j*, *n* represents the number of sensor nodes, S_{ec} represents the effective coverage area.

Definition 4: (Effective Coverage Rate) The ratio of the effective coverage area to the area of the monitoring area.

$$p_{ec}=\sum_{i=1,j=1}^{n}\left(\left(s_i\cup s_j\right)-\left(s_i\cap s_j\right)\right)\bigg/S\left(A\right) \tag{4}$$

Definition 5: (Network Life time) The longest time for the sensor network to work and run is called the network life time.

Definition 6: (Perception probability) According to the sensor nodes perception ability, the probability that any target node in the monitoring area is covered by the sensor node.

$$p=\begin{cases}0 & r_i\leq d\left(s_i,s_j\right)\\ \varepsilon^{-\alpha d} & r_i-r_e<d\left(s_i,s_j\right)<r_i\\ 1 & d\left(s_i,s_j\right)\leq r_i-r_e\end{cases} \tag{5}$$

where, $d(s_i,s_j)$ represents the Euclidean distance between the sensor nodes s_i and s_j, α represents the physical characteristic parameter, and r_e represents the variable parameter of the sensor node in the monitoring area.

3.1. Network Model Analysis

When a moving target node traverses the monitoring area, each sensor node on its traversing path will cover or monitor it. When the moving target node is traveling, the coverage density of each sensor node to the moving target node is different. The deployment of high-density sensor nodes indicates that the moving target node can be covered in the network with a higher probability, conversely, the low-density sensor node has a low coverage probability for moving target nodes, which further shows that moving target nodes are not easily exposed in a low-density deployment environment. Therefore, seeking an effective continuous coverage is an important subject of sensor network research, which is shown in Figure 1.

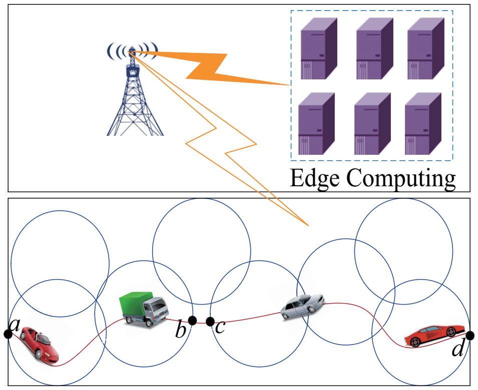

Fig. 1. The exposed discontinuous overlay network model

Figure 1 shows the exposed discontinuous overlay network model. It can be seen from Figure 1 that the trajectory of the moving target node is $a \rightarrow b \rightarrow c \rightarrow d$, and the moving target can be continuously covered by the sensor node in $a \rightarrow b$ and $c \rightarrow d$, and the moving target node in $b \rightarrow c$ is exposed to discontinuous coverage.

An effective way to solve the problem of sensor network coverage is to use the sensory characteristics of the sensor network to effectively cover the moving target node. Therefore, this paper proposes an optimized coverage algorithm (MEC-MS) based on mobile edge computing migration strategy. In the traditional coverage problem, the characteristic relationship between the coverage performance and the network life time is mainly studied. However, due to the limitation of the network space dimension, the traditional method cannot establish the complete geometric relationship between the multi-dimensional targets, and the research faces some uncertainty. In geometric space, the inner and outer products of vectors are expressed as follows.

$$a \cdot b = (ab + ba)/2 \tag{6}$$

$$a \times b = (ab - ba)/2 \tag{7}$$

where *a* and *b* are space vectors,$\times$ is not a multiplication sign, but also denoted as $\wedge$, the vertical component of the vector *a* is as follows.

$$a_{\perp} = a \times B/B \tag{8}$$

where $a_{\perp}$ is the vertical component of vector *a*, which is also the orthogonal complement of vector *a*, *B* is a reversible homogeneous order, corresponding to the number of adjacent sensor nodes.

Definition 7: (distance measurement) In geometric space, the distance between any two sensor nodes can be expressed as follows.

$$dist\left(s_i, s_j\right) = \left\|d_i - d_j\right\| \tag{9}$$

where d_i and d_j can be expressed as follows.

$$d_i = d\left(i, j\right) - s_{i\perp} \tag{10}$$

$$d_i = d\left(i, j\right) - s_{j\perp} \tag{11}$$

Substituting formula (8), formula (10) and formula (11) into formula (9), we can get the following formula (12).

$$dist\left(s_i, s_j\right) = \left(s_{i\perp} - s_{j\perp}\right) \times B/B \tag{12}$$

For a single node, we can change the above formula (12)

$$dist\left(s_i, s_j\right) = \left(s_{i\perp} - s_{j\perp}\right) \times B/B \tag{13}$$

By the above analysis, it can be seen that for the spatial coverage model, the distance between any point s_i and the target node s_t can be expressed by formula (13). In addition, when the value of B increases, the neighboring nodes of the sensor node s_i also increase, thus it forms an uninterrupted coverage chain to complete continuous coverage of the moving target node. In order to further increase the flexibility and diversity of the formula, we introduce the proportional dimension λ ($\lambda \in [0,1]$) for formula (13). We can adjust the distance measure of formula (13) by the controllability of λ.

$$D' = s_i \times B/B + \lambda B \tag{14}$$

$$D = \left(s_i - s_{i\perp}\right) \times B/B + \lambda B \tag{15}$$

Theorem 1: In the network space sensor node set *S*, there is at least one best path located in the edge set of the Voronoi graph.

Proof: In the Voronoi graph of the cyberspace sensor node set *S*, there is an edge set S_q in the Voronoi graph. According to the circle circumcenter theorem, there is a sensor node s_k that must fall on the vertical line of the edge set. It can be seen from formula (14) that the distance of this point is the smallest and the orthogonal complement between the vector in the orthogonal set corresponding to any points on the side S_q and s_k is also the smallest. In the same way, the other two sides of the triangle will repeat the above operation, and the minimum value of orthogonal set will also be obtained. Therefore, in the sensor node collective *S*, there must be an optimal path located in the edge set of the Voronoi graph. The proof is complete.

Theorem 2: In the network space sensor node set S, at least one path with the worst gap is located in the edge set of Delaunay Triangulation.
Proof: As shown in Figure 2, assuming the $P_m \in$ Delaunay Triangulation, the sensor nodes s_i and s_j are respectively at the two ends of the diameter of the sensor node s_c, and their coverage area is a solid line area, and the sensing radius distance of the area is measured as $(d_i - d_j)^d/d$, where d is the average of the unit vector measurement.
Discussion 1: In the common area covered by s_i and s_j, if there are no other sensor nodes except s_c, then there are sensor nodes s_i and s_j that do not include the coverage ‘sensing area of other sensor nodes. According to the nature of Delaunay Triangulation, the sensor node s_i and s_j must be connected by an edge of the Delaunay Triangulation, which contradicts the assumption.
Discussion 2: If there are other sensor nodes s_p in addition to s_c in the common area covered by s_i and s_j, the edge set can be regarded as ip and jp, and ip and jp can be substituted for ij, then ij is not the edge formed by the nodes with largest distance measure, i.e., p is not the worst gap path, which contradicts the assumption.
The proof is complete.

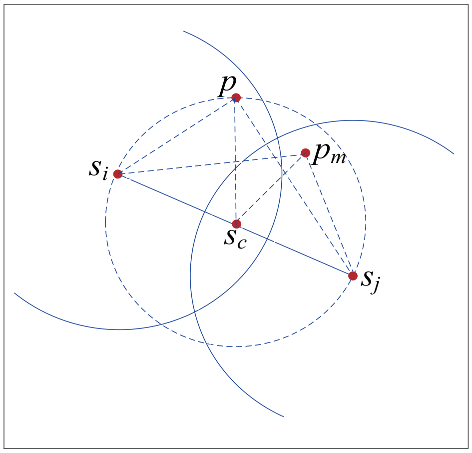

Fig. 2. Covering the worst gap path

4. Solution and Algorithm Analysis

Traditional sensor network coverage mainly achieves coverage of moving target nodes by adjusting the distribution of sensor node power to spatial location. Currently, network coverage is one of the basic problems that must be solved in network operation. Network interconnection mainly focuses on the connection between nodes, so that data can be transmitted from one node to another; while the coverage of sensor networks mainly reflects the sensor network’s perception ability and network service quality. But its concerns are different with traditional network coverage. From the perspective of network perception of the physical world, its main focus is on the location distribution of network nodes and the completion of effective coverage of target nodes under the conditions of coverage application. The main purposes of coverage control are as follows. (1) Optimizing sensor network coverage. (2) Reasonably allocating network space resources. (3) Better completing data perception and information collection. (4) Extend the network life time. With the help of the definition of perceptual probability, let us further analyze the proportional relationship between coverage membership function and coverage intensity.

4.1. Coverage Quality Analysis

Definition 8 (coverage intensity) In the monitoring area, the location information of a certain sensor node s_i is (x_i, y_i), and the location information of any target node p is (x, y), then the intensity from the coverage of the sensor node s_i to the target node p is defined as $I(s_i, p)$, which is represented by the membership function $F(x, y)$ as shown in formula (16).

$$I\left(s_i, p\right) = F\left(x, y\right) \tag{16}$$

Where the value range of $F(x, y)$ is in the closed interval of [0,1], and $F(x, y)$ reflects the coverage membership relationship of the target node p to the sensor node s_i.
Definition 9 (redundant coverage) In the monitoring area, the sensor set S composes with sensor nodes s_i, the proportion of the sensing area covering itself is called the redundant coverage.

$$p\left(s_i\right) = \frac{\sum_{s_i \in S}\left(s_i \cap s_j\right)}{s_i} \tag{17}$$

Since a large number of sensor nodes are randomly deployed in the monitoring area, and the Euclidean distance between any two or more adjacent sensor nodes is less than or equal to the sensing radius, and then the redundant nodes will appear. Then, after multiple cycles, the number of redundant nodes will greatly increase. When the redundant nodes with higher energy is started again, the redundant node will cover the target node only under certain limited conditions, i.e., when the redundant node changes from the sleep state to the working state, it must be greater than or equal to the current coverage threshold, otherwise the redundancy is still in the sleep state.
Theorem 3: The redundancy coverage of n adjacent redundant coverage nodes of sensor node s_i needs to satisfy the following condition.
$p\left(n\right) = 1 - \left\{1 - \frac{1}{\pi}\left[\frac{\pi}{4} - \frac{\lambda\sqrt{4-\lambda^2}}{8} + \frac{\lambda^2}{2}\arccos\left(\frac{\lambda}{2}\right) - \frac{\lambda^3\sqrt{4-\lambda^2}}{16}\right]\right\}^n$
Where λ is a controllable parameter, $\lambda \in [0, 1]$.
Proof. As shown in Figure 3, we suppose that the angle between any two sensor nodes B and C sensing radius lining and the intersection of the two circles is α. According to the uniform distribution characteristics of the redundant nodes, when the effective coverage area reaches the maximum value, the redundant coverage rate simultaneously reaches the maximum value. We suppose that the proportional relationship between the communication radius and the sensing radius is λ, i.e., $R = \lambda r$, λ is a controllable parameter. The distance L between the sensor node S_i and S_j is a random variable, which can be known

from the probability density formula as follows.

$$f_L\left(x\right) = \frac{2x}{\lambda^2 r^2} 0 \le x \le \lambda r \tag{18}$$

The area of the intersection area between the sensor node S_i and S_j is shown in formula (19).

$$S = \left(2\alpha - \sin 2\alpha\right) r^2 \tag{19}$$

The distance of the intersecting area is shown as follows.

$$l = 2r\cos\alpha \tag{20}$$

$$\mathrm{d}l = 2r\sin\alpha\mathrm{d}\alpha \tag{21}$$

where $\alpha \in \left[\arccos\frac{\lambda}{2}, \frac{\pi}{2}\right]$
We substitute formula (19) and (20) into the probability density formula can be obtained the following formula.

$$\begin{aligned} p_1 &= \int_{\frac{\lambda}{2}}^{\arccos\frac{\lambda}{2}} \left(2\alpha - \sin 2\alpha\right)\tfrac{4r^2\cos\alpha}{\lambda^2}\sin\alpha\mathrm{d}\alpha \\ &= \tfrac{1}{\pi}\left[\tfrac{\pi}{4} - \tfrac{\lambda\sqrt{4-\lambda^2}}{8} + \tfrac{\lambda^2}{2}\arccos\tfrac{\lambda}{2} - \tfrac{\lambda^3\sqrt{4-\lambda^2}}{16}\right] r^2 \end{aligned} \tag{22}$$

The neighbor node redundancy coverage rate for any redundant node can be expressed as follows.

$$p_2 = \frac{p_1}{\pi r^2} = \frac{1}{\pi^2}\left[\frac{\pi}{4} - \frac{\lambda\sqrt{4-\lambda^2}}{8} + \frac{\lambda^2}{2}\arccos\frac{\lambda}{2} - \frac{\lambda^3\sqrt{4-\lambda^2}}{16}\right] \tag{23}$$

Under the knowledge of probability, when n sensor nodes cover any target node, the resulting redundant coverage is shown as follows.

$$p\left(n\right) = 1 - \left\{1 - \frac{1}{\pi^2}\left[\frac{\pi}{4} - \frac{\lambda\sqrt{4-\lambda^2}}{8} + \frac{\lambda^2}{2}\arccos\frac{\lambda}{2} - \frac{\lambda^3\sqrt{4-\lambda^2}}{16}\right]\right\}^n \tag{24}$$

The proof is complete.

Corollary 1: For a given sensor node S_i, its own redundancy coverage satisfies the following condition.
$p\left(s_i\right) = 1 - \prod_{i=1}^{s_i \in S}\left(1 + \frac{\lambda\sqrt{4-\lambda^2}}{2\pi} - \frac{2\arccos\frac{\lambda}{2}}{\pi}\right)$
Proof: As shown in Figure 3, we assume that the distance between sensor nodes B and C is λ times than the sensing radius, the following relationship can be obtained.

$$\left\|S_B - S_C\right\| = \lambda r \tag{25}$$

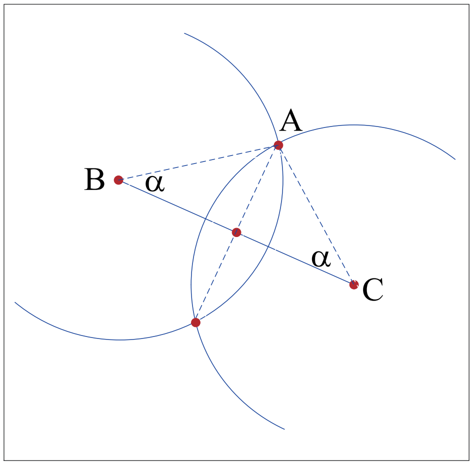

Fig. 3. Schematic diagram of redundant coverage of any adjacent sensor node

According to the trigonometric formula, we can obtain the following relationship.

$$\alpha = \angle ABC = \angle ACB = \arccos \frac{\lambda}{2} \tag{26}$$

The area of the intersection of sensor node B and C is shown as follows.

$$A_{(s_B, s_A)} = 2\alpha r^2 - \lambda r^2 \sin \alpha \tag{27}$$

The calculation for formula (27) can be obtained as follows.

$$A_{(s_B, s_A)} = 2r^2 \arccos \frac{\lambda}{2} - \frac{\lambda r^2 \sqrt{4-\lambda^2}}{2} \tag{28}$$

In the monitoring area, the probability of any point being covered by s_i is as follows.

$$p_i = \frac{A_{(s_B, s_A)}}{\pi r^2} = \frac{2r^2 \arccos \frac{\lambda}{2} - \frac{\lambda r^2 \sqrt{4-\lambda^2}}{2}}{\pi r^2} = \frac{4 \arccos \frac{\lambda}{2} - \lambda \sqrt{4-\lambda^2}}{2\pi} \tag{29}$$

In the monitoring area, the redundant coverage rate of a certain point covered by the sensor node s_i is as follows.

$$p\left(s_i\right) = 1 - \prod_{i=1}^{s_i \in S} \left(1 - p_i\right) = 1 - \prod_{i=1}^{s_i \in S} \left(1 - \frac{4 \arccos \frac{\lambda}{2} - \lambda \sqrt{4-\lambda^2}}{2\pi}\right) \tag{30}$$

Simplifying formula (30) can be obtained as follows.

$$p\left(s_i\right)=1-\prod\nolimits_{i=1}^{s_i\in S}\left(1+\frac{\lambda\sqrt{4-\lambda^2}}{2\pi}-\frac{2\arccos\frac{\lambda}{2}}{\pi}\right) \tag{31}$$

The proof is complete.

The purpose of sensor network coverage optimization is mainly embodied in the premise of ensuring a certain connectivity coverage rate, it uses the least sensor nodes to complete the largest area coverage in the monitoring area, thereby it will achieve the real-time network communication and maximizing the network life time.

In the actual application process, the location information of the mobile target node within the sensing range of the sensor node is often collected, analyzed and calculated in real time, which requires the sensor node to accurately cover the mobile target node, quantitative analysis of the sensor node coverage expectation and network coverage.

Theorem 4 is based on the research of Theorem 3, with the help of probability related knowledge, it derive and calculate the expected value of sensor node coverage.

Theorem 4: In the square monitoring area, the expected coverage of the sensor nodes is not greater than $E(X) = NP(n)$, where N is the number of sensor nodes and n is the number of working sensor nodes.

Proof. In the square monitoring area, n is the number of working sensor nodes, and $N-n$ is the number of sleeping sensor nodes. Therefore, the random variable leastways satisfies $((N-n), P(n))$ quadratic distribution .

$$P\left\{X=n\right\}=\begin{bmatrix}N-n\\ n\end{bmatrix}P^{n}\left(n\right)\left[1-P\left(n\right)\right]^{N-n} \tag{32}$$

$$E\left(X\right)=\sum\nolimits_{n=1}^{N}nP\left\{X=n\right\}=\sum\nolimits_{n=1}^{N}n\begin{bmatrix}N\\ n\end{bmatrix}P^{n}\left(n\right)\left[1-P\left(n\right)\right]^{N-n} \tag{33}$$

$$\sum\nolimits_{n=1}^{N}n\begin{bmatrix}N\\ n\end{bmatrix}P^{n}\left(n\right)\left[1-P\left(n\right)\right]^{N-n}=\sum\nolimits_{n=1}^{N}\frac{nN!}{n!\left(N-n\right)!}P^{n}\left(n\right)\left[1-P\left(n\right)\right]^{N-n} \tag{34}$$

After calculation, we can obtain the following formula.

$$\begin{aligned}&\sum\nolimits_{n=1}^{N}\tfrac{NP(n)(N-1)!}{(n-1)![(N-1)-(n-1)!]}\times P^{n-1}\left(n\right)\left[1-P\left(n\right)\right]^{N-n}\\ &=NP\left(n\right)\sum\nolimits_{n=1}^{N}\tfrac{(N-1)!}{(n-1)!(N-n)!}\times P^{n-1}\left(n\right)\left[1-P\left(n\right)\right]^{N-n}\end{aligned} \tag{35}$$

Simplify formula (35) we can get formula (36).

$$NP\left(n\right)\left[P\left(n\right)+1-P\left(n\right)\right]^{N-1}=NP\left(n\right) \tag{36}$$

The proof is complete.

4.2. Analysis for MS-MEC Algorithm

The coverage process of the MS-MEC algorithm is covering moving targets with multiple types and related dimensions.

Algorithm 1: Triangulation algorithm

Step1: Calculating the difference vector between any sensor node s_i and s_j in the sensor network.

$$\overrightarrow{s_i s_j} = \overrightarrow{s_i} - \overrightarrow{s_j} \tag{37}$$

Step2: Calculating the equation and direction vector of the perpendicular line connecting the two nodes s_i and s_j, passing through the perpendicular point and perpendicular to the line connecting s_i and s_j.

$$\begin{cases} m_{ij} = s_j + \dfrac{\overrightarrow{s_i s_j}}{2} \\ l_{ij} = \mathrm{e}^{-i\frac{\pi}{2}} \overrightarrow{s_i s_j} \end{cases} \tag{38}$$

Step3: Repeating Step1 and Step2, calculating the vertical equation and direction vector of the third sensor node s_k in the sensor network, at the same time, calculating the intersection point c coordinate of $s_i s_j$ and $s_i s_k$.

$$\begin{cases} m_{ij} = s_j + \dfrac{\overrightarrow{s_i s_j}}{2} \\ l_{ij} = \mathrm{e}^{-i\frac{\pi}{2}} \overrightarrow{s_i s_j} \end{cases} \tag{39}$$

Step4: Calculating the distance among c and all sensor nodes.

$$c = \frac{m_{ij} \wedge l_{ij}}{l_{ij} \wedge l_{ik}} l_{ik} + \frac{m_{ik} \wedge l_{ik}}{l_{ik} \wedge l_{ij}} l_{ij} \tag{40}$$

Step5: If the distance between any sensor node and c is greater than or equal to the distance between node s_i and s_j, a set of triangulation graphs are formed. Otherwise, the algorithm ends.

Step6: Repeating Step1 to Step5 until all sensor nodes are traversed.

For the MS-MEC algorithm, in the initial stage, the sensor node and its neighbor nodes perform information interaction operations, and cooperate to complete the election process of candidate nodes. The process is as follows. (1) In the initial stage of the algorithm, all sensor nodes are in a ready state, and a random parameter δ is set. The random parameter δ is used as the logical basis for randomly determining the distribution of a certain sensor node, and then generates M different groups working nodes and spread Hello messages within the sensing range. The message includes the sensor node ID, location information, and coverage. In order to avoid repeated selection of candidate nodes, we introduce the Back-off Mechanism (BM), and set a random response time $T_{waiting}$ for each sensor node, $T_{waiting} \in [0, T]$ where T is the unit period. If the sensor node does not receive the Hello message within the specified time $T_{waiting}$, it will change its state to the candidate state. If the sensor node receives the Hello message from its neighbor node within the specified time $T_{waiting}$, it will use Definition 4 and Theorem 3 to calculate the coverage $T_{waiting}$ of the sensor node to the location of the target node. (2) After a certain period T, all candidate nodes broadcast a notify message in a flooding manner, which includes coverage, node remaining energy, ID information, and node status information. If the energy of the candidate node is less than the threshold E_{min}, it will turn itself into a sleep state, where $E_{min}$is the threshold, and its setting formula is as follows.

$$E_{min} = \max\left(E_{tr} + E_{rx}\right) \tag{41}$$

Where E_{tr} and E_{rx} can be obtained as follows.

$$E_{tr} = E_{elec}\left(k\right) + E_{amp}\left(k, d\right) = \begin{cases} kE_{elec} + k\varepsilon f_s d^2 d < d_0 \\ kE_{elec} + k\varepsilon_{amp} d^4 d \geq d_0 \end{cases} \tag{42}$$

$$E_{rx}\left(k\right) = kE_{elec} \tag{43}$$

where E_{elce} represents the energy parameter consumed by the transceiver controller, εf_s represents the message energy parameter of the free space model, ε_{amp} represents the energy consumption parameter of the multi-channel attenuation model, d_0 is a constant, which depends on the actual application environment as shown in formula (43).

$$d_0 = \sqrt{\frac{\varepsilon f_s}{\varepsilon_{amp}}} \tag{44}$$

Algorithm 2: MS-MEC algorithm

Step1: Determining whether any sensor node can receive notify messages correctly. If it receives correctly, the sensor node is written into the candidate linked list N-Set, otherwise, the sensor node is not placed in the candidate linked list N-Set.

Step2: During the operation of the sensor node, if it receives an action message from the candidate node, it will update the state of the candidate node in the N-Set linked list, if it does not receive an action message, then enter Step 3.

Step3: If N-Set is non-empty, the set of sensor nodes in the linked list will be sorted according to the energy level. When the effective coverage rate of the target node is satisfied in advance, the sensor node with the highest energy sum will broadcast the action message and announce the node as working node. If the current coverage is not satisfied, the node with the second highest energy is selected; the above operation is repeated until a suitable sensor node is found, otherwise, the algorithm ends.

Step4: Determining whether the sensor node's perception probability $p(s)$ is greater than or equal to the threshold p_{th}, if it is greater than or equal to p_{th}, calculating the perception probability according to formula (44). If it is less than the threshold, we will continue to search the N-Set linked list to meet the conditions sensor node.

$$p\left(s\right) = 1 - \prod_{i=1}^{N-Set}\left(1 - p\left(s_i, s_j\right)\right) \tag{45}$$

Step5: If the N-Set linked list is empty, the sensor node will compete with the perceptual probability $p(s)$ until the entire N-Set linked list is traversed, in this case, if the N-Set

linked list is still empty, the algorithm jumps to Step2.
Step6: When a certain period ends, determining the status information of all sensor nodes, if it is a candidate or ready state, its sensor nodes will change to the sleep state.

4.3. MS-MEC Algorithm Complexity Analysis

In the worst state of the MS-MEC algorithm, the complexity of each sensor node is $O(1)$ when exchanging messages, and in a network with n sensor nodes, the complexity is $O(n)$. As far as each cycle is concerned, in order to make the distribution of randomly deployed sensor nodes more even, within the range of broadcasting Hello messages, the complexity of enabling neighbor nodes to receive this message is $O(1)$. In the loop iteration stage of n sensor nodes, if the number of loop iterations is m times, the maximum number of Hello messages broadcast by each candidate node is also m times, i.e., the complexity of exchanging messages is $O(m \times n)$.

5. Performance Evaluation

In the same simulation environment, the MS-MEC algorithm under different parameters is compared with other algorithms in three aspects, the number of sensor nodes, coverage and life time. Three different network monitoring areas are used: 100m × 100m, 300m × 300m, and 500m × 500m. The wireless sensor network is composed of 1200 nodes with a sensing radius of 10m, the initial energy of the sensor node is 5J, when the remaining energy of the sensor node is less than 0.005J, the sensor node can be considered as invalid.

5.1. Comparison Experiment of the Number of Sensor Nodes

In order to better verify the effectiveness of the MS-MEC algorithm in this paper, this paper uses different monitoring areas, takes the number of sensor nodes as the research background and compares with literature [24] (EMC-SC) and literature [28] (DCS-NC) and literature [40] (DR-ACO). Figure 4 to 6 show the difference between the number of sensor nodes and the number of working nodes of the MS-MEC algorithm, the DR-ACO algorithm, and the DCS-NC algorithm under different λ parameters and different time rounds in a monitoring area of 100m × 100m. Figure 7 to 9 show the difference between the number of sensor nodes and the number of working nodes in the MS-MEC algorithm, DR-ACO algorithm, and DCS-NC algorithm under different λ parameters and different time rounds in a monitoring area of 300m × 300m. Figure 10 to 12 show the difference between the number of sensor nodes and the number of working nodes of the MS-MEC algorithm, the DR-ACO algorithm, and the DCS-NC algorithm under different λ parameters and different time rounds in a 500m × 500m monitoring area.

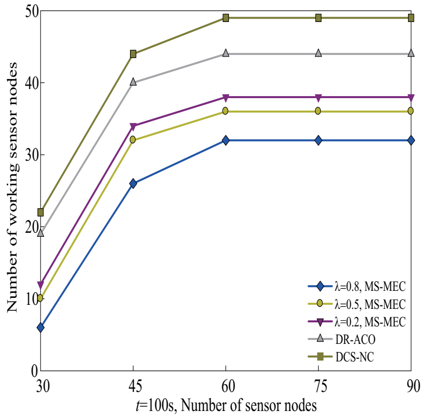

Fig. 4. 100m × 100m,(*t*=100s) the number of nodes and working nodes comparison between among the three algorithms

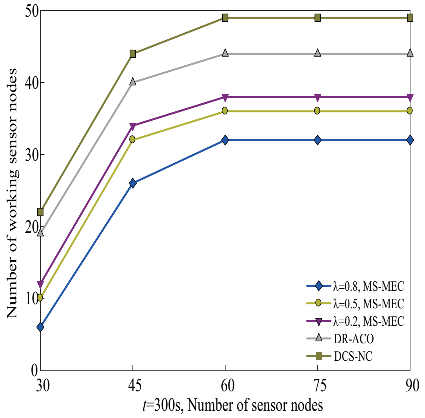

Fig. 5. 100m × 100m(*t*=300s), the number of nodes and working nodes comparison between among the three algorithms

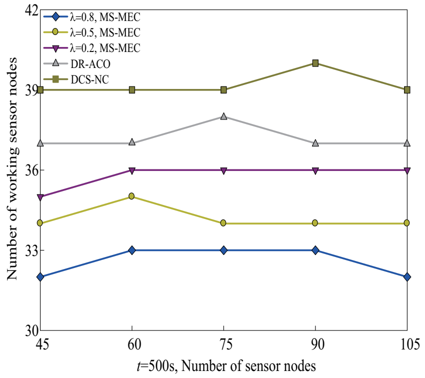

Fig. 6. 100m × 100m(*t*=500s), the number of nodes and working nodes comparison between among the three algorithms

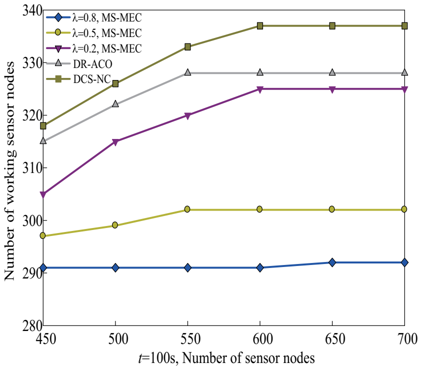

Fig. 7. 300m×300m(t=100s), the number of nodes and working nodes comparison between among the three algorithms

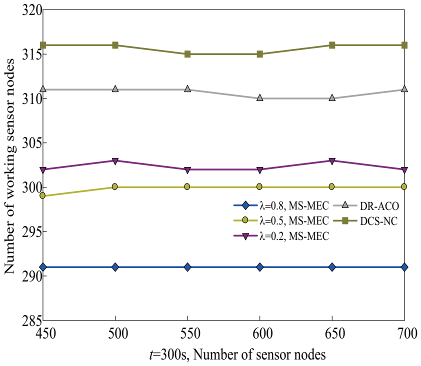

Fig. 8. 300m×300m(t=300s), the number of nodes and working nodes comparison between among the three algorithms

The MS-MEC algorithm is an optimized coverage algorithm with energy balance and migration strategy. The edge computing model effectively calculates the network coverage, node remaining energy and network life time and other attributes. In this paper, the MS-MEC algorithm uses the sensor node round mechanism to complete the effective coverage of the monitoring area, while DR-ACO uses the ant colony optimization algorithm to effectively cover the monitoring area. The algorithm only considers the optimization process and the one-way path. The coverage mechanism simply completes the coverage of a single target node without considering the problem of mobile multi-target coverage; the DCS-NC algorithm uses full coverage of the monitoring area to complete the coverage of the mobile target node without considering the sensor node energy consumption problem. It can be seen from Figure 4 to Figure 6 that in the 100m × 100m monitoring area, as the number of sensor nodes increases, the number of working nodes of the

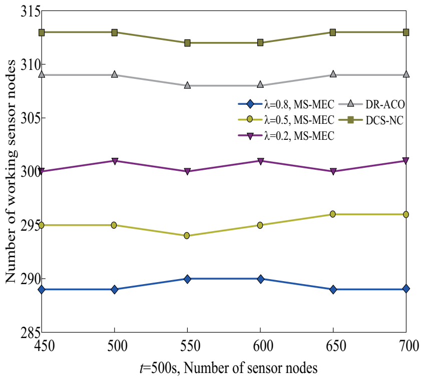

Fig. 9. 300m×300m(t=500s), the number of nodes and working nodes comparison between among the three algorithms

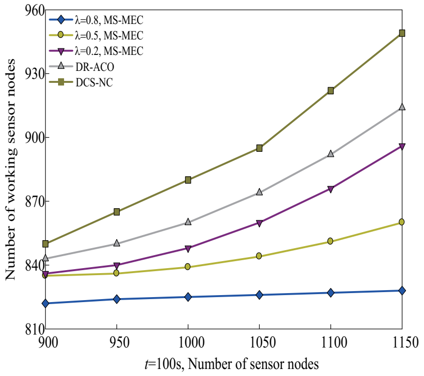

Fig. 10. 500m×500m(t=100s), the number of nodes and working nodes comparison between among the three algorithms

three algorithms also increases, but the increase in the MS-MEC algorithm in this paper is much smaller than the other two algorithms. When t=100s, λ=0.8, the number of working nodes required by the MS-MEC algorithm in this paper is 32, the increase value is the smallest, and the number of sensor nodes in working state is also the smallest. Secondly, when t=100s, λ =0.5, the number of working nodes required by the MS-MEC algorithm in this paper is 36, which means that the network energy balance is achieved. Thirdly, when t=100s and λ=0.2, the number of working nodes required by the MS-MEC algorithm in this paper is 38, which means that the network energy balance is achieved. But under the same conditions, the DR-ACO algorithm and the DCS-NC algorithm require 44 and 49 sensor nodes to achieve network equilibrium. In a 100m × 100m monitoring area, the average number of sensor nodes of the MS-MEC algorithm is 75.91% of the other two algorithms. At t=300s and t=500s, the average number of sensor nodes used in the MS-MEC algorithm is 86.65% and 89.47% of the other two algorithms. In terms of suppressing the number of nodes, the MS-MEC algorithm is within a 100m × 100m mon-

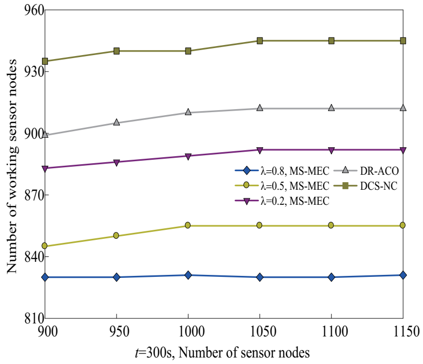

Fig. 11. 500m × 500m(*t*=300s), the number of nodes and working nodes comparison between among the three algorithms

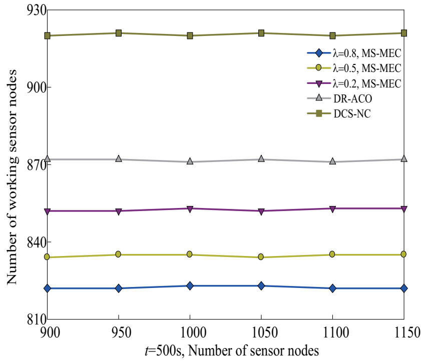

Fig. 12. 500m × 500m(*t*=500s), the number of nodes and working nodes comparison between among the three algorithms

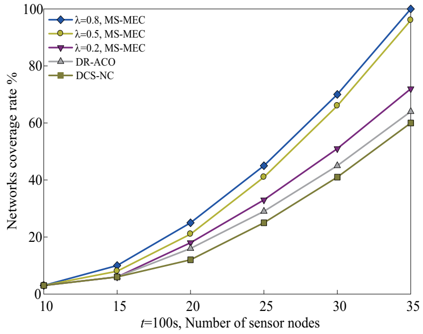

Fig. 13. 100m × 100m,(*t*=100s), the comparison of network coverage rate with the three algorithms

itoring area, and the average number of sensor nodes used is 15.99% less than the other two algorithms. According to the above analysis process, the average number of sensor nodes used in the MS-MEC algorithm is 94% and 92.78% of the other two algorithms. In terms of suppressing the number of nodes, the average number of sensor nodes used in the MS-MEC algorithm is 6% and 7.22% less than the other two algorithms in the monitoring area of 300m ×300m and 500m × 500m. Based on the above analysis, the average number of working sensor nodes of the MS-MEC algorithm is 9.74% less than the other two algorithms under different parameters, different monitoring areas and different time rounds.

5.2. Coverage Quality Comparison Experiment

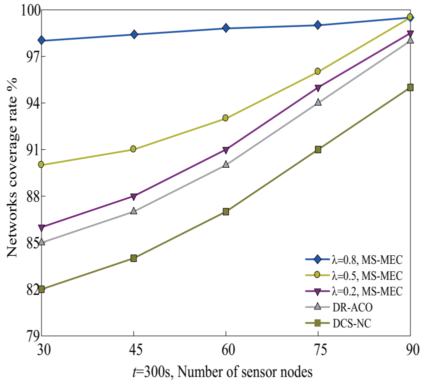

Fig. 14. 100m×100m(t=300s), the comparison of network coverage rate with the three algorithms

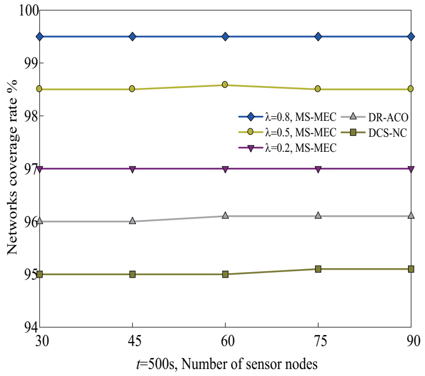

Fig. 15. 100m×100m(t=500s), the comparison of network coverage rate with the three algorithms

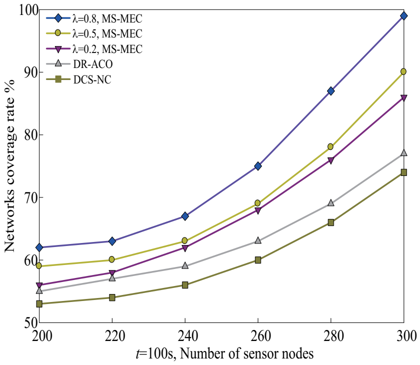

Fig. 16. 300m×300m(t=100s), the comparison of network coverage rate with the three algorithms

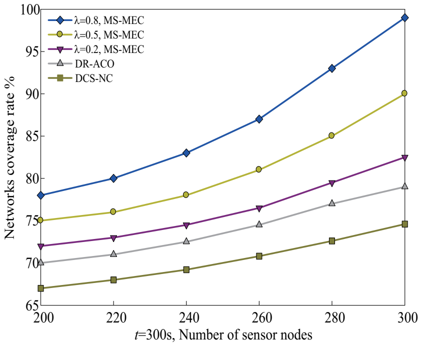

Fig. 17. 300m×300m(t=300s),the comparison of network coverage rate with the three algorithms

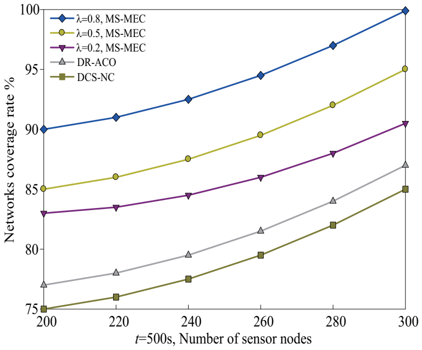

Fig. 18. 300m×300m(t=500s), the comparison of network coverage rate with the three algorithms

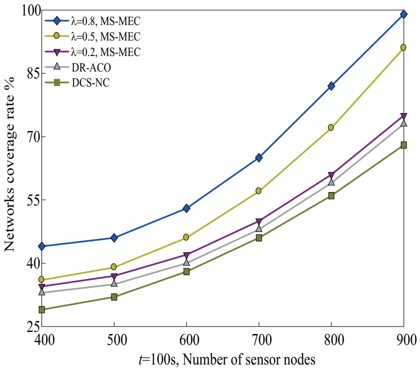

Fig. 19. 500m×500m(t=100s),the comparison of network coverage rate with the three algorithms

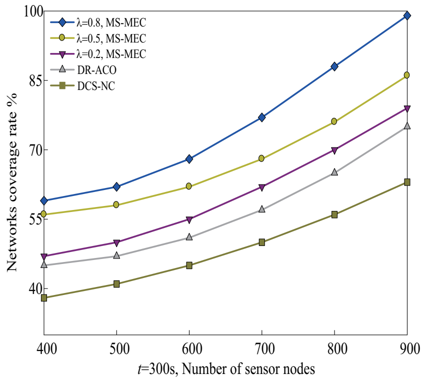

Fig. 20. 500m×500m(t=300s), the comparison of network coverage rate with the three algorithms

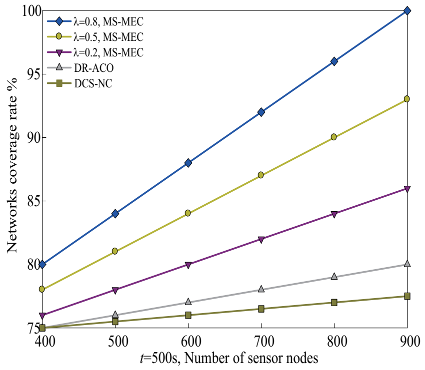

Fig. 21. 500m×500m(t=500s), the comparison of network coverage rate with the three algorithms

Figure 13 to Figure 21 respectively show the comparison of the network coverage rate and the number of sensor nodes of the three algorithms in different monitoring areas. We take Figure 16 to Figure 18 as an example for analysis. From the above three figures, it can be seen that with the increase in the number of sensor nodes, the network coverage rate of the three algorithms have increased, but the increase of MS-MEC algorithm is higher than that of DR-ACO algorithm and DCS-NC algorithm. When t=300s and the number of sensor nodes is 260, the MS-MEC algorithm network coverage is λ=0.8, p=87%, λ=0.5 p=81% and λ=0.2,p=76.5% . The network coverage rate of the DR-ACO algorithm is p=74.5%, the network coverage rate of the DCS-NC algorithm is p=70.8%, at this time, the average network coverage rate of the MS-MEC algorithm is 8.85% higher than the other two algorithms. When the number of sensor nodes is 300, the network coverage rate of the MS-MEC algorithm is λ=0.8,p=99%, λ=0.5, p=90% and λ=0.2,p=82.5%, and the network coverage rate of DR-ACO algorithm is p=79%, and the network coverage rate of the DCS-NC algorithm is p=74.6%. The average network coverage rate of the MS-MEC algorithm is 13.7% higher than the other two algorithms. The main reason is as follows. The MS-MEC algorithm effectively controls the network coverage by adjusting the parameters, thereby increasing the effective coverage of the local monitoring area, while the DR-ACO algorithm and the DCS-NC algorithm only use the full coverage characteristics of sensor nodes to cover effectively the entire monitoring area. The DR-ACO algorithm and the DCS-NC algorithm do not achieve effective coverage through certain parameter control, and on the other hand, in terms of the coverage, the two algorithms do not consider the entire network energy consumption problem, which increases the rapid consumption of sensor node energy. For a large-scale monitoring area of 500m × 500m, the comparison diagram of network coverage rate and sensor nodes given is shown in Figure 19 to 21. We take Figure 21 as an example for analysis. In Figure 21, we can see that the network coverage rate increases with the increase of the number of sensor nodes. The increase of network coverage rate of the MS-MEC algorithm is higher than that of the other two algorithms. When the number of sensor nodes is 600, the coverage rate of the MS-MEC algorithm network is λ=0.8, p=88%, λ=0.5,p=84% and λ=0.2,p=80%, and the DR-ACO The network coverage rate of the algorithm is p=77%, the network coverage rate of the DCS-NC algorithm is p=76%. However the average network coverage rate of the MS-MEC algorithm is 7.5% higher than the other two algorithms. When the number of sensor nodes is 900, the coverage of the MS-MEC algorithm network is λ=0.8, p=99%, λ=0.5, p=93%, λ=0.2, p=86%, and the network coverage rate of the ACO algorithm is p=80%, the network coverage rate of the DCS-NC algorithm is p=77.5%, however, the average network coverage rate of the MS-MEC algorithm is 13.91% higher than the other two algorithms. Based on the above analysis, the coverage rate of the MS-MEC algorithm network is 9.92% higher than that of the other two algorithms.

6. Conclusion

This article mainly conducts research from three aspects, the number of nodes in the sensor network, network coverage, and network energy consumption. The proposed MEC-MS algorithm uses the network coverage model to give the distance measurement judgment conditions, uses the probability-related theoretical knowledge to analyze the necessary conditions for improving the coverage quality and the preconditions for the existence of the redundant coverage of adjacent redundant coverage nodes. On the basis of this analysis, using the preconditions of redundant coverage, the calculation process of the sensor node's own redundant coverage and the calculation method of redundant node coverage expectations are given. The experimental results show that the MEC-MS algorithm is superior to the other two algorithms in terms of the number of nodes, network coverage and network energy consumption.

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