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Energy Balance-Based Steerable Arguments Coverage Method in WSNs

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ABSTRACT Coverage is one of the important performance indexes in wireless sensor networks. When the target is covered by k degrees by the sensor, more redundant data are generated, which may lead to network congestion, thus reducing the communication and coverage of the network and leading to a rapid depletion of energy. Therefore, this paper presents an energy balance and coverage control algorithm for the overlay network model based on node position relations. Areas are given by the analysis of the overlay network model. In terms of energy consumption, nodes with low energy consumption are scheduled by a given proportion of expected functions between the working nodes and the neighboring nodes, which balances the energy consumption of the entire network and optimizes network resources. Finally, the simulation results show that the proposed k-degree coverage algorithm not only improves the coverage quality of the network but also reduces the rapid energy consumption and prolongs the service life of the network.

INDEX TERMS Wireless sensor networks, energy balance, coverage rate, life cycle.

I. INTRODUCTION AND RELATED WORKS

Wireless sensor networks are composed of tens of thousands of sensor nodes [1], [2]. The network architecture of each sensor node formed by self-organization has certain perceptions, computing ability, communication ability and storage capacity. It is widely used in military defense, intelligent transportation, health care, environmental monitoring, earthquake relief, intelligent home furnishing and engineering fields. Its behavior is applied in the physical world mainly to perceive multi hops and complete data acquisition and transmission [3]. It is used to achieve unity between the physical world and information world, integration, as well as to realize data acquisition, data storage, and data calculation in the communication transmission chain network service system [4].

Coverage quality and network energy consumption are two important indexes to evaluate performance [5], [6]. The quality of systems of wireless sensor network coverage is directly reflected in the monitoring area of node deployment. Network lifetime directly influences the quality of network services and is mainly reflected in the deployment of node energy consumption [7]. In general, influenced by topography and environmental factors as well as many other conditions, the choice of node deployment is random. In the random deployment process, due to unpredictable node-specific location information, monitoring points are implemented in multiple coverage and K coverage deployments. Another case, due to the existence of randomness, may result in the monitoring area in [3] and [8]. To achieve effective coverage of the point, more nodes are necessary. Although the above two cases to some extent can achieve effective coverage of the target, there are also disadvantages. First, with respect to K coverage, during the process of calculation , data acquisition and transfer data by the communication link, this process will generates a lot of redundant data. These redundant data will lead to error and uncertainty during the procedure of computing and communication. Second, the true meaning of coverage is not to completely cover the entire monitoring area. However, it refers to the effective coverage based on one or several concerned target nodes. without considering the attentional target nodes, the monitoring area completely covered in the process will consume a great deal of node energy, speeding the collapse of the entire network system. Third, when nodes are deployed, due to randomness, the regional monitoring coverage of the node density will inevitably improved, and this can occur easily. It is easy to produce the bottleneck effect, which will eventually lead to information redundancy, channel interference and network scalability.

In recent years, many domestic and foreign experts and scholars have performed a great deal of research on wireless sensor network coverage K [9]. These units of work time in round numbers act as the research foundation. Four network configuration protocols have been proposed to cover the effective monitoring area. The study [10] introduces artificial intelligence theory research on the sensor node coverage process. The process first addresses a sensor node state scheduling heuristic algorithm to optimize scheduling using an iterative method. The theoretical calculation of the complete process of regional K monitoring is provided in [11] using coverage from the literature. In terms of distributed theory, this paper presents a nonlinear covering algorithm. The main idea of the algorithm is reflected in the use of the self-organized characteristic construction section of the sensor node covering set. When the mobile node enters the target coverage set and complete coverage, the administrator will transfer to the neighbor set coverage configuration protocol, at the same time waking up the neighbor nodes management coverage set and ultimately achieving effective coverage of the mobile node. The algorithm can achieve the coverage of the monitoring area of K to a certain extent, but there are also some problems. For example, the algorithm complexity will be very high, there will be a large amount of calculation, or the network configuration protocol will be much complex.

Taking into account the shortage of existing research, a coverage algorithm is proposed to balance energy controllable parameters. The algorithm uses the target node moving through the monitoring area. The coverage area rate of the sensor nodes and the expected value of the coverage are obtained by the sector region formed by the coverage. This multipoint transmission and single-point transmission solution process for sensor nodes in certain coverage, in scenarios where a target node is moving through the K coverage area, will be closed between sensor nodes within the energy threshold value or higher than the threshold limit of the sensor nodes through the adaptive switching mechanism or in sensor nodes in a dormant state. The other sensor nodes are processed through the energy scheduling algorithm to complete the energy conversion mechanism between sensor nodes and improve the network life cycle.

The contribution of this paper is mainly reflected in the following points:

1) In this paper, an analysis and summary of the relevant knowledge is presented on the basis of this proposed new algorithm network model.
2) According to the random deployment characteristics that were analyzed in the monitoring area, the distribution of sensor nodes deployed are subject to $\lambda, N(s)$ coverage method for random variables with Poisson distribution calculation and networks.
3) With the network model as the research object, a method to calculate the expected value is proposed, and the solution process of the desired value is given for a target node under joint coverage.
4) At the end of this paper, through a simulation comparison experiment, the effectiveness and stability of the algorithm is verified.

II. NETWORK MODEL AND COVERAGE QUALITY

In order to better study the issue of coverage of wireless sensor networks and to facilitate the research procedure of the problem, the proposed algorithm is based on the following four assumptions:

1) At the initial time, the sensor nodes are all isomorphic, and the sensing radius and the communication radius are all disk shaped model.
2) In addition, the energy value is equal, the sensing radius is the same value, and it is synchronized with the network time clock.
3) The sensor nodes are randomly deployed in monitoring square area with the length l and ensure that the sensing radius is much smaller than the length l of the side. The boundary effect can be neglected.
4) Any node does not need to use a certain location method to obtain its own position information.

A. BASIC DEFINITION

Definition 1 (Complete Coverage): In the monitoring region, any target node is at least covered, a sensor node is between sensor nodes and the target node is less than the Euclidean distance of the sensing radius of sensor nodes, $D(i, t) < R_s$, i.e., full coverage, composed of nodes to satisfy the conditions set, referred to as set coverage).

Definition 2 (k-Coverage): In the monitoring area, any target node is covered by at least k sensor nodes, it is called the k degree coverage of the target node. The monitoring area is called the k degree coverage area.

Definition 3 (Cover Quality): In the monitoring area, the ratio of the sensing area of all sensor nodes to the area of the monitoring area is called coverage quality, which reflects the degree of coverage of the target node in a certain degree.

Definition 4 (Joint Coverage): An arbitrary target node in the target set is covered by at least one sensor node, and the coverage rate is p:

$$p_n = 1 - (1 - p)^N \tag{1}$$

where p_n is the joint coverage rate, p is an arbitrary sensor node coverage and N is the number of sensor nodes [12].

Theorem 5: The random nodes in the monitoring area that are subject to the probability density are represented as λ, $N(s)$ is a Poisson distribution of random variables

Proof: Let S_{i-area} and S be expressed as arbitrary sensor nodes in the monitoring coverage area. S is the area value with length of side l. P is coverage probability of sensors monitoring region, namely, $p = |S_{i-area}|/S$, based on the binomial theorem. In the monitoring area, the joint probability of k working sensor nodes is given based on the binomial theorem.

$$p(N(s) = k) = C_N^k p^k (1-p)^{N-k} \tag{2}$$

For the entire monitoring area, sensor node density $\lambda = N/S$, λ and p are now substituted into (2) and the following can be obtained:

$$p(N(s) = k) = (1 - \frac{\lambda|S_{i-area}|}{N})^N \cdot \frac{(\lambda|S_{i-area}|)^k}{k!} \cdot \frac{N!}{(N-k)!(N-\lambda|S_{i-area}|)^k} \tag{3}$$

Substituted into (2), the following can be obtained, as $N \to \infty$:

$$p(N(s) = k) = \frac{e^{-\lambda|S_{i-area}|}(\lambda|S_{i-area}|)^k}{k!} \tag{4}$$

□

Based on **Theorem 5**, the sensor nodes that are randomly deployed in the monitoring area shown between nodes are independent and have a uniform distribution. The distribution of the number of sensor nodes subject to the probability density for λ, $N(s)$, which is also a Poisson random variable distribution.

The random deployment model of sensor nodes mainly solves the problem of sensor node distribution density [13], [14]. How to use the least effective sensor nodes to complete coverage of the monitoring area depends on the number of [15]. When the random deployment of sensor nodes in the monitoring area in the department of the internal monitoring area is sufficient for a large number of sensor nodes, although it can achieve complete coverage, the energy consumption of nodes and the redundant nodes make this approach unrealistic. First, when a large number of sensor nodes are deployed in the monitoring area, intangibles will consume a lot of energy from the sensor nodes, which is unfavorable for prolonging the network life cycle, in particular when a sink node runs out of energy, which makes the whole system collapse. Second, due to the large number of sensor nodes, in the process of communication between sensor nodes and redundant nodes, some redundant nodes are bound to interfere with the wireless channel and the energy consumption of redundant nodes as well as shorten the network lifetime and many other issues.

In order to overcome the above shortcomings, improve the network quality of service and maximally prolong the network lifetime. We need to achieve the effective coverage of the monitoring area so that it can improve the coverage ratio of the monitored area. Therefore, we introduce **Corollary 6**.

Corollary 6: In the monitoring area, the coverage probability of the sensors jointed coverage is given by $p = 1 - e^{-\lambda\pi R_s^2}$.

Proof: The coverage rate of any target node that is not covered by the sensor node is $p_1 = 1-(|S_{i-area}|/S)$. According to (3) and **Theorem 5**, we can obtain the uncovered rate that the target node lies in the range of the k sensors jointed coverage

$$p_u = \frac{e^{-\lambda|S_{i-area}|}(\lambda\,|S_{i-area}|)^k}{k!} - (|S_{i-area}|\,/S)^k \tag{5}$$

Next, the following is calculatedčž

$$p_u = e^{-\lambda\pi R_s^2} \tag{6}$$

□

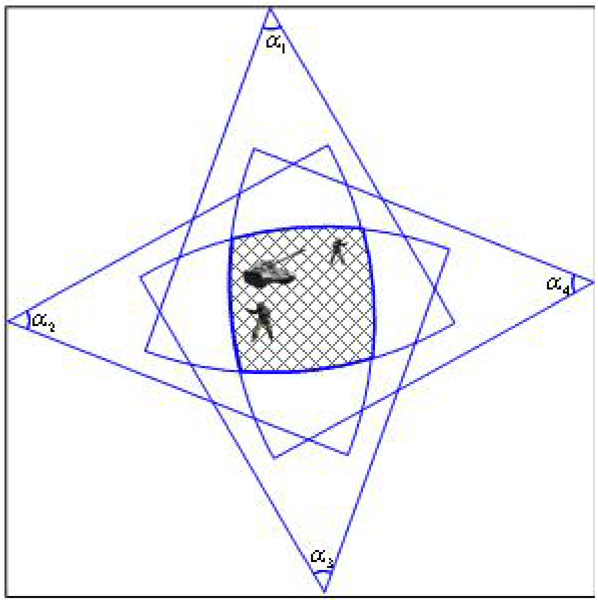

FIGURE 1. A k degree coverage network model.

B. NETWORK MODEL

A k degree coverage network model with a sector as the coverage area is given where the four sensor nodes, as well as tanks and soldiers are analyzed as the research objects, shown in Figure 1. l is the square monitoring area with sensor node, and the fan is the coverage area. In addition, a different angle between the four sectors is given in radians. The target node tanks and soldiers are in the $k = 4$ coverage, as well as the formation of the target node. The sensing radius of sensor nodes is also shown. For R_s, the fan area is given by

$$S_1 = \pi\theta R_s \tag{7}$$

where $\theta = \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4$.

The length of the monitoring area of the l square when the target node is always in the sensor node coverage area for the whole network coverage is given as follows:

$$P_N = \frac{\pi\theta R_s}{l^2} \tag{8}$$

Theorem 7: In the monitoring area, the expected value of the target node is covered by the sensor nodes:

$$E(X) = \frac{\pi\theta(\sigma^2 + l^2)}{l^2} \tag{9}$$

Proof: Figure 1 shows the network model as the research object. With R_s as the sensor nodes that are deployed randomly in the sensing radius, the length of l square as the monitoring area, and the sensor node sector as an effective coverage area. θ is the sum of the fan angle. The sensor node sensing radius R_s obeys the Yu Zheng normal distribution $N(l, \sigma^2)$, and the monitoring area covers the expected values:

$$E\,(X) = \int_0^{2l} P_N \frac{1}{(2\pi)^{\frac{1}{2}}\sigma} exp\left(-\frac{(R_s - l)^2}{2\sigma^2}\right) dR_s \tag{10}$$

Let x assume to $\frac{R_s - l}{\sigma}$,

$$E(X) = \int_{-\frac{l}{\sigma}}^{\frac{l}{\sigma}} \frac{\pi\theta(x\sigma + l)^2}{(2\pi)^{\frac{1}{2}}\sigma} \exp(-\frac{x^2}{2})\sigma\, dx$$
$$= \frac{\pi\theta(\sigma^2 + l^2)}{l^2} \tag{11}$$

□

Corollary 8: To satisfy a certain coverage rate in advance, the minimum number of sensor nodes is used to complete the joint coverage of the monitoring area and the corresponding coverage expectation value is $(1 - \epsilon)/\ln(1 - \pi\theta(\sigma^2 + l^2)/l^2)$.

Proof: All of the sensor nodes deployed randomly in the monitoring area are relatively independent. According to theorem 2, in the monitoring area, the target node expected value which is covered by any coverage-set nodes is given by:

$$E(k_1) = \frac{\pi\theta(\sigma^2 + l^2)}{l^2} \tag{12}$$

If there are n working sensor nodes in the monitoring area, the expected value generated by the joint coverage of any target node is given by

$$E(k) = 1 - (1 - \frac{\pi\theta(\sigma^2 + l^2)}{l^2})^n \tag{13}$$

In a certain quality of coverage, the number will maintain a minimum ϵ. This is combined with the coverage of the expected value that is less than ϵ, the limit, i.e.

$$1 - (1 - \frac{\pi\theta(\sigma^2 + l^2)}{l^2})^n \leq \epsilon \tag{14}$$

Then

$$n \geq \frac{\ln(1 - \epsilon)}{\ln(1 - \pi\theta(\sigma^2 + l^2)/l^2)} \tag{15}$$

Namely, when the effective coverage of the monitoring area is completed, the expected value of the minimum number of sensor nodes is $\ln(1 - \epsilon)/\ln(1 - \pi\theta(\sigma^2 + l^2)/l^2)$. □

Theorem 2 and **Corollary 2** give the coverage of expectations and expectations combined with the coverage calculation process. In general, the moving trajectory of the target node in the monitoring area is covered by the sensor nodes when showing a fan shape. In the calculation used to cover the expected value, probability theory and mathematical theory from computation geometry are used to complete the method. However, for the moving target node entering the monitoring area for the first time, the first expected coverage value must be obtained.

Theorem 9: Sensor nodes complete the coverage of mobile targets for the first time. The coverage is expected to be $E(X) = [1-(1-p)^M]p^{-1}$*, where M is the maximum number of mobile target nodes to complete the transfer and p is the coverage of the sensor nodes.*

Proof: According to probability theory, the number of random variables with X transferred for the mobile target node may range, where $X \in \{1, 2, \cdots, M\}$, and as $X = m$ and satisfies $1 \leq m \leq M - 1$. Namely, $M - 1$ times before moving the target node is not covered by the sensor nodes, and the distribution density function of X is given by

$$p(X = k) = \begin{cases} p(1-p)^{k-1}, & k = 1, 2, \cdots, M-1 \\ (1-p)^{N-1}, & k = N \end{cases} \tag{16}$$

By covering the desired formula:

$$E(X) = \sum_{k=1}^{M-1} kp(1-p)^{k-1} + M(1-p)^{M-1} \tag{17}$$

assume $q = 1 - p$, $S = \sum_{k=1}^{M-1} k(1-p)^{k-1}$. Namely, $S = \sum_{k=1}^{M-1} kq^{k-1}$. Multiply the two ends of the equation by q, obtaining $qS = \sum_{k=1}^{M-1} kq^k$. Namely,

$$S = \frac{1 - (1-p)^M}{p^2} - \frac{M(1-p)^{M-1}}{p} \tag{18}$$

The formula (18) can be obtained by the formula (17),

$$E(X) = [1 - (1-p)^M]p^{-1} \tag{19}$$

□

III. ALGORITHM DESCRIPTION AND ANALYSIS

A. ENERGY TRANSFORMATION

In the square monitoring area, after the networks run for one or more cycles, the energy consumption of nodes will inevitably lead to changes in the corresponding area of coverage. In order to reduce the sensor node energy consumption and maximize the network lifetime, this paper adopts the node energy model of multilateral and unilateral transmission data consumption. The node energy is analyzed while the calculation is ignored; based on node storage and the control of energy consumption, the energy consumption model for the sending end node is given by

$$E_{Tx}(l,d) = lE_{T-elec} + E_{amp}(l,d) = \begin{cases} lE_{T-elec} + l\varepsilon_{fs}d^2, & d < d_0 \\ lE_{T-elec} + l\varepsilon_{amp}d^4, & d \geq d_0 \end{cases} \tag{20}$$

Receiver energy consumption model

$$E_{Rx}(l) = E_{R-elec}(l) = lE_{elec} \tag{21}$$

l represents the transmission of data bits between d sensor node and the neighbor node represents the Euclidean distance. d_0 is the threshold of distance communication between nodes. When the communication distance between nodes is less than d_0, the energy attenuation index is 2, and the attenuation index is 4. E_{elec} represents the communication between the nodes receiving and sending and the consumption of energy of the [16] module.

The new algorithm is implemented with the help of neighbor nodes in the sensing radius of the sensor nodes within the scope of the formation of the alliance. All nodes are divided into several alliances, and nodes with higher energy, computing power and communication ability of the node are used as a manager node. Other nodes are referred to as member nodes. In the network initialization stage, due to the same node attribute, a node is chosen as the administrator node. Member nodes first send a '*Coverage*' message to the manager node storage administrator node according to the ability to open up a certain capacity. Information will be collected and stored in a list of the CL open space, which mainly contains the '*Coverage*' message, the sending node and the current state, such as: the changes in the energy transmitting node, ID information and sending node attention to node coverage. In the round or rounds of the cycle, the administrator node collects send information for all nodes in the alliance. The administrator node is based on the collection of all kinds of information in the nodes in the residual energy and the expected coverage value to sort all member node sizes. This is stored in the list when, given a certain weight for all nodes, the top is ranked higher than the weight of the node weights node by node according to the coverage of the administrator. The target node member node find qualified nodes sequentially from the list and marks a member node to satisfy the conditions. At the same time, the member node sends the message '*Notice*' to other members to complete the coverage node scheduling the corresponding task.

B. ALGORITHM DESCRIPTION

The algorithm implementation process is divided into seven steps as following:

1) First calculate the expected value of the coverage of each node in each coalition structure $E(X) = \bigcup(s_i, L)|s_iN(l, \sigma^2)/l^2$
2) The administrator node stores the information stored in a CL list, in which the '*Coverage*' message contains information about the ID information of the sending node, the energy information and the desired value.
3) After one round or several rounds cycle, the administrator rank list all membership that is stored in the linked list by the value of cover the remaining energy and the expectation value of coverage.And the higher weight is assigned to the top of nodes.
4) The administrator node of the nodes list in the node is covered by the target node to find and satisfy the conditions of the member nodes.
5) The administrator for finding the node list of member nodes when a member node residual energy is higher than the threshold value E_{thr} sends a '*Notice*' message to the member node after receiving the message, starting the perception module for monitoring area coverage.
6) If there is a target node that is covered by k member nodes, the administrator node will re-traverse the list to find the member nodes that meet the coverage requirements and close the member nodes.
7) As the administrator node completed list traversal. The administrator node searches for sensor nodes with satisfied coverage condition in the next round based on the adaptive scheduling mechanism. Else, turn to step 2).

TABLE 1. Simulation parameter list.

parameter	value	parameter	value
Monitoring area	$100*100$	R_c	20m
Monitoring area	$200*200$	E_{R-elec}	50J/b
Monitoring area	300*300	E_{T-elec}	50J/b
R_s	10m	ϵ_{fs}	10(J/b)/m2
Initial energy	5J	ϵ_{amp}	100(J/b)/m2
time	600s	e_{min}	0.005J

IV. SYSTEM EVALUATIONS

In order to verify the effectiveness and stability of the new algorithm, this paper uses MATLAB7 as the simulation platform, and [11], [14]–[26] (Energy-Efficient Target Coverage Algorithm, ETCA) and [11], [15]–[28] (Event Probability Driven Mechanism documents, EPDM) the two algorithms were compared. The simulation parameters are shown in Table 1: Experiment one: the algorithm and the literature ETCA algorithm are compared with in the aspect of extend the network lifetime. The experimental data is the average value of the 200 times simulation experiment, as shown form Figure 2 to figure 4. Experiment two: among the different monitoring areas, the experiments contrast the new algorithm and ETCA algorithm in the network life cycle. In the experiment, k takes different values by changing the random deployment of nodes in the monitoring area to change the number of the network scale. For a monitoring area that is smaller, the initial value of randomly deployed nodes is 15. Value 15 as the base, gradually increasing. Through the simulation, the lifetime of wireless sensor networks is increased

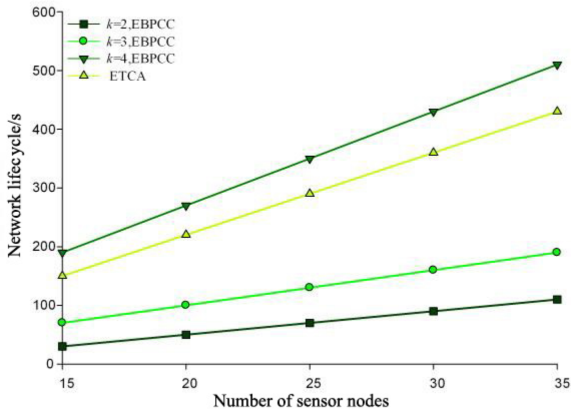

FIGURE 2. 100 ∗ 100 network life cycle change graph.

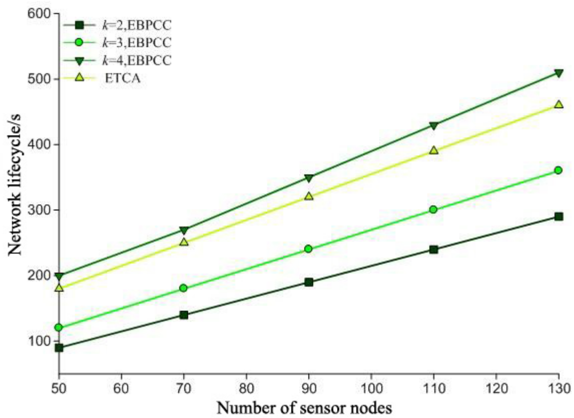

FIGURE 3. 200 ∗ 200 network life cycle change graph.

with the number of sensor nodes in a linear upward trend. The member nodes among the sensor nodes set finish the coverage procedure for the target node in turn based on the scheduling mechanism of nodes. Hence, it can extend the lifetime of the network. In the same network environment, this algorithm is better than the network life cycle ETCA algorithm. There was an average increase of 11.71%. For a larger scale network monitoring area, the numbers of nodes are randomly deployed, the initial value is 50,with 50 as the base unit and gradually increasing. The network life cycle curve with an increasing number of sensor nodes also shows a rising trend. The range of the rise is more than a small-scale network monitoring area. Compared with the ETCA algorithm, the network lifetime average increases by 13.19%.

Experiment 2: the algorithm and [11], [15]–[36] algorithm proposed by the EPDM algorithm in terms of coverage ratio experiment. In order to use 200 ∗ 200 as an example, the experimental data is 200 times the average value of the simulation data, as shown in Figure 5 and Figure 6: In Figure 5, with the increase in the number of sensor nodes, the coverage rate is also increasing. The change in coverage rate is 99.9%. As $k = 2$, the sensor node number is 144. As $k = 3$, the sensor node number is 137. As $k = 4$, the sensor node number

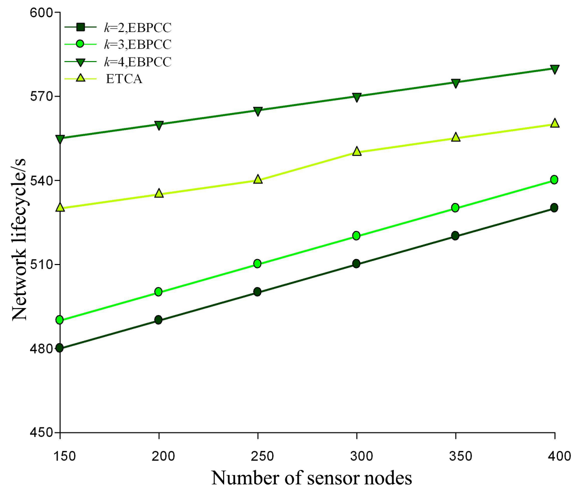

FIGURE 4. 300 ∗ 300 network life cycle change graph.

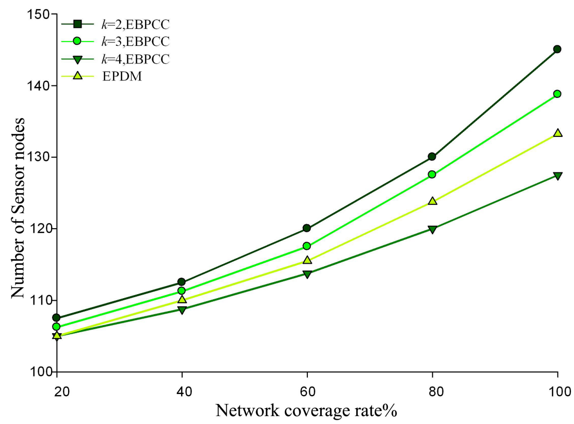

FIGURE 5. 200 ∗ 200 network coverage curve diagram.

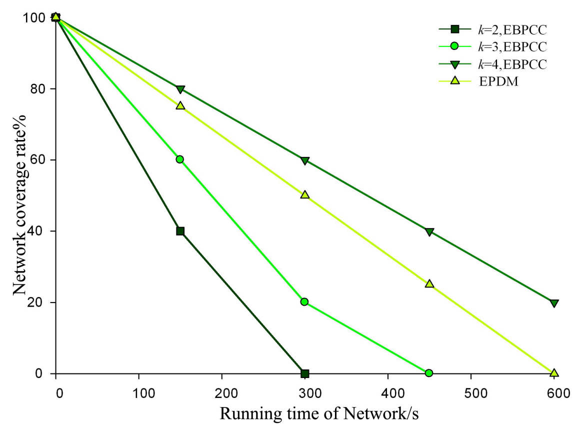

FIGURE 6. 200 ∗ 200 network running time curve diagram.

is 126, while the EPDM algorithm has not yet reached 100%. This shows that the new algorithm is better than the EPDM algorithm in the coverage degree. Verifying the effectiveness of the proposed algorithm. In Figure 6, the initial program, there are two algorithms of coverage. With the passage of time, the two algorithms are compared and the coverage decrease. The EPDM algorithm in the network time is within the sensor node uninterrupted coverage method. In addition, it is the target node of the monitoring area for continuous coverage until the energy consumption of the nodes is completed. At $t = 150$, this algorithm and the EPDM algorithm of the coverage rate decreased, the coverage rate is $k = 2$, $p = 40.24\%$; $k = 3$, $p = 64.05\%$; $k = 4$, $p = 82.19\%$. EPDM algorithm coverage of $p = 75.13\%$. It is shown that this algorithm is in the entire network survival period. The average coverage in $k = 4$ was higher than that of the EPDM algorithm average coverage rate, which can be explained by the fact that the same node under the action that has the coverage of the new algorithm is obviously higher than that of EPDM algorithm, verifying the effectiveness of the proposed algorithm [35]–[41].

V. CONCLUSIONS

The wireless sensor network coverage based on characteristic analysis proposes an energy balanced coverage algorithm with controllable parameters. The algorithm of the monitoring area coverage expected value calculation method proved the solving process using the least sensor node to complete the monitoring area of the expected value. At the same time, the algorithm of the moving target node completing the first coverage period expected value is calculated and deduced. In terms of energy, this paper gives a concrete algorithm to restrain the node energy consumption step and the algorithm description process. Finally, this paper uses different K value ranges, and the lifetime of the network and the network simulation experiments covering two aspects simultaneously are compared with the ETCA algorithm and EPDM algorithm. The validity and stability of this new algorithm has been verified. In the future, the main focus will be how to achieve effective coverage of multi-target nodes and how to improve the coverage of the boundary of the monitoring area.

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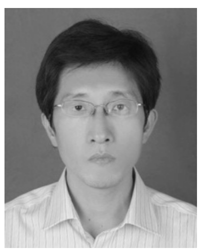

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