EBKCCA: A Novel Energy Balanced *k*-Coverage Control Algorithm Based on Probability Model in Wireless Sensor Networks

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Abstract

In the process of *k*-coverage of the target node, there will be a lot of data redundancy forcing the phenomenon of congestion which reduces network communication capability and coverage, and accelerates network energy consumption. Therefore, this paper proposes a novel energy balanced k-coverage control algorithm based on probability model (EBKCCA). The algorithm constructs the coverage network model by using the positional relationship between the nodes. By analyzing the network model, the coverage expected value of nodes and the minimum number of nodes in the monitoring area are given. In terms of energy consumption, this paper gives the proportion of energy conversion functions between working nodes and neighboring nodes. By using the function proportional to schedule low energy nodes, we achieve the energy balance of the whole network and optimizing network resources. The last simulation experiments indicate that this algorithm can not only improve the quality of network coverage, but also completely inhibit the rapid energy consumption of node, and extend the network lifetime.

Keywords: Wireless Sensor Network, Event Driven Mechanism, Coverage Probability, Network Lifetime

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1. Introduction

Wireless sensor network [1-4] is a new type of network architecture, which is formed by thousands of sensor nodes [5,6]. Each node has the abilities of sensing, computing, communicating and storage [7,8]; the characteristic of behavior is that the data acquisition and communication transmission is completed by multi hop method in the physical word. The physical world and information world are organically integrated [9-11], which realizes data acquisition, data storage, data computing and communication transmission link network service system [12,13].

Coverage quality and energy consumption are two important index of evaluating system performance of wireless sensor networks. Coverage quality is directly reflected in the deployment of the monitoring area nodes [14-16]. Network lifetime directly affects the quality of the entire network service, which is mainly reflected in the deployment of the energy consumption of nodes. In general, by topography， environmental factors and many other constraints, on the deployment node mode selection is a random pattern. Random deployment process, due to the unpredictable node location information in advance, would make a monitoring node in the midst of multiple covers, namely *k*-coverage, in the case of military battlefield, as shown in **Fig. 1**. Another case, due to the randomness, it is possible to make a monitoring area in the blind area. In order to achieve complete coverage, more nodes can only be added to achieve the coverage. Although the above two conditions can achieve complete coverage of the target in a certain extent, there are still some shortcomings. First, because of *k*-coverage exists, in the process of collecting and calculating data and the data in the process of communication, it is necessary to produce a large amount of redundant data, which will lead to large error and uncertainty. Second, the real meaning of the cover is not the entire monitoring area completely covered, but the target node of a certain are completely covered; without considering the presence of the target node, In the process of the complete coverage of the whole monitoring area, it will consume a lot of energy, and accelerated the speed of the collapse of the whole network system. Third, deployment nodes, due to the randomness, will inevitably lead to a covered area node density is too large, bottlenecks, and will eventually generate information redundancy in the channel, but also reduce the network expansibility.

Aiming at the shortage of the above, we proposed a novel energy balanced *k*-coverage control algorithm based on probability model. In this paper, the coverage probability and covering expectations of sensor nodes are solved by using the sector domains of the coverage area when the moving target node is passing through the monitoring area; in the energy, this paper gives the solution of multi point transmission and single point transmission. for the working of sensor nodes, under meet certain coverage, when the moving target node crosses the *k*-coverage area and the energy of a sensor node is within the threshold value or above the threshold limit, the node is placed in the sleep state by the sensor node adaptive transformation mechanism, and other sensor nodes use the node energy scheduling mechanism to complete the conversion of the energy of the sensor nodes to improve the network lifetime.

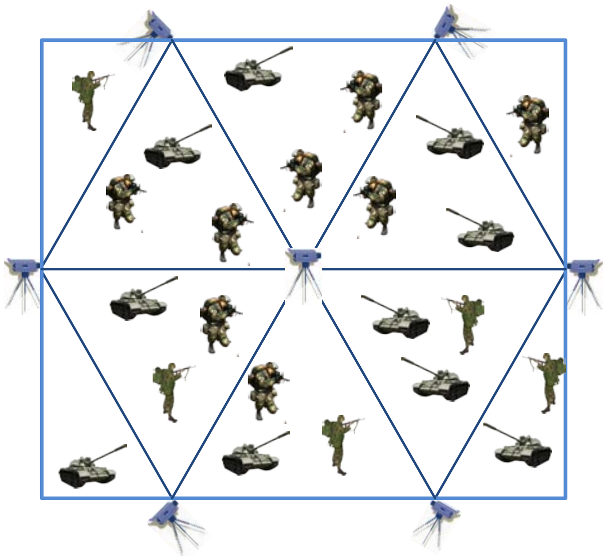

Fig. 1. Multi-objective coverage topology

2. Related Work

In recent years, many domestic and foreign experts have done a lot of detailed and in-depth research on the various characteristics of the wireless sensor network. A method of preserving connected covering algorithm is put forward in [17], which is based on the relative adjacency graph and the node's own deployment characteristics, and gives the network connectivity and coverage in the mobile deployment of sensor nodes. The topology structure of the sensor nodes in any mobile direction is maintained by the network connectivity, and the coverage of the moving target node is mainly determined by the constraints of network connectivity. Although the algorithm can keep the connectivity of the network to a certain extent, it is mainly reflected in the locality. For global, when the target node is accumulated to a certain number, the coverage probability will show a clear declining trend, the algorithm has some limitations. A configuration protocol of centralized cluster k-coverage is proposed in [18], which is analyzed by using the constructed network model of coverage protocol. It is proved that when k is larger than or equal to 3 and coverage of the network model formed the sensing radius r, at least k sensor nodes; the relationship between the communication radius and the sensing radius is given, and the calculation formula of the minimum number of sensor nodes in the coverage and the density of the sensor nodes in the monitoring area are also given at the same time. Although the results of the study can achieve the effective coverage of the target nodes in the monitoring area with the least sensor nodes, the algorithm complexity is high, and the deployment of sensor nodes is very rigor. Paper [19] proposed network lifetime maximize of *k* discrete obstacles coverage algorithm. The algorithm analyzes the conditions of the upper bound and the lower limit of coverage probability of the network model, and completes the effective coverage of the mobile target node; in the energy, a sensor node scheduling algorithm is proposed, which is based on the greedy algorithm for sensor nodes. The state transition is achieved by using the scheduling mechanism of sensor nodes; ultimately achieve the purpose of maximizing the network lifetime. In this paper, the sensor nodes in the monitoring area are always kept connected or intersect when the moving target nodes are covered. Once the mobile target node appears in blind area, it can not complete the effective coverage of the mobile target node; the network model is too idealistic. Paper [20] Gives a heuristic algorithm by mixed integer programming approach, which is a heuristic coverage for the sensing radius of the sensor nodes. It has great computational quantity and poor adjustability. In order to improve the algorithm of [20], Yang S H [21] will the target node coverage area as the monitoring area, and use the high density deployment sensor nodes to complete the connected coverage of the target coverage area. On the basis of the above two documents, Liu H [22] has done a lot of research work on target coverage problem. When a sensor node can only cover a target node, the solution process of the target node coverage probability is given. But the coverage of the monitoring area is narrow, which is not suitable for the actual coverage. The problem of sensor node scheduling is optimized by using artificial bee colony algorithm and particle swarm algorithm in [23]. Through the heuristic scheduling configuration, the optimal deployment path is found out, and the calculation method of the upper bound of network lifetime is given. An energy-efficient coverage and connectivity preserving routing algorithm is proposed in [23], which uses the network model to construct a double coverage area, and calculates the coverage probability and the coverage expected value by the probability related knowledge. Finally, the upper bound of the coverage expected value and the minimum number of sensor nodes are determined. Paper [23,24] can effectively cover the monitoring area in a certain degree, which can suppress the energy consumption of sensor nodes, but the calculation of the two algorithms is relatively high, and the coverage time of the monitoring area is longer.

Based on the probability model as the research background, this paper proposes the calculation method of the coverage expected value, and gives the proof of the probability relationship between the sensor nodes. Meanwhile, it also gives the proof of the coverage expected value of sensor node's energy consumption. In the energy, the energy scheduling strategy is introduced to optimize the communication path between nodes. Its purpose is to reduce the unnecessary network connectivity between nodes, to improve the entire network work time, and then to achieve the purpose of prolonging the network lifetime. Finally, the effectiveness and stability of the EBKCCA algorithm are verified by simulation experiments.

3. Network Model and Coverage Quality

In order to study the coverage problem of wireless sensor networks, the EBKCCA algorithm is based on the following four assumptions [25]:

(1) The sensor nodes are isomorphic form; perception radius and communication radius are disc-shaped.
(2) The sensor nodes can obtain the position information by GPS.
(3) All the sensor nodes have equal initial energy, the same perception radius, and the synchronous clock.
(4) The sensor nodes are randomly deployed in monitoring area by a square with L side length, and ensure the node's perception radius is far less than the length L, boundary effect can be ignored.

3.1 Basic Definition

Definition 1(complete coverage): In the monitoring region, all the target nodes are at least covered by a sensor node, namely: Euclidean distant is less than perception radius between sensor nodes and target nodes, $d_{(i,t)} \leq R_s$, it is called the complete coverage; sensor nodes that satisfy the condition are called the cover set.

Definition 2(*k*-coverage): In the monitoring region, any target node is covered by at least k

sensor nodes, which is called the *k*-coverage of the target node; the monitoring region is called *k*-coverage area.

Definition 3(coverage quality): In the monitoring region, the ratio that the sensing area of all the sensor nodes and the monitoring area are called the coverage quality. To some extent, it reflects the degree of coverage of the target node.

Definition 4(Multi-level coverage): probability, that any target node is covered by at least one sensor node, is *p*; when the target node is covered by multiple sensor nodes, the coverage probability is:

$$p_n=1-(1-p)^n \quad (1)$$

p_n is a multi-level coverage probability; p is the coverage of any sensor node; n is the number of sensor nodes.

3.2 Network Model

From the coverage angle of wireless sensor network, a network model is introduced, with a square for the monitoring area, with the sector for coverage area, as shown in **Fig. 2**.

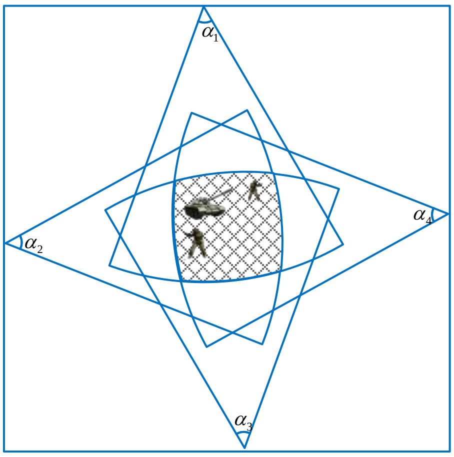

Fig. 2. *k*-Coverage network model

As you can see from **Fig. 2**, for the sensor nodes, square with L side length is the monitoring area, coverage area is a sector. At the same time it also gives different included angles of four sectors in radians. Tanks and soldiers as target nodes are placed in the k=4 coverage, and formed the target nodes. If the perception radius of sensor nodes is R_s, the area of sector is:

$$S_1=\pi R_s(\alpha_1+\alpha_2+\alpha_3+\alpha_4) \quad (2)$$

Set $\theta=\alpha_1+\alpha_2+\alpha_3+\alpha_4$,

$$S_1=\pi\theta R_s \quad (3)$$

For a square with L side length of the monitoring area, when the target node is always in the coverage area of sensor nodes, the entire network coverage probability was:

$$p_n=\pi\theta R_s/l^2 \quad (4)$$

Theorem 1: In the monitoring area, the expected value that the target node is covered by the sensor nodes is: $E(X)=\pi\theta(\sigma^2+l^2)/l^2$

Prove: **Fig. 2** network models as the research object. Assumes that perception radius of sensor nodes is R_s, which is randomly deployed in the monitoring area of a square with L side length. Sector is effective coverage area, and θ is the sum of included angles；Because the sensor node's perception radius R_s obeys the Normal Distribution，for the monitoring area of a square, the coverage expected value is:

$$E(X)=\int_0^{2l} P_N \frac{1}{(2\pi)^{\frac{1}{2}}\sigma}\exp\left(-\frac{(R_s-l)^2}{2\sigma^2}\right)\mathrm{d}R_s \tag{5}$$

Set: $x=\frac{R_s-l}{\sigma}$,

$$\mathrm{d}R_s=\sigma\mathrm{d}x \tag{6}$$

Bring formula (4)and (5) to formula (6):

$$E(X)=\int_{-\frac{l}{\sigma}}^{\frac{l}{\sigma}} \pi\theta(x\sigma+l)^2 \frac{1}{(2\pi)^{\frac{1}{2}}\sigma}\exp\left(-\frac{x^2}{2}\right)\sigma\mathrm{d}x=\frac{\theta\pi(\sigma^2+l^2)}{l^2} \tag{7}$$

Inference 1: Meet certain coverage probability, the use of a minimum number of sensor nodes to complete the monitoring area of multi-level coverage, the corresponding of the coverage expected value is: $(1-\varepsilon)/\ln(1-\pi\beta(\sigma^2+l^2)/l^2)$

Prove: All sensor nodes are relatively independent, which are randomly deployed in the monitoring area. According to the definition 4 and theorem 1, we can see that the coverage expected value, that any target node is covered by at least one sensor node from covering set, is:

$$E(K_1)=\pi\beta(\sigma^2+l^2)/l^2 \tag{8}$$

If the covering set exist n working nodes, the multi-level coverage expected value of any target nodes is:

$$E(K)=1-(1-\pi\beta(\sigma^2+l^2)/l^2)^n \tag{9}$$

When it satisfies a certain coverage quality, it is necessary to exist a minimal numberε, and it makes the multi-level coverage expected value is less thanε, limit existence.

$$1-(1-\pi\beta(\sigma^2+l^2)/l^2)^n\leq\varepsilon \tag{10}$$

Solving:

$$n\geq\ln(1-\varepsilon)/\ln(1-\pi\beta(\sigma^2+l^2)/l^2) \tag{11}$$

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

The calculation process of the coverage expected value and the multi-level coverage expected value are given in theorem 1 and inference 1. Generally, the moving trajectory of the target node is a fan shape. The probability theory and the method of mathematical geometry theory are used to accomplish the calculation of the coverage expected value. But, for the first time, when the moving target node enters the monitoring area, the problem that we must solve is how to get the first coverage expected value. Therefore, this paper introduces the theorem 2.

Theorem 2: When the target node is first entered into the monitoring area, the first coverage expected value of the moving target is: $E(X)=[1-(1-p)^N]p^{-1}$, N is the maximum number of transfer for mobile target nodes, p is the coverage probability of sensor nodes.

Prove: According to the probability theory, if X is the maximum number of transfer for mobile target nodes, the range of possible values for the X is $X\in[1,2,3\ldots N]$, When $X=m$ and $1\leq m\leq N-1$, namely: moving target nodes of the former n-1 times are not covered by the sensor nodes, the distribution density function of X:

$$P(X=k)=\begin{cases} p(1-p)^{k-1}, k=1,2,3\cdots N-1 \\ (1-p)^{N-1}, k=N \end{cases} \tag{12}$$

By the coverage expected formula:

$$E(X) = \sum_{k=1}^{N-1} kp(1-p)^{k-1} + N(1-p)^{N-1} \tag{13}$$

Set q=1-p, $S = \sum_{k=1}^{N-1} k(1-p)^{k-1}$, each side of the equation is multiplied by q, $qS = \sum_{k=1}^{N-1} kq^k$,namely:

$$S = \frac{1-q^{N-1}}{(1-q)^2} - \frac{(N-1)q^{N-1}}{1-q} = \frac{1-(1-p)^N}{p^2} - \frac{N(1-p)^{N-1}}{p} \tag{14}$$

Bring formula (14) to formula (13):

$$E(X) = p\left(\frac{1-(1-p)^{N-1}}{p^2} - \frac{(N-1)(1-p)^{N-1}}{p}\right) + N(1-p)^{N-1} = \frac{1-(1-p)^{N-1} + p(1-p)^{N-1}}{p} = \left[1\text{-}(1\text{-}p)^N\right]p^{-1} \tag{15}$$

Theorem 3: The sensor nodes are randomly deployed in the monitoring area according with the Poisson distribution with node density as parameter, N(s) as random variables. s is the network coverage area of any sensor node, and S is the area of the whole monitoring area.

Prove: The probability of any sensor nodes in the monitoring area is p, $p = |s|/S$. By the binomial theorem, when the k numbers of sensor nodes are in the monitoring area, the joint probability is:

$$p(N(s)=k) = C_N^k p^k (1-p)^{N-k} \tag{16}$$

For the entire monitoring area, sensor node density is $\lambda=N/S$, bring λ and p into formula (16):

$$p(N(s)=k) = C_N^k \left(\frac{\lambda|s|}{N}\right)^k \left(1-\frac{\lambda|s|}{N}\right)^{N-k} \tag{17}$$

According to calculations:

$$p(N(s)=k) = \left(1-\frac{\lambda|s|}{N}\right)^N \frac{(\lambda|s|)^k}{k!} \frac{N!}{(N-k)!(N-\lambda|s|)^k} \tag{18}$$

When the number of sensor nodes in the monitoring area increase indefinitely, namely: $N\to\infty$,

$$p(N(s)=k) = \frac{e^{-\lambda|s|}(\lambda|s|)^k}{k!} \tag{19}$$

3.3 Energy Conversion

The working sensor nodes will have certain energy consumption in a square monitoring area after a time t [26-27]. Because of the energy consumption of the sensor nodes, the coverage area is changed correspondingly. In order to inhibit the energy consumption of sensor nodes, and prolong the network lifetime, the energy consumption of multilateral and unilateral transmission is analyzed by using the node energy model in this paper, and the energy consumption of the computing, storage, and control, is ignored. The energy consumption model of the sender node is:

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

The energy consumption model of the receiver node is:

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

L is bits of transmitting data, *d* represents the Euclidean distance between the sensor nodes and the neighbor nodes, d_0 is the threshold of the distance between the communications nodes, when the distance between the communication nodes is less than d_0, the energy decay index is 4. On the contrary, decay index is 2; $E_{T\text{-elec}}$ represents the energy consumption of the communication node between the receiving and sending module.

EBKCCA algorithm regards network running time round number as the basic unit. Each round contains coverage control information and node state stable information two aspects. In the work stage, the working nodes always remain open, and in order to save the network energy all the redundant nodes are closed. Each node has a total of five kinds of running state which respectively are: judgment, competition, waiting, starting and sleeping state. The transformation relationship among the five kinds of states, are as shown in **Fig. 3**. When node density of a monitoring area is too large, the vast majority of the nodes in the region will meet the redundant nodes judging conditions. At this time, the nodes will enter a dormant state. Although this state can inhibit the node energy consumption, there also exists some shortage. The reason for this is that the perceived neighbor nodes once enter into a dormant state, it can cause large cover blind area in monitoring area, thus reduce the coverage quality. In order to avoid the happening of this kind of situation, EBKCCA algorithm uses that once a node enters into a sleeping state, wake up the neighbor nodes immediately, and let the neighbor nodes in the waiting state. The aim is that, first, reduce the density of nodes which may work, namely, select a node as a candidate working nodes directly. The rest nodes which are not chosen enter into sleeping state directly. Then in a candidate working nodes, we conduct the redundant nodes scheduling. Each candidate node elects itself into preliminary work state by probability. The candidate nodes which are failed to elect enter into the preliminary sleeping state. **Fig. 3** shows the node scheduling relationship in the covering control phase.

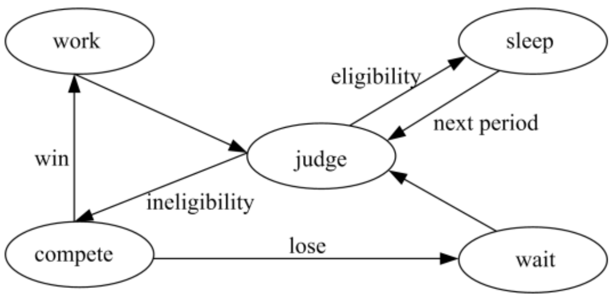

Fig. 3. State transition of nodes

A is a series of target area, *S*(*A*) represent the coverage area which is covered by the sensor nodes. Under the condition of coverage, the target coverage area is reconstructed by using the data acquisition of sensor nodes. Assuming that the target coverage area is based on the basic signal field and gives the specific spatial relation, when a sensor node receives a signal from the point (*x*,*y*), it can form a circular area with (*x*,*y*) as the center, with *R* as the radius and reconstructed every nodes in the circular area. In this case, it is more suitable for data acquisition in wireless sensor networks. The first case is suitable for some simple problems, namely, each sensor nodes in wireless sensor networks have perception region with the point as the center, with r as the radius. In a certain precision, each sensor nodes can collect or retrieve every target node from signal field in this area. The second case is suitable for some complex problems; this paper considers a random field of space homology. In the first case, all the target nodes *S*(*A*) have a mean value μ which is subject to the variance σ^2; the relation of any two sensor nodes are determined by the Euclidean distance in the second case:

$$\begin{aligned} R\left((x_1,y_1),(x_2,y_2)\right) &= \sqrt{(x_1-x_2)^2+(y_1-y_2)^2} \\ &= E\left[\left(S(x_1,y_1)-u\right)\left(S(x_2,y_2)-u\right)\right] = R(d) \end{aligned} \tag{22}$$

Measured value *S*(*x*,*y*) is implemented at the target node (*x*,*y*), and the data which needs to be transmitted to the access point is achieved, which contains some of the measurement data. *M* represents measurement data is collected in information retrieval for all the nodes. *M* was used to reconstruct a random field *S*(*A*). Using *M*, a sensor node of the closest point (*x*,*y*) is used to calculate the measured values to estimate the signal field in complementary set *A*. Therefore, the estimated value $\hat{S}(x_0,y_0)$ of the signal field at the point (*x*,*y*) is:

$$\hat{S}(x_0,y_0) = S(x_1,y_1) \tag{23}$$

$$(x_1,y_2) = \arg\min_{(u,v)\in A} d\left((x_0,y_0),(u,v)\right) \tag{24}$$

(*u*,*v*) is the closest (*x*,*y*) in *M*, meeting the quality requirements of network services, we set that the maximum distortion is D, defined as:

$$E\left[\left(\hat{S}(x,y)-S(x,y)^2\right)\right] \le D \quad \forall (x,y)\in A \tag{25}$$

Theorem 5: The distance between adjacent nodes (*u*,*v*) and (*x*,*y*)should be less than or equal to the difference between the variance and the half of maximum distortion.
Prove: According to formula (31) and formula (32):

$$E[\left(S(x,y)-\mu\right)\left(S(u,v)-\mu\right)] = E\left[\left(\hat{S}(x,y)-S(u,v)\right)^2\right] = 2\sigma^2 - 2R\left(d\left((x,y),(u,v)\right)\right) \tag{26}$$

Bring the formula (32) into the formula (33): $2\sigma^2 - 2R\left(d\left((x,y),(u,v)\right)\right) \le D$, namely:

$$R\left(d\left((x,y),(u,v)\right)\right) \le \sigma^2 - D/2 \tag{27}$$

Therefore, we set that the distance between two nodes is:

$$r = \max\left(d : R(d) \le \sigma^2 - D/2, d \in [0, d_{\max}]\right) \tag{28}$$

Considering the remaining energy of the node and the connection of signal field space at the same time, in order to prolong the network lifetime in each data information retrieval operation, a subset of the available sensor nodes is selected to collect data [29-31]. Therefore, the subset of the sensor nodes is selected to ensure the quality of the network service. So far, the problem of this paper is how to select the subset of the optimal sensor nodes in each data collection. If the subset of the optimal sensor nodes can be determined, the network can be reconstructed in the maximum and the network lifetime can be maximized.

4. Description and Analysis of Algorithms

4.1 EBKCCA Algorithm

The EBKCCA algorithm is based on a set of neighbor nodes in the Perception radius, the nodes are divided into several sub sets, and the nodes with high energy, computing power and communication ability are administrator nodes, other nodes are member node. In the network initialization, since the attributes of node are the same, we randomly select a node as the administrator node. First the member node sends a "Coverage" message to the administrator node. The administrator node sets up a certain storage space according to their own characteristics, and the information is stored in a list CL, the "Coverage" message mainly contains the attributes of the sending node and the current state, such as: the energy of the sending node, the ID information and the coverage of nodes and so on. After one or several cycles, the administrator node collects the sending information of all the nodes. According to the collected information, the administrator can sort the member nodes with the remaining energy and the coverage expected value, and it is stored in the list, all nodes are given a certain weight, so that the weight of the top node is higher than that of the rear node. According to the coverage of target node, the administrator node seeks member nodes from the list which are qualified to meet the conditions, and the member nodes are labeled. The administrator node sends a "Notice" message to the member node which schedules other member nodes to complete the corresponding coverage task.

4.2 EBKCCA Algorithm Description

EBKCCA algorithm is mainly divided into seven steps:

Step1: The coverage expected value of each member node is calculated, namely: $E(X) \cup \{(s_i,L)|s_i N(l,\sigma^2)/l^2\}$.

Step2: The administrator node stores the information of member nodes in a list CL; the "Coverage" message mainly contains the energy of the sending node, the ID information and the coverage expected value and so on.

Step3: After one or several cycles, the administrator can sort the member nodes with the remaining energy and the coverage expected value, and the higher weights are given to the top of the member nodes.

Step4: According to the coverage of target node, the administrator node seeks member nodes from the list which are qualified to meet the conditions, and the member nodes are labeled.

Step5: The administrator node seeks member nodes from the list. When the remaining energy of member node is higher than the threshold E_{thr}, a "Notice" message is sent to a member node, and then when a member node receives the message, the monitoring area is covered by the perception module.

Step6: If there is a target node that is covered by k member nodes, the administrator node will traverse the list once again to seek the member nodes that meet the coverage, and close them.

Step7: First the administrator node completes the list of traversal, if it can find out the best node by adaptive scheduling, the coverage of the monitoring area is completed, else go to Step 2.

4.3 Complexity of EBKCCA algorithm

Theorem 6: the complexity of algorithm is O(n) in best case; the complexity of algorithm is O(n^2) in worst case.

Prove: EBKCCA algorithm completes the conversion between member nodes by sending and receiving different types of information, and it can get the best nodes to complete the coverage by finding the list. If the EBKCCA algorithm completes the coverage of monitoring area is in a cycle or less than one cycle, the complexity of the algorithm is O(n); if the EBKCCA algorithm is more than one cycle or less than the maximum number of cycles, it needs to complete the coverage of N cycles, and the complexity of the algorithm is O(n^2).

5. System Evaluations

In order to verify the effectiveness and stability of the EBKCCA algorithm, this paper selects MATLAB7 as the simulation platform, the algorithms were compared with the four algorithms of [32] (Energy-Efficient Target Coverage Algorithm, ETCA), [33] (Linear programming maximum lifetime coverage with energy harvesting, LP_MLCEH), [26] (Optimization Strategy Coverage Control, OSCC). And [28] (Event Probability Driven Mechanism, EPDM) Experimental environment is WIN XP; RAM 2G, Dual-core CPU 1.7 G, the simulation parameters are shown in **Table 1**.

Table 1. Parameters of the simulation table

parameter	value	parameter	value
Monitoring area Ⅰ	100*100	R_c	*10m*
Monitoring area Ⅱ	200*200	$E_{\text{R-elec}}$	50J/b
Monitoring areaⅢ	300*300	$E_{\text{T-elec}}$	50J/b
R_s	5m	ε_{fs}	10(J/b)/m^2
Initial energy	5J	ε_{amp}	100(J/b)/m^2
time	600s	e_{min}	0.005J

Experiment 1: the simulation area is 300*300, this paper gives the coverage probability of different k values.

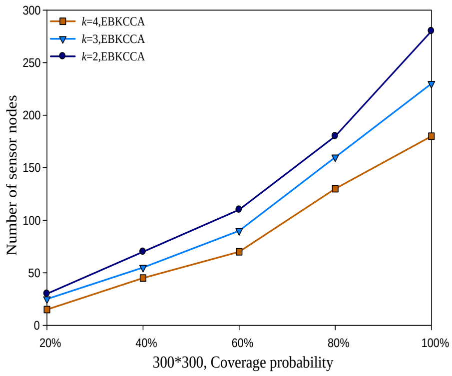

Fig. 4. Curves of k-coverage

In experiment 1, **Fig. 4** reflects a schematic diagram which shows the sensor nodes and the coverage probability of different k values in the 300*300 monitoring area. As it can be seen from **Fig. 4**, when the monitoring area is determined, coverage probability is increasing with the increasing number of sensor nodes. When k=2, Coverage Probability (CP) is increasing with the increasing number of sensor nodes. When CP=99.9%, it can be considered that the wireless sensor network achieves effective coverage, at this time, the number of sensor nodes are 280; when *k*=3 and the effective coverage is achieved, the number of sensor nodes are 231; when *k*=4, the number of sensor nodes is 183. When the coverage probability is between 85% and 99.9%, the coverage probability is increased obviously, and the main reason is that the greater the *k* value, the greater the coverage area [34,35].

Nodes are randomly deployed in different monitoring area. The communication path is optimized by the sensor node scheduling strategy, which reduces the energy consumption of sensor nodes, as shown in **Fig. 5**.

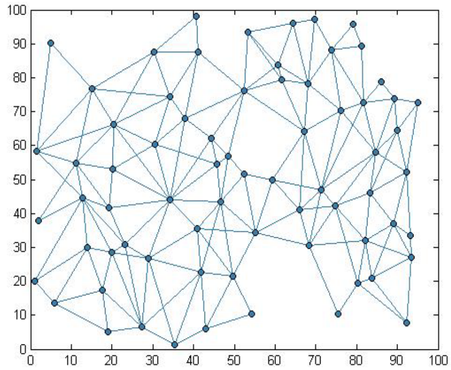

Fig. 5(a). 100*100m^2, Randomly deployed

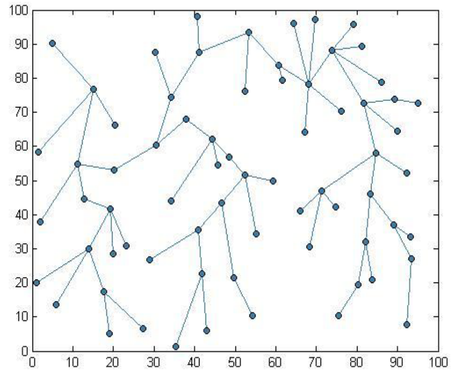

Fig. 5(b). 100*100m^2, Optimization Schematic

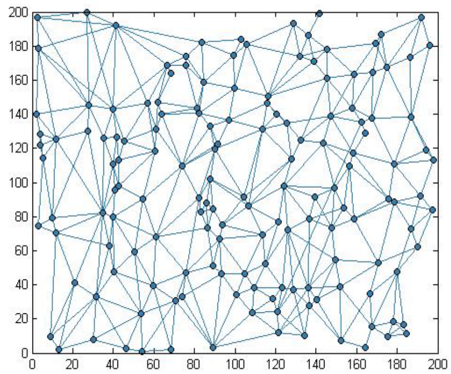

Fig. 5(c). 200*200m^2, Randomly deployed

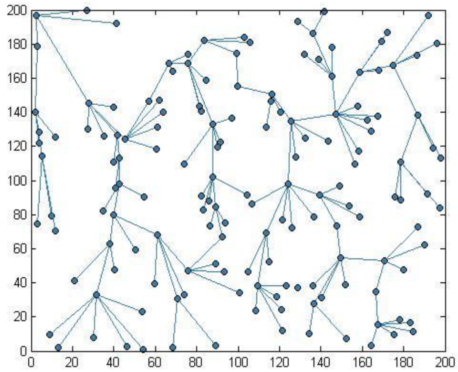

Fig. 5(d). 200*200m^2, Optimization Schematic

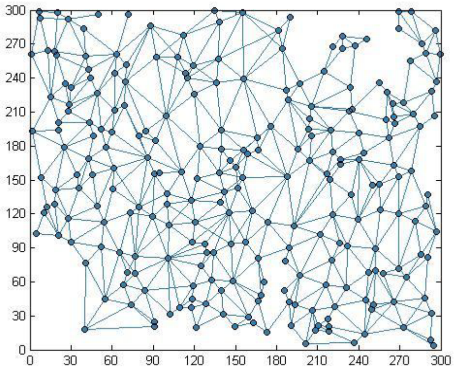

Fig. 5(e). 300*300m^2, Randomly deployed

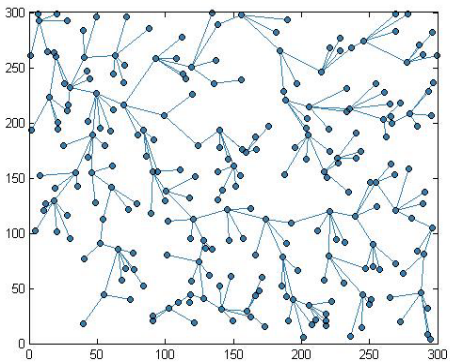

Fig. 5(f). 300*300m^2, Optimization Schematic

Fig. 5 reflects a state diagram which shows the initial distribution of the sensor nodes is in different monitoring area and communication path of sensor nodes is optimized. This paper takes 300*300 as an example. As it can be seen from **Fig. 5**, at the initial moment, the random deployment of 260 sensor nodes constitutes a large number of communication paths. Because of the existence of a large number of communication paths, the energy consumption of sensor nodes is very fast. If the sensor node energy is greater than or equal to the threshold of energy *E*, the EBKCCA algorithm shows that sensor node which the coverage probability is less than *p* enters the waiting state; sensor node which the coverage probability is more than or equal to *p* enters the competitive state. Once the competition is successful, the node becomes the starting node, and enters the working state. When sensor nodes sense a target node, they wake up the neighbor nodes, and continue to estimate whether the target node is selected as a working node by wake-up nodes with probability *p*. If the probability of acquisition is greater than or equal to *p*, they enter the working state; otherwise, they enter the waiting state. After some cycles, the energy of the nodes reaches balance; at this time, the number of sensor nodes is 188, and the total number of 72.3%. If the energy of sensor nodes is less than the energy thresholdε, the node is in the "death" state and it will not enter the scheduling state. The algorithm can suppress the energy consumption of a large number of sensor nodes, and prolong the network lifetime; at the same time, it also ensures the communication link between any sensor nodes.

Experiment 2: In the network lifetime, the EBKCCA algorithm is compared with the ETCA algorithm and the LP_MLCEH protocol. The experimental data is the mean of the 200 simulation data, as shown in **Fig. 6** to **Fig. 8**.

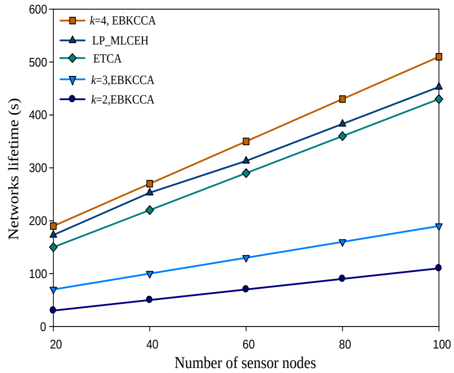

Fig. 6. 100*100m^2, Curves of network lifetime

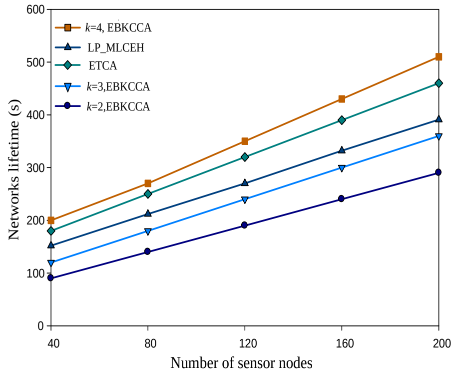

Fig. 7. 200*200m^2, Curves of network lifetime

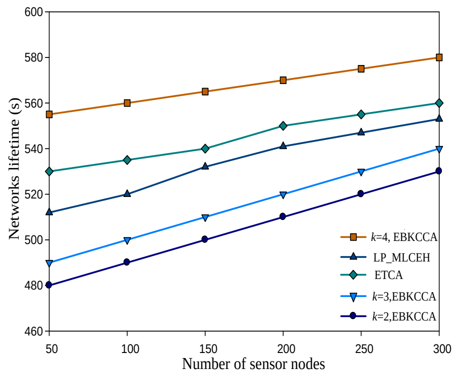

Fig. 8. 300*300m^2, Curves of network lifetime

The second experiment is in the different monitoring area, EBKCCA algorithm and ETCA algorithm and LP_MLCEH protocol in the contrast experiment of the network lifetime. In the experiment, *k* selects different numerical value; the network scale is changed by the number of nodes in the monitoring area. For the smaller scale of the monitoring area, the initial value of the number of nodes is 20, and gradually increases. It can be seen from the simulation that the lifetime of the wireless sensor network is a linear rising trend with the increase of the number of sensor nodes. The main reason is that the member nodes in the node set cover the target node by scheduling mechanism of nodes. In the same environment, compared with the ETCA algorithm and the LP_MLCEH protocol, the network lifetime of the EBKCCA algorithm is increased by 10.11%, 7.17%; for the larger scale of the monitoring area, the initial value of the number of nodes is 50, and gradually increases. The lifetime of the wireless sensor network is a linear rising trend with the increase of the number of sensor nodes. The rise is more than that of the smaller monitoring area, compared with the ETCA algorithm and the LP_MLCEH protocol, the network lifetime is increased by 15.23%, 12.79%.

Experiment 3: The EBKCCA algorithm is compared with the OSCC algorithm and the EPDM algorithm in the coverage probability. The simulation area is 300*300, the experimental data is the mean of the 200 simulation data, as shown in **Fig. 9** to **Fig. 11**.

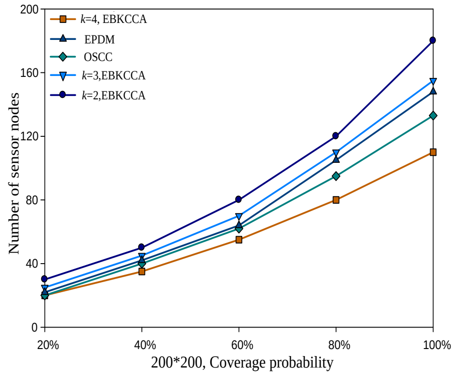

Fig. 9. 200*200m^2, Curves of network coverage probability

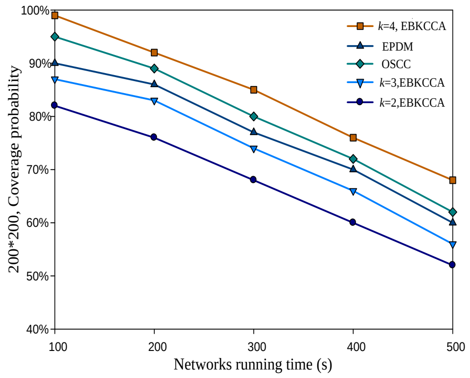

Fig. 10. 200*200m^2, Curves of network running time

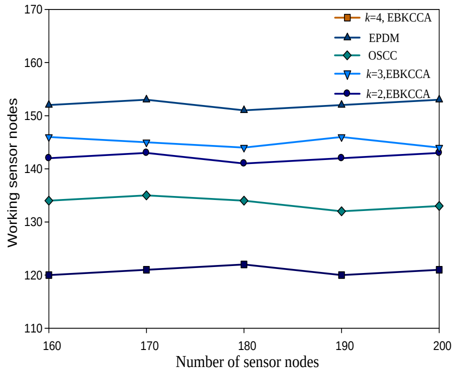

Fig. 11. Working nodes and sensor nodes contrast

The coverage probability of the three algorithms is increasing with the number of sensor nodes in **Fig. 8**. When CP=99.9% and k=2, the number of sensor nodes is 185; when k=3, the number of sensor nodes is 152; when k=4 and the number of sensor nodes is 185, the algorithm has reached 99.9%, namely, it has completed the k-degree coverage. However the EPDM algorithm and EBKCCA algorithm has not yet reached 100%, it shows that the coverage of the EBKCCA algorithm is higher than the EPDM algorithm and the EBKCCA algorithm, and the effectiveness of the algorithm is verified. In **Fig. 9**, the coverage probability of the two algorithms is quite in the initial, the coverage probability of two algorithms is declining trend with the time increasing. The main reason is that the EPDM algorithm and EBKCCA use uninterrupted coverage of the sensor nodes in the running time. That is, the target node is covered constantly in the monitoring area until the energy is consumed. When t=150, the coverage probability of three algorithms declines obviously. When k=2,3,4, CP_EBK2CCA=77.83%, CP_EBK3CCA=86.83%, CP_EPDM=88.52%, CP_OSCC=94.58%, CP_EBK4CCA=97.26%. When k=4, the coverage probability is higher than the mean coverage probability of EPDM and EBKCCA algorithm, which shows the coverage probability of EBKCCA algorithm is obviously higher than the two algorithms in the same node. The effectiveness of the algorithm is verified. When **Fig. 10** gives the same coverage probability, the number of working nodes of the EBKCCA algorithm is compared with that of the EPDM algorithm and the EBKCCA algorithm. When the number of sensor nodes is maintained between 140 and 180, the number of sensor nodes basically tends to be stable. When k=2,3,4, the number of nodes for this algorithm is maintained between 121 and 146, while the number of nodes in EBKCCA and EPDM algorithm is maintained between 134 and 152. Therefore, the mean value of the number of sensor nodes for this algorithm is less than the average of the number of nodes in the other algorithms, that is, the number of sensor nodes is reduced by 5.49%.

6. Conclusion

Based on the analysis of the coverage in wireless sensor network, this paper proposes a novel energy balanced k-coverage control algorithm based on probability model (EBKCCA). The algorithm gives the calculation method of the coverage expected value with the sector, and proves the solving process which uses the least sensor node to complete the monitoring area of the expected value. At the same time, the first coverage expected value of the moving target node is calculated and deduced in this algorithm. In the energy, this paper gives a detailed algorithm for restraining the energy consumption of nodes, and through the corresponding calculation, it is proved that the energy consumption of the multi transmission is less than that of the single transmission. Finally, in the network lifetime and coverage probability, the EBKCCA algorithm is compared with the ETCA algorithm, the LP_MLCEH protocol and the EPDM algorithm. The effectiveness and stability of the EBKCCA algorithm is verified.

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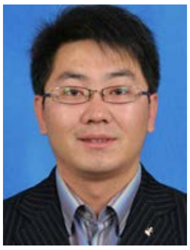

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