

A Novel Energy Efficient Multi-Target Associated Coverage Control in Wireless Sensor Network

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Abstract: The covering problem and node deployment is a fundamental problem in the research of wireless sensor network. The number of nodes and the coverage of a network can directly affect performance and operating costs. For this reason, we propose an EMAC algorithm (Energy Efficient Multi-target Associate Coverage Algorithm). The algorithm uses the correlation between the nodes and dynamic grouping to adjust coverage area. Within the coverage area, we use the greedy algorithm to optimize the coverage area. So, the target node is uniformly covered by other sensor nodes and the network resources is optimized. To ensure the energy balance in wireless sensor network and extend the lifetime of it, we only wake partial nodes to work in a cycle, so that, they can work in turn. Experiments show that the algorithm can effectively reduce energy consumption, with better adaptability and effectiveness.

Keywords: Coverage control, coverage rate, energy efficient, wireless sensor network(WSN).

1. INTRODUCTION

A wireless sensor network (WSN) is a self-organized network formed from a large number of sensor nodes with the ability of sensing, computing and communicating. And it's widely used in national defense, transportation, medical, environment monitoring and various scientific fields [1, 2].

As one of the fundamental issues in WSN. Node deployment and plan can effectively reflect the monitor of physical space and directly affect the service quality provided by the network. Through the node relevance and dynamic adjustment to improve the network coverage, and make it better to implement target monitoring, data obtaining and data processing tasks with the help of greedy algorithm to optimize network resource allocation [3-5]. In addition, how to optimize the node configuration with minimal working nodes for effective monitoring and covering and low energy consumption while satisfying the coverage quality is a key problem in WSN. In recent years, numerous scholars and experts have made much effective research about the coverage and energy consumption of WSN, and have gain some progress. An efficient bipopulation-based evolutionary full area coverage (BEFAC) algorithm is put forward. The algorithm constructs a complete covering area mainly based on population optimization, and through the adaptive function to calculate the minimum number of required nodes within monitoring area, finally determines the minimum number of

nodes and the corresponding coverage. A centralized K-degree coverage protocol is given in paper [6]. The network model is established mainly through the communication function between nodes and node perceiving area in this protocol, and using the proportional relationship between the model to determine the K-degree coverage. Paper [7] introduces an energy-saving coverage calculation method. This method gets the coverage of target node through the way node moves. In the direction of energy, it was mainly to achieve effective coverage of the monitoring area by the scheduling policy of nodes. Paper [8] proposes a linear energy-saving covering method. Firstly, and scheduling the nodes. Supply them after the completion of certain coverage to extend the lifetime of network.

The constraints of algorithms above are based on perceptual model. Using the geometric calculation method allows redundant nodes dormancy by scheduling mechanism. But In the actual application, it is often restricted by external factors. In theoretical calculation, the network model is too idealistic with a high complexity. We present an energy efficient multi-target associated coverage algorithm. Cover aged the monitored area as long as meet certain coverage from the perspective of the coverage accuracy. Let some nodes in working state by using the sensor scheduling strategy in the covering process, the remaining in a dormant state or others. Then optimized by the greedy algorithm and waking some nodes after a period of τ_i . Then, regrouping target and nodes and repeating the above until the target set is empty to prolong the lifetime of the network, reduce the generation of redundant data, improve the configuration of the network resource. Simulation results show the proposed method can prolong the lifetime of the entire network at a low cost,

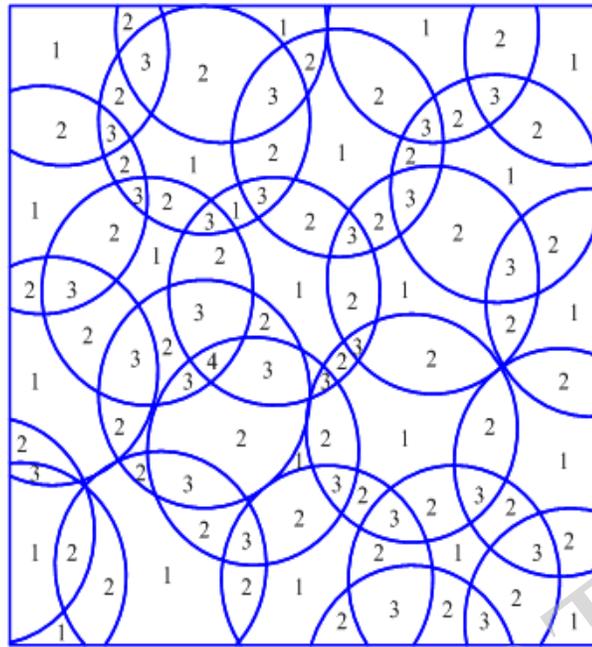


Fig. (1). Network K-Degree Coverage Model.

reduce the complexity, depress the network overhead generated by the forwarding data between nodes, and optimize the configuration of the network resource to uniformly distribute within the coverage area.

2. NETWORK MODEL AND ANALYSIS

2.1. Problem Description

This research is based on the following basic assumptions:

Assumption 1: The communication range and sensing range of the wireless sensor networks are disc-shaped.

Assumption 2: coverage radius of nodes is equal, and the movement of nodes is synchronized and parallel.

Assumption 3: The node localization is acquired by some position algorithm.

According to the situation, in order to obtain data exactly and comprehensively, it is often need to deploy a large number of sensor nodes in the monitoring area to multiple-cover the target. However, the conclusion is opposite from the perspective of energy consumption. So, it is better to multiple-cover the target node only and keep the others remain.

Generally, the attention of a target is directly reflected by the coverage number. The concerned target nodes have a higher coverage number, as shown in Fig. (1):

2.2 Correlation Coverage

Considering the coverage relationship between the correlation sensor nodes and the target nodes within the target area, data mining technology is imported into the correlation

coverage [9]. Supposing that, one or more nodes having a higher energy, then, allowed them to work firstly, the remaining nodes utilize the redundant node scheduling mechanism to enter the dormant state. After a period τ_i , waking some nodes, and then selecting one or more nodes with a higher energy by taking the residual energy and the covering quality into account, and repeated above to keep monitoring the target area. The concerned target nodes are uniformly distributed within the coverage area after optimized by the greedy algorithm. After removing the selected target nodes, it reforms a new target set. Repeating the operation until the target set is empty. The energy of nodes is not only balanced, but also saved after several times.

Intercepting partial coverage area of Fig. (1) and taking working nodes, dormant nodes and target nodes into analysis, as Fig. (2) shows.

Fig. (2) shows the correlation among working nodes, dormant nodes and target nodes. Let the sensing radius of the sensor nodes to be r . Node 1,2,3,4 are in working state, the others in dormant state, acquiring the information of target nodes by sensing range. The relationship between node coverage and target nodes is shown in Table 1:

To calculate the correlation between them, let the frequent item to be 2. We can classify the correlation between sensor nodes and target nodes from correlation coverage within target area in Fig. (2) and the relationship between node coverage and target nodes in Table 1, as shown in Table 2:

2.3. Solution

Let point A represents a series of target areas and $S(A)$ shows the coverage area which is covered by placed sensor

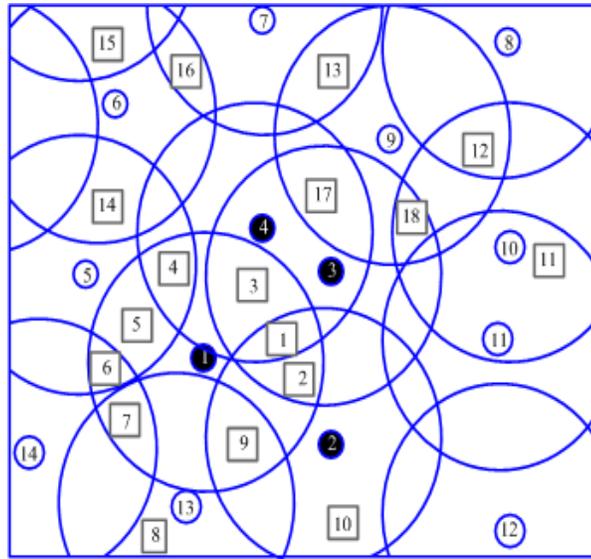


Fig. (2). Correlation Coverage with Target Area.

Table 1. The Relationship Between Node Coverage and Target Nodes.

Nodes	Target	Nodes	Target
1	1,2,3,4,5,6,7,9	8	12
2	1,2,9,10	9	12,13,17,18
3	1,3,4,17,18	10	11,12,18
4	1,3,4,17	11	11
5	4,5,6,14	12	0
6	14,15,16	13	7,8,9
7	13,16	14	6,7

Table 2. The Correlation Between Sensor Nodes and Target Nodes.

Nodes	Target	Nodes	Target
1	1,2,3,4	1,3	1,3,4
2	1,2,3	1,4	1,4
3	1,3,4	1,9	1,2
4	1,4,5	1,17	3,4
5	1,5	2,3	1,3
6	1,5,14	2,9	1,2
7	1,13,14	3,4	1,4
8	0	3,17	3,4

Table 2. contd...

Nodes	Target	Nodes	Target
9	1,2,13	4,5	1,5
10	0	4,6	1,5
11	10,11	5,6	1,5
12	8,9,10	6,7	1,14
13	7,9	12,18	9,10
14	5,6	17,18	3,9
15	0	1,2,3	1,3
16	6,7	1,2,9	1,2
17	3,4,9	1,3,4	1,4
1,2	1,2,3		

nodes. Under the coverage conditions, the access sensor nodes are used for collecting data and reestablished a target coverage area. Assume that the target coverage area is established based on basic signal field and the relationship with a particular space is known to us. When a sensor node receives a signal from a point (x,y) , the node forms a roundness with the center is (x,y) and the radius is r , and reestablished each node within the circular area. The case is more suitable for data acquisition operations for wireless sensor networks. The first scenario is adapted to some simple questions, which means that each sensor node in a wireless sensor network should make the point as a center of a sensitive area with a radius r . Each sensor node can collect or retrieve the every target node within the signal field under certain accuracy. The second scenario applies to some complex problems. In this paper, we research a space homologous random field, for the first case, all the target nodes $(x,y) \in A$, $S(A)$ has a mean value μ subordinate to variance σ^2 . For the second case, the relationship between any two sensor nodes in set A is determined by the Euclidean distance between two points:

$$R((x_1,y_1),(x_2,y_2)) = \sqrt{(x_1-x_2)^2 + (y_1-y_2)^2} = E[(S(x_1,y_1)-u)(S(x_2,y_2)-u)] = R(d) \tag{1}$$

The equation achieves the measured value $S(x,y)$ of the target node (x,y) , and completes the collection of data for a access point, which contains some measurement data. Suppose M represents all nodes which are retrieved for data collection. \bar{M} is the complementary set of A . The data obtained from M are used for reestablishing random field $S(A)$. The sensor node which is closest to the point (x,y) in M is used to calculate a measurement value for estimating the signal field in \bar{M} . Therefore, the estimated value $S_e(x_0,y_0)$ in (x,y) can be calculated as follows:

$$S_e(x_0,y_0) = \lambda S(x,y) \tag{2}$$

$$(x_1,y_2) = \arg \min_{(u,v) \in A} d((x_0,y_0),(u,v)) \tag{3}$$

Where (u,v) is the closest point to (x,y) in M . Under meeting the requirements of network service quality, we define the maximum distortion D as follow:

$$E[(S_e(x,y)-S(x,y))^2] \leq D \tag{4}$$

In the considering of residual energy and space contact in signal field, in order to prolong the network lifetime in each data retrieval operations, it is necessary to select a subset from available sensor nodes for collecting data. Therefore, the subset ensures requirements of a particular network service. So far, the problem addressed in this paper is how to select an optimal subset of sensor nodes in each data collection, which can be used for reestablish the network and maximum the lifetime of the network.

2.4. Algorithm Description

In the need of algorithm description, the target set is expressed as $T = \{t_1, t_2, t_3, \dots, t_k\}$ and sensor node set is indicated as $S = \{s_1, s_2, s_3, \dots, s_n\}$. Because the frequent item is 2, any target node is covered by two or more sensor nodes.

Step 1: deploying N sensor nodes randomly within the target monitoring area, select the target set from frequent itemset T_{max} and sensor node set S_{max} by the coverage area and the relationship between sensor node and target node, where we could select the high-energy sensor nodes.

Step 2: Let the optimal subset $G'(S', T', E', W') = G(S, T, E, W)$, greedy algorithm is applied to calculate the coverage set and energy consumption of target node. When the energy of a target node is less than a specific value, return to G' , otherwise, select a higher energy sensor node as a coverage node.

Table 3. The Relationship Between New Association Target and Association Nodes

Nodes	Target	Nodes	Target
11	10,11	17	3,4,9
12	8,9,10	12,18	9,10
13	7,9	17,18	3,9
14	5,6	1,17	3,4
16	6,7	3,17	3,4

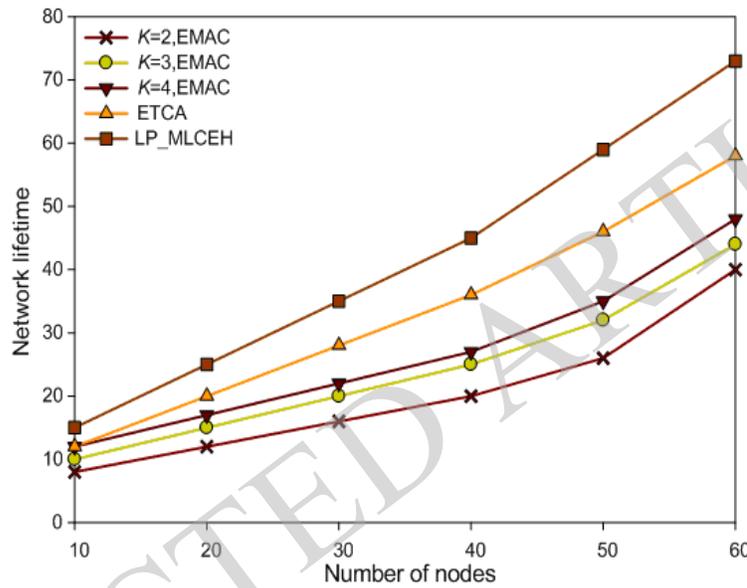


Fig. (3). 100*100m2, Number of Nodes and Network Lifetime.

Step 3: After remove the selected frequency items from set T , a new target set T_k is formed. Determine whether the target set T_k is empty, if empty, go to step 5.

Step 4: Apply greedy algorithm. Suppose input items: $G(S,T,E,W)$; output items: optimal subset $S_N = \{S_{hn} \mid n=1,2,3,\dots\}$. Initialize $S_N = \Phi$, $n=1$, $G(S',T',E',W') = G(S,T,E,W)$, judge whether S_N is empty. If not, $S_N = S_N \cup S_{hn}$, $n=n+1$.

Step 5: calculate the energy cn of converged target area for current sensor node, if $c_n \geq w$, go to step 2.

Step 6: Calculate whether exist a target node uncovered. If existed, the target is covered only by one sensor note. If the targets are all covered, then the complete coverage is achieved.

Process analysis: Let Table 2 as an instance, Table 2 shows that association set of target nodes $T_1 = \{1,2,3\}, T_2 = \{1,2,9\}, T_3 = \{1,3,4\}$ is covered by sensor nodes $S'_1 = \{1,3\}, S'_2 = \{1,2\}, S'_3 = \{1,4\}$. Select a higher

energy sensor node to work, if energy of sensors $(s_1, s_2) \geq (s_3, s_4)$, let (S_1, S_2) works first and (S_3, S_4) sleep. After a time cycle τ_i , determined whether the energy of sensor node is smaller than w (an give value), if the energy is greater than or equal to the given value, remove target node $T' = \{1,2,3,4,5,6,7,9,10\}$ which is covered by node (S_1, S_2) , and then reestablish the relationship between sensor nodes and target nodes, as show in Table 3:

3. SYSTEM EVALUATION

In this paper, we took two experiments to illustrate the adaptability and effectiveness of the algorithm to evaluate the performance. In order to verify the balance of network energy more, the proposed algorithm was compared with algorithms in [10] and [11] by compared experiments. Three different monitoring areas were applied respectively under the same conditions in the experiments and the comparison experiment processes of different parameters were shown from Fig. (3-8):

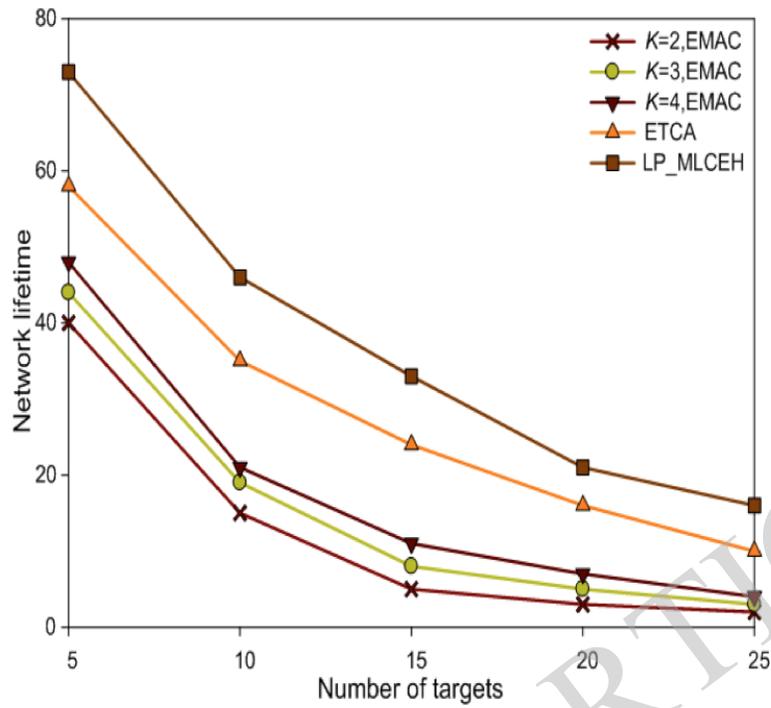


Fig. (4). 100*100m2, Number of Target and Network Lifetime.

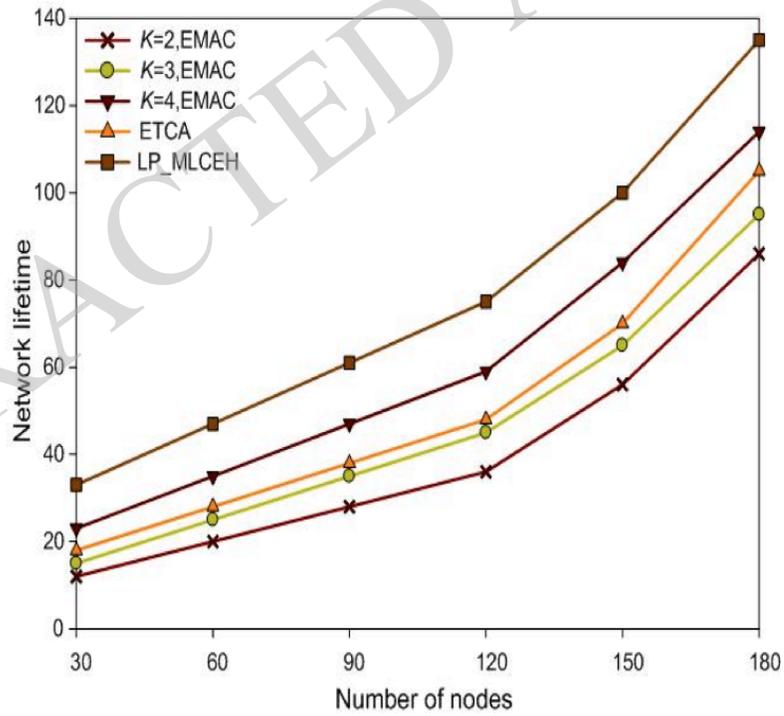


Fig. (5). 200*200m2, Number of Nodes and Network Lifetime.

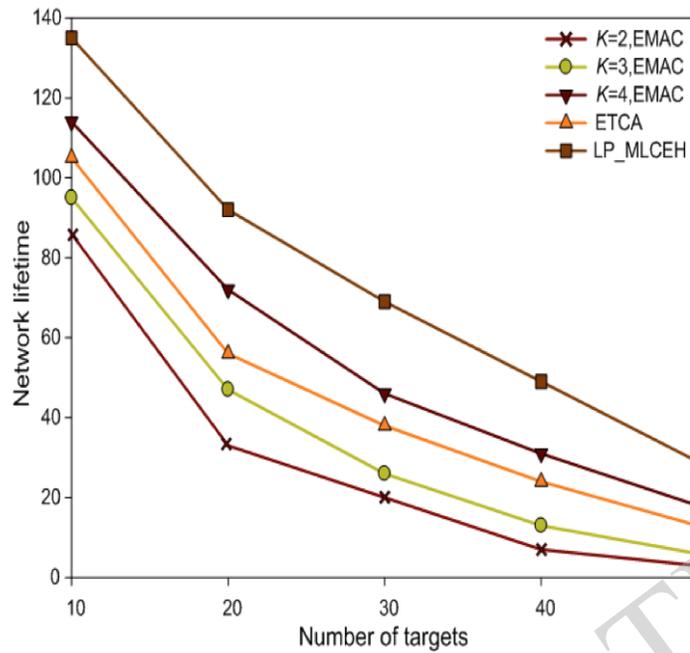


Fig. (6). 200*200m2, Number of Target and Network Lifetime.

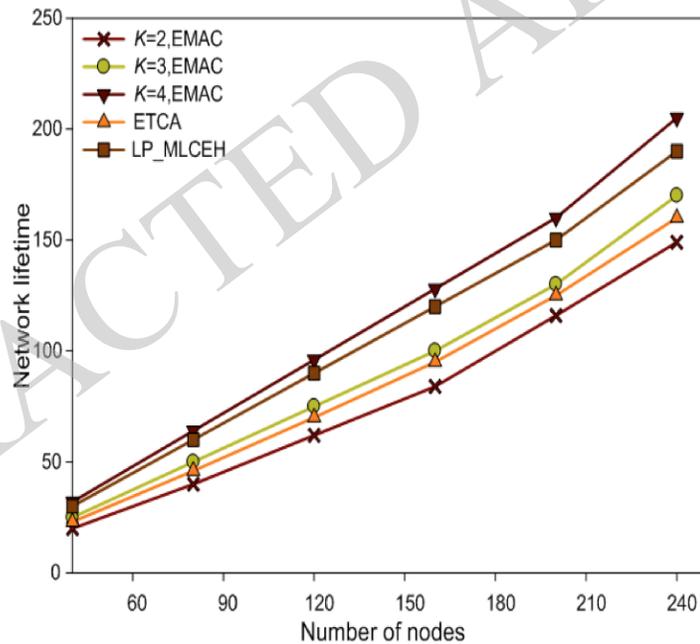


Fig. (7). 300*300m2, Number of Nodes and Network Lifetime.

Form Fig. (3-5) shows the network energy consumption in different monitoring areas. Energy-efficient target coverage algorithm (ETCA) [9] and Linear programming maximum lifetime coverage with energy harvesting (LP_MLCEH) [10] were contrast algorithms of the proposed algorithm. Fig. (3) shows that at the beginning period of three algorithms, the network lifetime was increased with the increase of the number of nodes. However, due to the limit of the range of parameters and the closed state of redundancy nodes, the network lifetime in our algorithm is less than that of other two algorithms at the balance of network energy

state. Because of the same reason, the network energy is also less than that of the other two algorithms in the process of covering the target node. In Fig. (5), due to the expansion of monitoring area, most of the redundant nodes are in working condition, which prolong the network lifetime. When $K=3$, the network lift cycle calculated from the proposed algorithm was greater than that of ETCA algorithm; when $K=4$, the network lifetime was greater than that of contrast algorithms. Fig. (6) illustrate the changing process of network lifetime during the process of the coverage of target nodes. With the increase of the number of target node, network lifetimes of

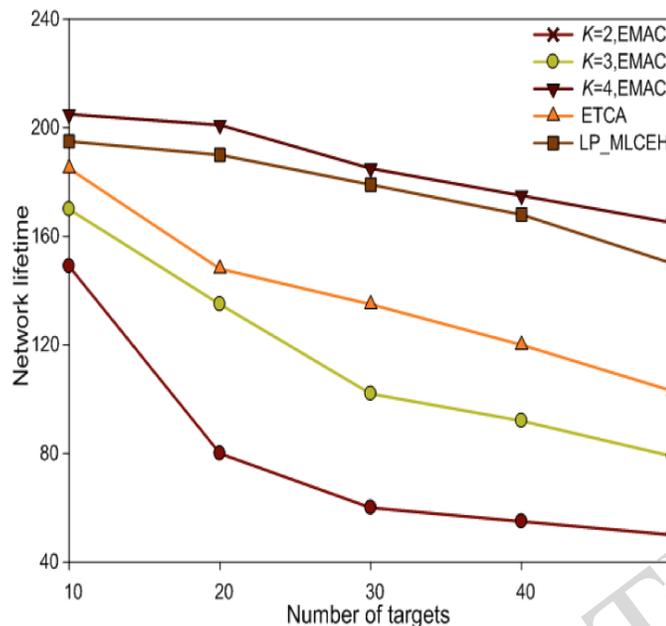


Fig. (8). 300*300m², Number of Target and Network Lifetime.

three algorithms were reduced and keep balance at last. But the average decline rate of our algorithm was less than that of other two algorithms during the process of decline. The mainly reason of the phenomena is when some parts of the monitoring area with dense sensor nodes, which means that the coverage expected value of the area is larger than others. Wake up partially redundant sensor nodes in working condition by scheduling mechanism of sensor node, which increase the coverage strength and improve the network lifetime. The same principle described above for monitoring area of 300*300m².

CONCLUSION

In this paper, we proposed an energy-efficient multi-target association covering algorithm through theoretical analysis of wireless sensor network. The algorithm makes full use of the association between sensor nodes and target nodes and wake up mechanism to achieve the coverage of the target nodes in monitoring area. In terms of extending network lifetime, we designed the wireless sensor network lifetime problem to looking for the maximization of coverage set under condition of energy constrained, and then the greedy algorithm and scheduling mechanism were converted dynamically to resolve this problem. The experiment results show that the proposed algorithm is effectively and prolong the wireless sensor network lifetime. In the future work, we will focus on how to solve the multi-hop transmission energy consumption problem in between sensor nodes and access points.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

ACKNOWLEDGEMENTS

This work is supported by the Natural Science Foundation of Henan Province Education Department under Grant (No.2014B520099, 14A510009); the Natural Science and Technology Research of Foundation Major Project of Henan Province under Grant (No.142102210471, 142100220568, 14210221 0063); China Postdoctoral Science Foundation under Grant (No. 2014M562153); the Natural Science Foundation of Luoyang Major Project under Grant (No. 1401037A).

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Received: September 16, 2014

Revised: December 23, 2014

Accepted: December 31, 2014

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