



NODES CONTROL ALGORITHM DESIGN BASED COVERAGE AND CONNECTIVITY OF WIRELESS SENSOR NETWORK

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Abstract- Coverage and connectivity are two important problems in wireless sensor network. This paper focuses on the wireless sensor network communication radius in the high density of sensor nodes deployed randomly and two times smaller than the sensing radius; put forward a distributed k coverage multi connected node deployment algorithm based on grid. Simulation results show that the algorithm in this paper while guaranteeing the wireless sensor network coverage and connectivity can reduce the number of the active state nodes effectively, prolong the wireless sensor network lifetime. Theoretical analysis results show that this article nodes deployment algorithm achieves multi connected

Index terms: Stay cable; positive pressure arch effect; mechanism; friction coefficient; ANSYS; contact analysis.

I. INTRODUCTION

With the development of wireless sensor technology and manufacturing microelectronic technology, the wireless sensor network consist of a large number of micro sensor nodes which own perception, calculation and communication ability is applied to the military or civilian areas, such as environmental monitoring, industrial control, battlefield surveillance, detection of high-risk environment, biological medicine, intelligent household and health monitoring [1].

Wireless sensor network is composed of large number autonomous nodes which densely deployed in the target region and using multi hop, wireless communication mode, self large-scale high density wireless sensor network system organization. Wireless sensor network is widely used in fields of military, environmental monitoring, medical and health and forecast system. The effective of nodes deployment in the wireless sensor network is an important prerequisite for the normal operation of the wireless sensor network [2].

Coverage problem is the basic problem in wireless sensor network nodes deployment, under the condition of the sensor node energy, perception, communication and computing ability limited, using a certain strategy of software and hardware, and ensure the coverage area and coverage time, realize effective awareness and monitoring, is an important indicator of wireless sensor network perception service quality, is also a hot problem in wireless sensor network research [3].

In many applications, there are usually a variety of monitoring objects in the monitoring area. Such as, the sensors nodes need to monitor water temperature, salinity, ph, etc in water environmental monitoring, and the sensors nodes need to monitor a variety of chemical diffusion in factory pollution warning [4].

Since the hardware cost of current sensor node is higher, in Multi-Object monitoring applications, each node assembly a variety of different types of sensors, the nodes are heterogeneous. When the node energy is limited, carrying the more sensors, the life of node is shorter. Two important problems should be considered in multiple objects monitoring wireless sensor network coverage, namely how to use smaller cost of wireless sensor network to obtain the ideal wireless sensor network coverage performance, and how to weigh the importance of wireless sensor network monitoring of different child objects according to different child objects [5].

Heterogeneous characteristics of heterogeneous wireless sensor network give expression to three aspects including node heterogeneity, link heterogeneity and wireless sensor network protocol heterogeneity [6]. Nodes heterogeneity includes perception ability, calculation ability, communication ability; communication ability, the heterogeneity of the respect such as energy, communication ability, perception ability, and energy make the biggest influence about coverage.

The coverage problem research in the existing literature about randomly deployment of the wireless sensor network is less [7]. References [8] in view of the heterogeneous cluster node, this paper proposes a routing protocol based evolutionary algorithm, effectively reduce the cluster nodes when handling data combination and separation of errors, prolong the survival time of wireless sensor network, but did not give the algorithm of non-cluster node. References [9] put forward the efficient dynamic clustering strategy (EDCS) effectively solve the selection problem of the multi-level heterogeneous wireless sensor network cluster node, effectively improve the performance of wireless sensor network and prolong the survival time of wireless sensor network, but did not give a specific node deployment algorithm. References [10] proposed by increasing heterogeneous nodes to prolong the survival of WSN, but did not consider heterogeneous node perception problem. References [11] proposed to expand virtual force algorithm (EX - VFA) algorithm, to solve the sensing radius of heterogeneous wireless sensor network node deployment problem, but consider less to the connectivity and data fusion problem. References [12] put forward a kind of applicable to perceive the radius of the heterogeneous wireless sensor network coverage optimization algorithm, effectively improve the heterogeneous wireless sensor network coverage. References [13] is proposed based on integer vector planning multi-objective multiple coverage algorithm, can effectively solve the problem of multiple target monitoring, but perception model used in the two algorithm is relatively simple.

Nodes deployment in wireless sensor network can be divided into randomly deployment and deterministic deployment. Randomly deployment refers to the scattering mass nodes deployment, according to the specific deployment means, often assume that nodes are distributed uniformly or Gauss distribution in target area. This deployment method is suitable for harsh environment or large-scale wireless sensor network. Deterministic deployment is by the artificial node placed in the specified location, suitable for small scale environment. Because different applications require different coverage in reference [14] and the nodes energy, memory, computer ability is limited, nodes failure due to energy depletion or being affected by environment factors. Therefore

the wireless sensor network needs to have higher fault-tolerant ability to ensure the normal operation of the wireless sensor network. In the fault tolerance ability of the higher wireless sensor network, every point in the region is coverage by at least k ($k > 1$) nodes and the wireless sensor network to achieve the multi connected.

Nodes coverage method in reference [15] can be centralized, distributed or local. For the centralized algorithm, according to the information of the entire wireless sensor network, calculated from a decision node and the node deployment decision.

For example: coverage decision method proposed by references [16] application of voronoi diagram, using the concept of k order voronoi diagram to test the wireless sensor network coverage. This algorithm is slow, low efficiency, but the demand of the decision node communication ability and energy is very high. In the distributed or local algorithm nodes according to oneself and the information of surrounding neighbors independent deciding the state of nodes.

For example, references [17] proposed the combination by method CAP and SPAN protocol to realize coverage and connectivity of wireless sensor network, the CAP algorithm is a distributed control strategy, independently determine the status of the node, the efficiency is higher than the centralized algorithm. The existing k coverage algorithm does not consider the connectivity of nodes, especially the connectivity of the communication radius less than two times sensing radius.

For example, references [18] proposed a heuristic greedy deployment algorithm; only consider the coverage of the target without considering the connectivity of nodes. References [19] proposed a distributed algorithm for perimeter covered only considers the communication radius is greater than or equal to two times sensing radius. References [20] proposed the algorithm does not consider the node energy in the selection node, node redundancy is high.

This paper presents a distributed node deployment algorithm in the communication radius is less than two times sensing radius, the monitoring region is divided into grid, according to the energy of the nodes and grid coverage contribution to select nodes to the active state, making the monitoring area to k coverage, achieving multiple connected. The remaining nodes go to sleep state.

II. RELATED WORK

A Assumption

To simplify the calculation, randomly deploy the quantity N of the same mobile nodes in the monitored region and mobile wireless sensor node s_j owns wireless sensor network ID number j .

The same wireless sensor nodes in the wireless sensor network own the same sensing radius R_s , the same communication radius R_c , and $R_c = 2R_s$.

The wireless sensor node can obtain the location information of itself and its neighbor nodes.

The mobile node owns E_{ini} initial energy and is sufficient to support the completion of the mobile node position migration process.

The mobile node sending 1 byte data consumes E_s energy and receiving 1 byte data consumes E_r energy.

The distance between the node s_a and the node s_b is $d(s_a, s_b)$.

B. Coverage Model

The monitored area owns $A \times B$ pixels which means that the size of each pixel is the $\Delta x \times \Delta y$.

The perceived probability of the i -th pixel is perceived by the wireless sensor network is $P(p_i)$, when $P(p_i) \geq P_{th}$ (P_{th} is the minimum allowable perceived probability for the wireless sensor network), the pixels can be regarded as perceived by the wireless sensor network.

The i -th pixel is whether perceived by the wireless sensor node perceived to be used $P_{cov}(P_i)$ to measure, i.e.

$$P_{cov}(p_i) = \begin{cases} 0 & P(p_i) < P_{th} \\ 1 & P(p_i) \geq P_{th} \end{cases} \quad (1)$$

The coverage rate is the perceived area and the sum of monitoring area ratio is defined in this article, i.e.

$$R_{area} = \frac{S_{area}}{S'_{area}} = \frac{\Delta \times \Delta \times \sum_{x=1}^n \sum_{y=1}^n P_{cov}(p_{xy})}{\Delta \times \Delta \times n \times n} \quad (2)$$

Among them, S_{area} is the perceived area while S'_{area} is the sum of monitoring area.

C. Perceived Model

This article defined the event that the i -th pixel p_i is perceived by the ID number j wireless sensor nodes is r_{ij} and the probability of occurrence of the event is $P(r_{ij})$ which is the perceived probability $P(p_i, s_j)$ that the pixel p_i is perceived by wireless sensor node s_j , i.e.

$$P(p_i, s_j) = \begin{cases} 1 & \text{if } d(p_i, s_j) \leq R_s - R_e \\ 0 & \text{if } d(p_i, s_j) \geq R_s + R_e \end{cases} \quad (3)$$

Among them, the $d(p_i, s_j)$ is the distance between the i -th pixel p_i and the j -th wireless sensor node s_j , the sensing radius of the k -th type wireless sensor node is R_s , the perceived error range of the k -th type wireless sensor node is R_e .

A number of wireless sensor nodes cooperative sensing monitoring method is used in this article and the pixel p_i is perceived by all underwater wireless sensor nodes collaborate perceived probability is

$$P(p_i) = \prod_{j=1}^{N_j} P(p_i, s_j) \quad (4)$$

III. PROBLEMS DESCRIPTION

A. Network Model

Usually a sensor node includes the following modules:

Micro control block (MCU): mainly responsible for calculating function.

The communication module (Radio): send and receive messages.

The perception module (Sensor): the perception of the surrounding environment, the collection of relevant information.

Node state usually has three modes: listen, active, sleep.

Definition 1: If the point P is covered by the k sensor nodes, called the point P is k cover. If at any point in a given region R is k coverage, called the region R is k cover.

Definition 2: Set $S = \{s_1, s_2, \dots, s_n\}$ consisting of N nodes in given regional R , if for any two nodes $s_i, s_j \in S$, there is at least one path between them, so that the two nodes in the wireless

sensor network is connected. If there are at least two paths between them, so that the two nodes achieve the multi connected.

Definition 3: Given area R and the nodes set S , if a subset S' of S is cover set of regional R , and any sub S' sets are not R cover set, called S' as the minimal covering set. Among them, the number of nodes containing at least minimal cover set called the minimal covering set.

Definition 4: Greedy principle. In the current situation based on an optimization measure to make optimal choices, instead of considering all possible overall situation. It adopts a top-down, by using iterative method to make successive greedy selection, to guarantee to obtain the local optimal solution of each step, to obtain an approximate solution of the optimal overall, thus greatly shorten the time required for the algorithm.

B. Problem Analysis

The existing nodes coverage distributed deployment algorithm is the premise $R_c \geq R_c$, for two reasons:

(1) When $R_c \geq R_c$, can mutual communication between two nodes sensing disk intersection, convenient distributed algorithm operation.

(2) When $R_c \geq R_c$, when nodes in the wireless sensor network achieving k coverage, also reach k connectivity between nodes. The goal of algorithm in this paper is to realize the distributed k coverage and multi connected in condition $R_c \leq R_c$.

According to the nodes in dormant state energy consumption is only 1% under the condition of active state. The sensor nodes are randomly deployed in monitoring region in A is dense; if all nodes have been active in the state will certainly waste a lot of energy. Therefore based on the algorithm is set to turn, the start of each round all the nodes in the listening state, then select the minimum covering set to the active state, to enable the wireless sensor network to achieve the k coverage multiple connectivity, the remaining nodes into sleep state. For solving the minimum covering set problem, it is a NP hard problem. Greedy principle to get the approximate solution used in this article.

The algorithm model can be expressed as follows:

Algorithm input: monitoring area A , nodes $S = \{s_1, s_2, \dots, s_n\}$ are randomly deployed in A .

The output of the algorithm: $C = \{c_1, c_2, \dots, c_m\}$.

The basic hypothesis:

The set of nodes $S = \{s_1, s_2, \dots, s_n\}$ sufficiently dense, can guarantee the regional A at least k coverage multiple connected.

The sensor node using the Boolean model, and all nodes have the sensing radius R_s and the same communication radius R_c , and $R_c \leq R_s$.

The same place can only be placed one node. Each sensor node knows its own location information.

Each node has a clock, each round of time synchronization can be maintained.

The goal of the algorithm:

1. $C \subset S$.
2. Min $\|C\|$.
3. $\forall s_i \in C, R_c \geq R_s$.
4. The node in C achieves multi connected.
5. Max $(t_{end} - t_0, t_{end} > t_0)$ respectively represent wireless sensor network termination and initiation time.

IV. PROCESS ANALYSIS

A. Algorithm Process

Step 1: The start of each round, all nodes are in the listening state. The regional A is divided into $W \times L \times \frac{\sqrt{2}}{2} R_c \times \frac{\sqrt{2}}{2} R_c$ square grid, the residual energy of each node updates.

For the adjacent all grid M and N, found node in adjacent grid and inter in communication range.

$$SC_{MN} = \frac{e_i + e_j}{2} \leq \frac{R_c}{d(s_i, s_j)} \in [0, 1] \quad (5)$$

Among them, M and N are two adjacent the grid, Euclidean distance between s_i, s_j is $d(s_i, s_j)$, R_c is the communication range of nodes.

To calculate the connected priority according to the residual energy of node and the distance between the nodes, choose the highest priority node to become active state.

$$P_c = \frac{e_i + e_j}{2} + \frac{1}{d(s_i, s_j)^z} \quad (6)$$

Among them, e_i, e_j are the remaining energy of s_i, s_j , z is random number between 0 and 1 used to reduce the appearance of the same probability.

Step 2: At this time, for only one active state node grid, and arbitrary monitoring state node in a neighbor grid to repeat the steps above, in order to ensure the completion of Step 2 each grid at least two nodes in active state.

Step 3: In the grid: if they do not reach k coverage, according to the node residual energy e_i in the grid and the grid coverage contribution C calculated priority p_s of node coverage. To select the highest priority node becomes active state.

$$P_s = \dots + \dots \quad (7)$$

Among them, Z is the 0-1 random number.

Step 4: Coverage update grid, if the grid reached k coverage, all listening state nodes in the grid is sleep; or turn to the Step 3.

B. Algorithm Analysis

Time complexity Analysis:

Initial N nodes are in total, area A is divided into $W \times L \times \frac{\sqrt{2}}{2} R_c \times \frac{\sqrt{2}}{2} R_c$ square grid, average node is $\frac{N}{WL}$ in each grid.

The step1: Choose between two adjacent grid connected nodes with at most of time $(\frac{N}{WL})^2$, and the adjacent grid consists of $(W-1) \times (L-1)$, so the first step time complexity is $O(N^2)$. Because the connected priority p_c by nodes on the decision according to the residual energy and distance of nodes. The dense nodes in the grid, non boundary grid has 4 neighbor grids (boundaries at least two neighbor grids), so the end of Step 1 all the basic grids have at least two nodes to the active state, so in the step 1 and step 2 the time complexity is $O(N^2)$.

In step 3 and Step 4: The grid is a distributed implementation, mainly for the compute node coverage contribution degree, and the time complexity is $O(N)$.

So, in this paper, the time complexity of the algorithm is $O(N^2)$.

Connectivity Analysis:

Definition 5: The multiply connected graph. In figure G, if the delete vertices V and V related side, figure G a connected component is split into two or more than two connected component, called the vertex v is a joint point of the graph. A no articulation points of connected graph are called a multiply connected graph.

In the multiply connected graph, any one of at least two path exists between vertices, i.e. deleting a vertex and its related each side after didn't break the connectivity of graphs.

Theorem 1: In two multiply connected graph G_1 and graph G_2 of for two different vertices add side, the formation of the graph G_3 is still multiply connected graph. And they are shown in Figure 1, graph G_1 and graph G_2 are multiply connected graph, in two pairs of nodes $\langle 3,5 \rangle$ and $\langle 4,8 \rangle$ belong to graph G_1 and graph G_2 add sides composed of graph G_3 is still multiply connected graph.

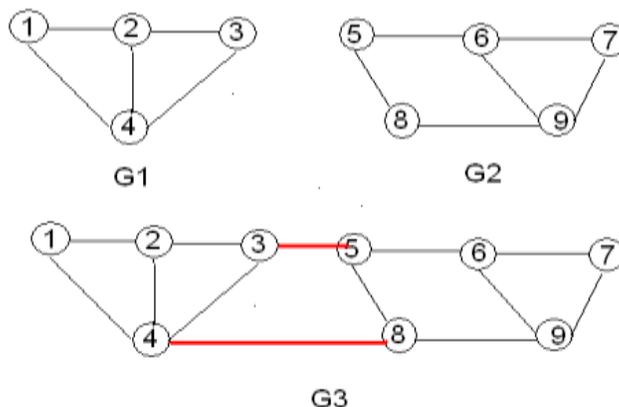


Figure 1. Multiply connected graph

Proof: The graph $G_1 =$ and graph $G_2 =$ are multiply connected graph, two different pair of vertices between graph G_1 and graph G_2 adding sides, assume that $a_1, a_2 \in$, $b_1, b_2 \in$ adding two edges \langle \rangle and \langle \rangle and the formation of graph G_3 .

Assume that graph G_3 is not multiply connected graph, according to the multiply connected graph defined so graph G_3 must exist joint point. Because the graph G_1 and graph G_2 are multiply connected graphs, so the joint point of the graph G_3 will only appear in a_1, a_2, b_1, b_2 . In the case of a vertex and its relevant side can be deleted in , between graph G_1 and graph G_2 is connectivity by \langle \rangle , graph G_3 is still a connected graph, so a_1, b_1 is not the joint point. Similarly, if a vertex is deleted in a_2, b_2 by the side connectivity can be between graph G_1 and graph G_2 , a_2, b_2 is also not the joint point. So graph G_3 does not exist joint point, contradiction to hypothesis. So graph G_3 is a multiply connected graph.

The algorithm of this paper, in order to the vertex as active state nodes, there are sides formed between graph nodes in communication range. Because the nodes in the same grid can be communicated with each other, so each grid can be seen as a multiply connected graph. There are

at least two different sides between each grid and neighbor grid. So the whole wireless sensor network composed of nodes in the graph is active state multiply connected graph, namely the existence at least two paths between any two nodes. So the wireless sensor network to achieve the multi connected.

V. SIMULATION

In order to verify the performance of this algorithm, this paper carries on the simulation of the algorithm in Matlab, different coverage of the active state nodes and the CAP algorithm are compared, the effects of different communication radius on the active state node number; and the CAP algorithm for comparison lifetime of different coverage wireless sensor network. The simulation environment is the square area of a $400\text{m}\times 400\text{m}$ area distributed randomly 2000 nodes, sensing radius $R_s =$.

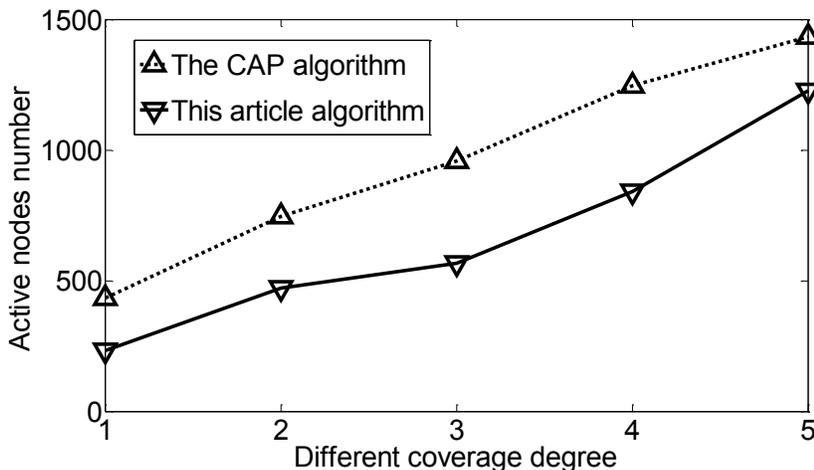


Figure 2. Active nodes number comparison in this article algorithm and the CAP algorithm under different coverage degree

Figure 2 is the active state nodes number comparison in this article algorithm and the CAP algorithm under different coverage degree. Along with the wireless sensor network to improve the wireless sensor network coverage degree, increase the number of active state node in wireless sensor network. By comparing with the CAP algorithm, the number of active state nodes in this article algorithm is less than the CAP algorithm. When the wireless sensor network coverage degree is three, with the coverage increased; the numbers of active nodes in the two algorithms are large. This shows that the algorithm ensures the wireless sensor network coverage and connectivity, consideration nodes on the wireless sensor network coverage contribution degree, thereby reducing the number of active state nodes.

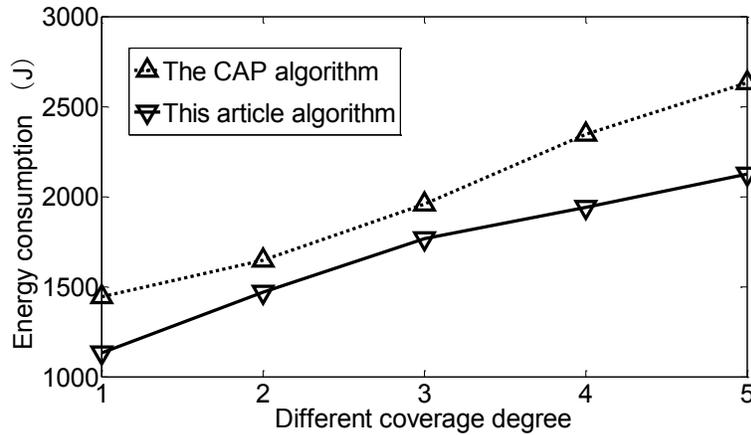


Figure 3. Energy consumption comparison in this article algorithm and the CAP algorithm under different coverage degree

Figure 3 is the energy consumption comparison in this article algorithm and the CAP algorithm under different coverage degree. The coverage degree of the wireless sensor network is higher, the energy consumption is larger. The CAP algorithm consume more energy than this article algorithm when the coverage degree is the same. When coverage degree is three, with the coverage increased; the energy consumption of active state nodes in the two algorithms are large. This shows that the algorithm ensures the wireless sensor network coverage and connectivity, consideration nodes on the wireless sensor network coverage contribution degree, thereby reducing the number of active state nodes to reduce the energy consumption of active state nodes.

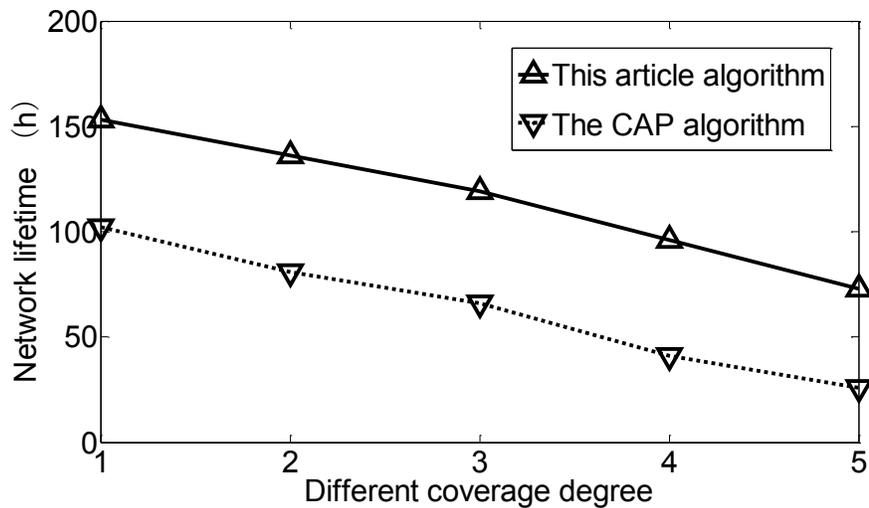


Figure4. Network lifetime comparing in this article algorithm and the CAP algorithm under different coverage degree

Figure 4 is the wireless sensor network lifetime comparing in this article algorithm and the CAP algorithm under different coverage degree. In different wireless sensor network coverage, the wireless sensor network lifetime of this article algorithm is longer than the CAP algorithm. And coverage degree is higher, wireless sensor network lifetime is shorter. When coverage degree is three, with the coverage increased; the wireless sensor network lifetime of active state nodes in the two algorithms are short. This shows that the algorithm ensures the wireless sensor network coverage and connectivity, consideration nodes on the wireless sensor network coverage contribution degree, thereby reducing the number of active state nodes and the energy consumption of active state nodes to extend the lifetime of the wireless sensor network.

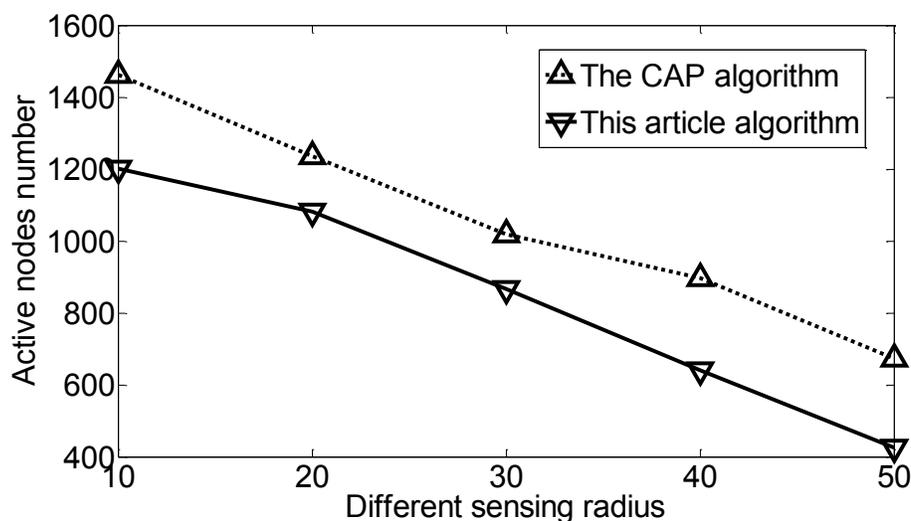


Figure 5. Active nodes number comparing in this article algorithm and the CAP algorithm under different sensing radius

Figure 5 is the active state nodes number comparison in this article algorithm and the CAP algorithm under different sensing radius. Along with the wireless sensor network to improve the sensing radius, decrease the number of active state node in wireless sensor network. By comparing with the CAP algorithm, the number of nodes in the wireless sensor network active state in this algorithm is less than the CAP algorithm. When sensing radius is 30m, with the coverage increased; the numbers of active state nodes in the two algorithms are large. This shows that the algorithm ensures the wireless sensor network coverage and connectivity, consideration nodes on the wireless sensor network coverage contribution degree, thereby increasing the sensing radius of active state nodes to reduce the number of active state nodes.

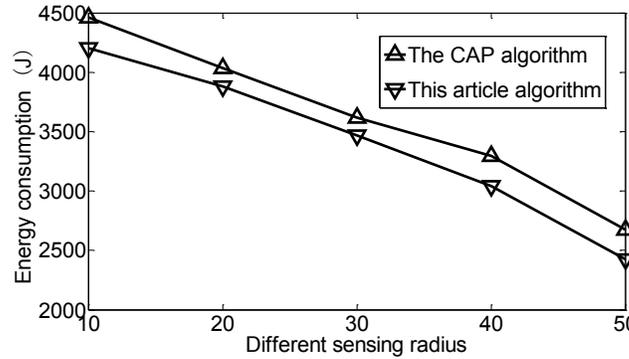


Figure 6. Energy consumption comparing in this article algorithm and the CAP algorithm under different sensing radius

Figure 6 is energy consumption comparison in this article algorithm and the CAP algorithm under different sensing radius. It can be seen from Figure 6 when the same coverage degree is three, the sensing radius is higher the number active state nodes is less, so the energy consumption is less. The CAP algorithm consume more energy than this article algorithm when the sensing radius is the same. When coverage degree is three, with the sensing radius increased; the energy consumption of active state nodes in the two algorithms are small. This shows that the algorithm ensures the wireless sensor network coverage and connectivity, consideration nodes on the wireless sensor network coverage contribution degree, thereby reducing the number of active state nodes to reduce the energy consumption of active state nodes when increase the sensing radius of active state nodes.

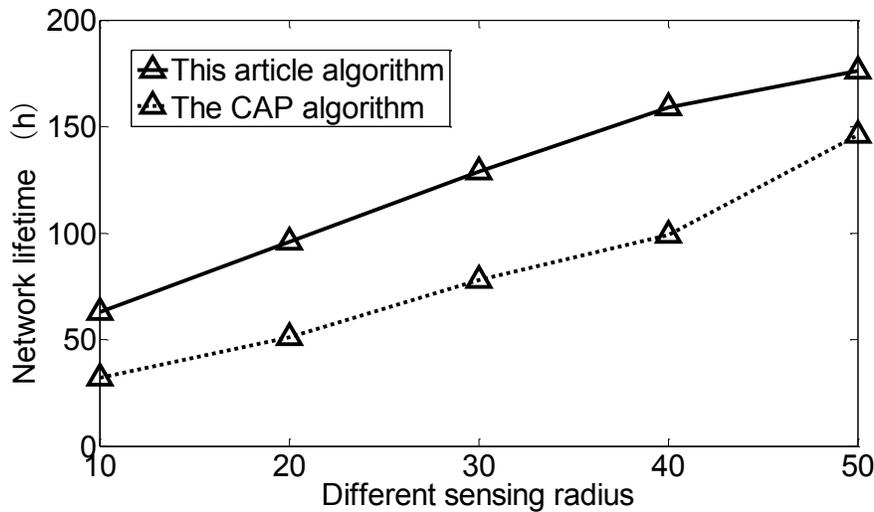


Figure 7. Network lifetime comparing in this article algorithm and the CAP algorithm under different sensing radius

Figure 7 is the wireless sensor network lifetime comparing in this article algorithm and the CAP algorithm under different sensing radius. In different sensing radius, the wireless sensor network lifetime of this article algorithm is longer than the CAP algorithm. And the sensing radius is higher, the wireless sensor network lifetime is longer. When coverage degree is three, with the coverage increased; the wireless sensor network lifetime of active state nodes in the two algorithms are short. This shows that the algorithm ensures the wireless sensor network coverage and connectivity, consideration nodes on the wireless sensor network coverage contribution degree, thereby reducing the number of active state nodes and the energy consumption of active state nodes to extend the lifetime of the wireless sensor network when increase the sensing radius of active state nodes.

VI. EXPERIMENTAL

The same various parameters which are used in the section of the simulation are also used in the experimental processes of this article.

The experimental results are shown in the table 1 to table 6.

Table 1. Active nodes number comparison in this article algorithm and the CAP algorithm under different coverage degree

Coverage Degree	The CAP algorithm	This article algorithm
1	468	275
2	569	399
3	863	482
4	1232	568
5	1487	1256

Table 2. Energy consumption comparison in this article algorithm and the CAP algorithm under different coverage degree

Coverage Degree	The CAP algorithm	This article algorithm
1	1457J	1128J
2	1663J	1357J
3	1859J	1598J
4	2214J	1678J
5	2632J	2156J

Table 3. Network lifetime comparing in this article algorithm and the CAP algorithm under different coverage degree

Coverage Degree	The CAP algorithm	This article algorithm
1	109h	152h
2	78h	135h

Coverage Degree	The CAP algorithm	This article algorithm
3	56h	101h
4	43h	85h
5	31h	69h

Table 4. Active nodes number comparing in this article algorithm and the CAP algorithm under different sensing radius

Sensing Radius	The CAP algorithm	This article algorithm
10m	1487	1205
20m	1239	1156
30m	1053	962
40m	982	718
50m	695	456

Table 5. Energy consumption comparing in this article algorithm and the CAP algorithm under different sensing radius

Sensing Radius	The CAP algorithm	This article algorithm
10m	4458J	4251J
20m	4123J	3969J
30m	3689J	3452J
40m	3412J	3218J
50m	2857J	2482J

Table 6. Network lifetime comparing in this article algorithm and the CAP algorithm under different sensing radius

Sensing Radius	The CAP algorithm	This article algorithm
10m	55h	39h
20m	96h	48h
30m	112h	66h
40m	156h	78h
50m	169h	146h

The experimental results and simulation results are similar, so the experimental results and simulation results are reliable.

CONCLUSION

This article focuses on the wireless sensor network nodes communication radius and sensing radius in the high density of wireless sensor network nodes deployed randomly and the wireless sensor network nodes communication radius is two times of the sensing radius; put forward a distributed k coverage multi connected nodes deployment algorithm based on grid. This article algorithm simulation results show that the algorithm in this article while guaranteeing the

wireless sensor network coverage and connectivity can reduce the number of the active state nodes effectively, prolong the wireless sensor network lifetime. Theoretical analysis results show that this article nodes deployment algorithm achieves multi connected.

Because what this article algorithm assumes is ideal and ignore some factors of the actual wireless sensor network, so the next step proposed on the basis to improve and optimize the model. In the future to study and try to other fusion strategy is used to optimize the wireless sensor network nodes deployment algorithm and make it more efficient.

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