



# Design and Improvement of Optimal Control Model for Wireless Sensor Network Nodes

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**Abstract.** Sensor network coverage is one of the basic problems in the Internet of Things. Coverage is one of the important indicators to measure the performance of sensor network nodes. Through the research on coverage problems, we can seek ways to improve the quality of sensor network services. A wireless sensor network node control effect is proposed. A distributed algorithm based on probability model is first constructed to optimize the probability perception algorithm. The above-mentioned two-dimensional space algorithm is extended to three-dimensional space, and the greedy heuristic algorithm is used to obtain the control solution to achieve the optimal control of the current wireless sensor network. In addition, the matlab simulation program is written, and the algorithm is compared with the simulation results of the average algorithm and the random algorithm. The simulation results of the proposed algorithm have significant advantages.

**Keywords:** Wireless sensing · Network control · Optimization control

## 1 Introduction

Wireless Sensor Networks (WSNs) are composed of many sensor nodes. The sensor nodes are placed in the area to be monitored according to certain methods through certain topologies. Through some suitable methods and their respective information exchanges, achieve the role of collaboratively perceiving physical world information, collecting and collating information of perceived objects within the network coverage area. The development of wireless sensor networks allows people to perceive the Earth's information more through sensor nodes, especially in radiation coverage areas, virus-infected areas or environments that humans cannot reach. Wireless networks can play an irreplaceable advantage [1]. WSNs are not the Internet of Things [2]. In fact, WSNs have been widely used before the emergence of IOT. The temperature control network consists of multiple temperature sensors and works by inspection. It has multiple sound, light and electricity. Security nets for mechanical and even image detection capabilities, etc. Therefore, although the sensor network in the traditional sense has developed very mature, compared with WSNs, the sensor nodes and the network architecture are completely different. In response to this situation, the academic community has proposed a larger IOT. The concept and include the WSNs

concept. WSNs has a relatively important coverage problem, which not only relates to the quality of service of the network, but also affects the research of other problems in the network [3, 4]. When studying the coverage problem, it is necessary to consider the characteristics of limited wireless sensor network resources and strong topological dynamics. Researchers have done a lot of research work on the coverage of wireless sensor networks for different application scenarios. Coverage is a measure of the detection of the target surveillance area, which directly affects the quality of the monitoring of the area to be tested. The research on wireless sensor network coverage problem can improve the service quality of the monitoring network in the area to be tested. At present, the existing wireless sensor network node control method can not complete the node, and ensure that the network can cover the entire area. In reference [5], a load balancing control method of channel boundary nodes in optical fiber networks is proposed. The task scheduling server is used to allocate node tasks, and the operation results are fed back to the relevant clients. When allocating the acquired blocking nodes, the priority quantification method of the nodes needs to be considered. In combination with the four relevant factors of the available memory of the optical network nodes, the main frequency of the CPU, the number of running nodes and the number of waiting nodes, the priority of the nodes is obtained and the accuracy of node allocation is optimized. At last, the node queue is defined, and the load balancing model of the channel boundary node is constructed. However, the positioning error of this method is large under unknown power, and the control accuracy of wireless sensor network nodes is low.

In response to the above problems, the optimal control model of the wireless sensor based on the probability model is proposed to improve the optimal control problem of the current network node [5].

## 2 Wireless Sensor Network Node Optimal Control Model

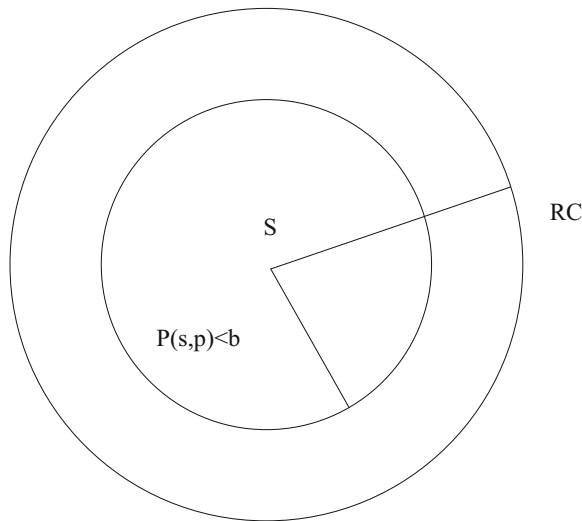
### 2.1 Optimized Probabilistic Perception Algorithm

The sensor node is determined by its own monitoring conditions. Only the information to be monitored within its sensing range may be “perceived”. For the establishment of different wireless sensing network perception models, the sensing network can be better simulated because only a good sensing model can design a good simulation coverage algorithm [6].

The optimized probability-aware model is different from the traditional probability-aware model, which is closer to the physical world. The monitoring of the information to be measured is not a constant 0 or 1, but the distance between the sensor and the information to be measured, and the sensor. The physical properties and the number of neighbors of the sensor are determined by variables. As the distance between the target and the sensor changes, the probability that the information to be tested is monitored by a sensor changes exponentially.

For conventional areas, the design is adopted  $P(s, p) = e^{-ad}$ . In the form of setting the current target  $p$  to the sensing node  $s$  to a distance  $d$ , at this time,  $P(s, p)$  denotes the probability that  $p$  is monitored by  $s$ , related to the distance between the two. If a

represents the coefficient at which the current target to be measured is attenuated by the distance detected by the sensing node, refer to the following Fig. 1.



**Fig. 1.** Probability based sensor node monitoring model

Generally speaking, the greater the distance of the sensor node from the target to be measured, the smaller the probability that the target to be measured can be monitored. When the distance does not exceed a certain threshold, the probability of monitoring is not zero; otherwise, the sensor node is away from the target to be tested. The smaller the distance, the greater the probability that the target to be measured can be monitored [7].

Usually we define that the probability that the detection target at grid point  $j$  can be detected by the sensor node at grid point  $i$  is  $p$ :

$$p_{ij} = \begin{cases} e^{-ad} & e^{-ad} > b \\ 0 & e^{-ad} < b \end{cases} \quad (1)$$

$p_{ij}$  indicates the target to be measured, and  $i$  represents the monitoring probability of the sensing node  $j$ . In general, the positive and negative distance of  $p_{ij}$  is the same without obstacles. If there are obstacles, the distance between the two is different. The above coverage model is obtained in the absence of neighboring nodes. If the target  $j$  to be tested is simultaneously covered by  $K$  sensor nodes, the  $K$  sensing regions are respectively represented as  $R(s_1), R(s_2), \dots, R(s_K)$ , then to the sensing overlap area  $p(j)$ :

$$p(j) = 1 - \prod_{i=1}^k (1 - p_{ij}) \quad (2)$$

Among them,  $p_{ij}$  is the probability defined above [8].

Since the sensor node senses the target to be measured by converting the excitation of the physical environment into an electrical signal, the quality of the excitation signal is closely related to the distance of the sensor node to the target to be measured. The signal is interfered by electromagnetic waves, and the distance increases. The strength of the signal will also change. It is considered that the monitoring of the target to be measured will be greatly attenuated as the transmission distance of the signal increases. Therefore, the path attenuation model is used to describe the sensor node's sensing ability [9, 10].

## 2.2 Dimensional Greedy Heuristic Algorithm

The above process optimizes the probability model of the wireless sensor network. According to the optimization results, a two-dimensional heuristic control algorithm is constructed based on the greedy algorithm. The greedy method is a method that does not pursue the optimal solution and only obtains a more satisfactory solution. The greedy method can generally get a satisfactory solution quickly because it saves the time it takes to find the optimal solution. The greedy method often makes the best choice based on the current situation, without considering the various possible overall situations, so the greedy law does not require backtracking. The heuristic algorithm uses the same constraint equation or function at each step to direct the algorithm to proceed. The schematic is as follows (Fig. 2):

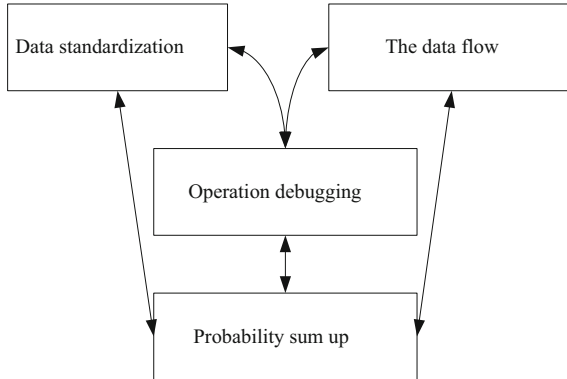


Fig. 2. Schematic diagram of the greedy algorithm

Since the two-dimensional space based on the probabilistic model sensor network will be affected by the inequality of obstacles and geographical environment, such as the presence of obstacles, the point  $j$  in the node sensing area will be monitored by node  $i$  with a probability of 0, that is, both. The distance is similar. Different cluster nodes and ordinary nodes have different status, which will make the monitoring probability different. The design is designed with ideal conditions.

The minimum probability of covering each point in the area to be tested, the minimum coverage by  $K$  sensor nodes ( $K$ -coverage), and the algorithm for deploying up to  $MS$  sensor nodes in the area: the monitoring area is dimensioned, the minimum number of sensor nodes are determined and the placement position in the grid is determined, so that each grid point realizes  $K$ -coverage with probability  $T$ , that is, each target grid point of the monitoring area is at least Monitored by  $K$  sensors, where  $K > 1$ ,  $P(j) > T$ . Among them,  $MS$  is the maximum number of sensor nodes provided,  $K$  is the coverage, and  $T$  is the three basic conditions of the algorithm.

Some basic requirements for the design algorithm can be referred to the above probabilistic algorithm, such as each point is monitored by at least  $k$  sensors, etc. In addition, the design algorithm discusses the current sensor network node coverage, if for regional coverage problems, Refer to the above probability optimization algorithm to transform the grid point coverage problem into the coverage problem of the relevant area.

First, the two-dimensional to-be-monitored plane region is divided by an  $n \times n$  grid (the ideal plane region is considered here, and other regions can be converted into similar regions), and the number of grid points on the plane is  $N = n^2$ , which is known by the probability algorithm. The probability  $p_{ij}$  that the grid point.  $J$  is detected by the sensor node  $i$  in the area to be tested is called the monitoring matrix  $D$ :

$$D = [p_{ij}]_{N,N} \quad (3)$$

The monitoring matrix has  $n^2$  elements. According to the definition of missed detection probability and the monitoring probability matrix  $D$ ,  $M = (n \times n)$  can be defined as the missed detection probability matrix, where  $m_{ij} = 1 - p_{ij}$ , in the two-dimensional greedy heuristic algorithm. Initialize  $M = (1, 1, \dots, 1)$ , where the elements of the matrix are all 1 means that all grid points are not detected. The position of the sensor nodes in the grid is determined by the iterative greedy heuristic algorithm. The algorithm iteratively deploys the position of one sensor node at each step, and refreshes the coverage probability  $p(j)$ ,  $j = 1, 2, \dots, N$ . When the required grid point reaches the requirement with the coverage degree  $K$  and the probability  $T$ , or the total number of sensor nodes reaches the slave, the preset node number upper limit termination algorithm.

Regarding the coverage  $K$ , a vector  $L = (L_1, L_2, \dots, L_N)$  may be preset, where  $N$  is the number of grid points  $n^2$ . The element  $L_j$  represents the coverage obtained by the grid point  $j$  during the running of the program, and the vector set  $L$  represents the set of coverage. Since all the grid points (Grid) are not covered by the node (Sink) at the beginning of the program,  $L = (0, 0, \dots, 0)$  can be used to initialize the coverage set with the zero vector.  $L$ .

The key step of the two-dimensional greedy heuristic algorithm is iteration, that is, by deploying the nodes in the two-dimensional grid, the missed detection probability  $m_{ij}$  of all the grid points of the node is obtained, and the sum of the missed detection probabilities  $m_{ij}$  is minimized by each iteration, and the update coverage is The  $(i, j)$  position in the degree vector set  $L$  updates the missed detection probability matrix  $M$ , and when the coverage of a certain grid point satisfies the coverage degree  $K$ , the row

corresponding to the grid point is deleted in the matrix M Columns to reduce the dimension of the matrix until the dimension of the matrix is zero. The overall calculation steps are as follows:

- (1) Dividing the two-dimensional to-be-monitored plane area by  $n \times n$  mesh, and the adjacent grid point distance can be determined according to the precision required by the sensor node configuration;
- (2) Given the monitoring accuracy  $t$ : the input scalar value indicates that all nodes are the same; otherwise, the corresponding vector should be input. Given coverage  $k$ : the input scalar value indicates that all nodes are the same; otherwise, the corresponding vector should be input.
- (3) Initialization:  $N = size(D, 1)$ ;  $D = N * N$  The number of grid points is  $n = 0$ .
- (4) Cycle start: deploy sensor nodes at current grid point  $k$ , request grid points  $\sum k$  The smallest.
- (5) If  $P(j) > T$ , then  $j = 1, \dots, N$ , corresponding to  $L_j$  plus 1. Update vector  $L = (L_1, L_2, \dots, L_N)$
- (6) Sensor node plus 1;
- (7) If the current  $L_j$  reaches a given coverage, the M matrix is deleted.
- (8) Priority is given to coverage, where  $L_j > C$ , C represents the current sensor node coverage required for each grid.
- (9) The algorithm terminates, and the process is as follows (Fig. 3):

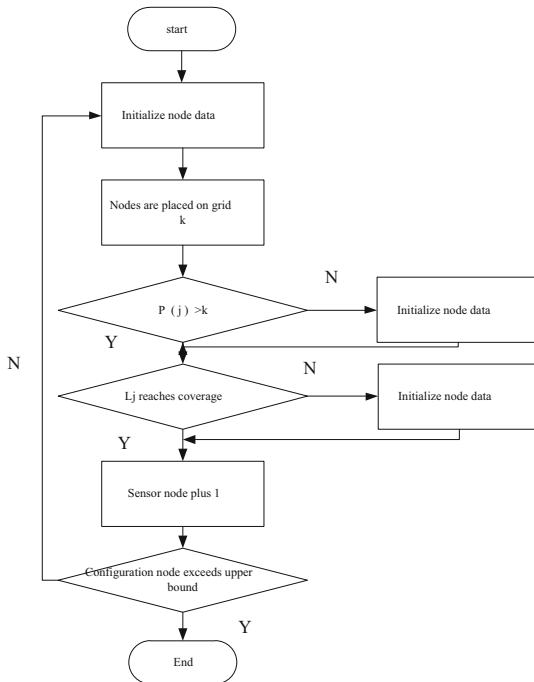


Fig. 3. Probabilistic two-dimensional greedy heuristic algorithm flow

### 2.3 Three-Dimensional Greedy Optimal Control Algorithm

In order to achieve optimal control, on the basis of the above, the design extends the greedy heuristic algorithm in two-dimensional space to three-dimensional space. Compared with two-dimensional space, three-dimensional space has more complexity. For example, in the two-dimensional space, the inequality of the geographical environment directly affects the spatial sensing node probability monitoring. This is especially true in the space environment. In addition, the three-dimensional space is more complex than the network topology of the two-dimensional space, simplifying the “obstacle” in the space as much as possible, and simplifying all the grid points into the ideal space. As with the two-dimensional space, we first need to give the premise and basic requirements of the algorithm. What is different from the two-dimensional space is that our pre-defined grid points are divided into three-dimensional to-be-monitored areas by  $n \times n \times n$  grids.

For the three-dimensional space, the design idea of the algorithm is to satisfy: to the three-dimensional to-be-monitored area divided by the mesh, to find the minimum number of sensor nodes, and determine the placement position in the grid, so that each grid point is the probability  $T$  implements  $K$ -coverage, that is, each target grid point of the monitoring area is monitored by at least  $K$  sensors, where  $K > 1$ ,  $p(i) > T$ ,  $P$  is the maximum number of sensor nodes provided,  $K$  is called Coverage,  $T$  is called monitoring accuracy, is the three basic conditions of the algorithm (Fig. 4).

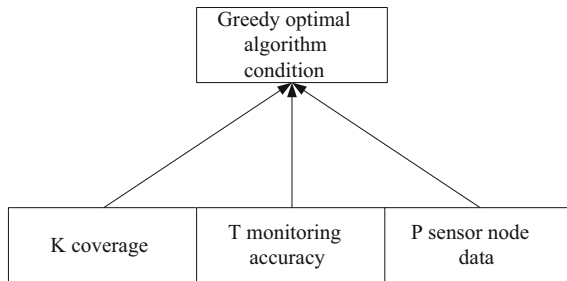


Fig. 4. Greedy optimal algorithm conditions

First, divide the three-dimensional space to be monitored with  $n \times n$  mesh (the ideal spatial region is considered here, and other regions can be transformed into similar regions). The number of mesh points in space is  $N = n^3$ , from the upper part. It can be confirmed that the probability  $p_{ij}$  of the grid point  $J$  detected by the sensing node  $i$  in the area to be tested is called  $D = p_{ij}$ . The monitoring matrix has a total of  $n^6$  elements. According to the probability of missed detection and the probability matrix  $D$  of monitoring, we can define  $M = [m_{ij}]_{N,N}$ . For the current missed probability matrix.

In the three-dimensional greedy heuristic algorithm, the  $m$  value is initialized, where the elements of the matrix are all 1 means that all the grid points are not detected. The sensor nodes in the grid are determined by the iterative greedy heuristic algorithm.

Each step of the iteration must deploy the location of a sensor node to refresh the coverage probability  $P(j)'$ , whose expression is:

$$P(j)' = D[m_{i,j}]_{N,N}, j = 1, 2 \dots, N \tag{4}$$

When the required grid points are covered by the degree of coverage  $k$ , the probability  $t$  reaches the requirement, or the total number of sensing nodes reaches  $m_s$ , that is, the preset number of nodes is limited to the upper limit termination algorithm. Considering that there are special requirements in the three-dimensional space, for some grid points, there are priority coverage requirements (coverage priority and monitoring accuracy priority), etc., the following two-dimensional algorithm has the following modifications:

- (1) Dividing the two-dimensional to-be-monitored planar area by a grid of  $n \times n$ , and the distance between adjacent grid points can be determined according to the precision required by the configuration of the sensing node;
- (2) Given the monitoring accuracy  $t$ : the input scalar value indicates that all nodes are the same; otherwise, the corresponding vector should be input. Given coverage  $k$ : The input scalar value indicates that all nodes are the same; otherwise, the corresponding vector should be input.
- (3) Initialization:  $N = \text{size}(D, 1)$ ;  $//D = N * N$  number of grid points
- (4) Start of the loop: deploy the sensor node (Sensor) at the grid point (Grid), request  $\sum k$  most
- (5) If  $P(j) > T, j = 1, 2, \dots, N$ , there is a corresponding  $l$  plus 1. update vector  $l$ ;
- (6) The number of sensor nodes is increased by 1;
- (7) If  $l$  reaches the specified coverage, the matrix  $m$  can be deleted;
- (8) The algorithm loop terminates, the process is as follows (Fig. 5):

Considering that the current three-dimensional spatial algorithm value of the wireless sensor network node model is one-dimensional vector than the two-dimensional space, it is necessary to set the difficulty when performing optimal control  $O(mN)$ . Where  $m$  represents the amount of network node sensors for the entire control core and  $N$  represents a boundary of the current  $m$ . Under ideal conditions, when the sensor nodes are deployed in the wireless sensor network, the minimum coverage of each grid point needs to be  $K$ , and the minimum coverage probability is  $T$  (or  $1 - N1$ ). – Express).

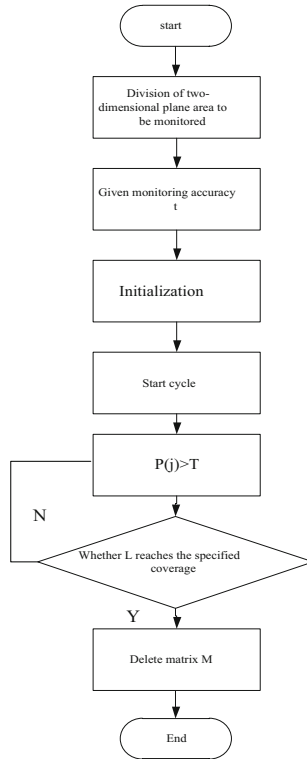


Fig. 5. Three dimensional greedy optimal control algorithm flow

### 3 Experimental Performance Analysis

#### 3.1 Simulation

Consider a region of size  $20\text{ m} \times 20\text{ m}$  for simulation. Five beacon nodes are deployed in this region. The position of the beacon node is known. The coordinates are:  $(0, 0)$ ,  $(20, 0)$ ,  $(0, 20)$ ,  $(20, 20)$  and  $(10, 10)$ , a target sensing network node is randomly deployed within the test area. 500 simulation experiments were performed on each algorithm on a desktop computer with Intel Corei5-4590, main frequency 3.3 GHz, memory 16 GB, 1600 MHz DDR3. For the existing MLE algorithm and LLS algorithm, it is assumed that the transmit power is known for each simulation. For the proposed optimal control model, the transmit power  $P_0$  will be in the interval  $[5, 25]$  randomly selected between.

Figure 6 shows the sensor positioning error of different algorithms under different noise effects when the transmit power is unknown.

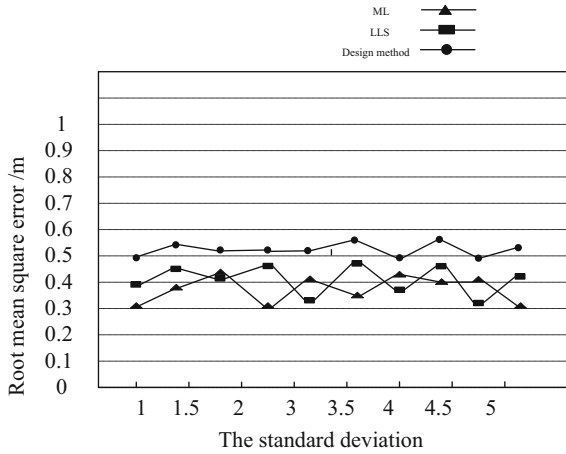


Fig. 6. Positioning error of different control methods

It can be seen from the figure that when the standard deviation of noise gradually increases, the positioning error of all algorithms will increase accordingly, and the MLE algorithm has the largest increase and the worst positioning performance. When the transmit power is unknown, the proposed control model treats the transmit power as an unknown variable during the positioning process, which reduces the impact of the transmit power on the positioning accuracy. Therefore, the proposed algorithm is far superior to the MLE and LLS algorithms. Positioning performance. When the noise is small, the proposed VTPNL algorithm and VTPLL algorithm have smaller sensing node positioning errors. Figure 7 depicts the positioning errors of different algorithms when the transmit power is different. In the simulation process, it is assumed that the

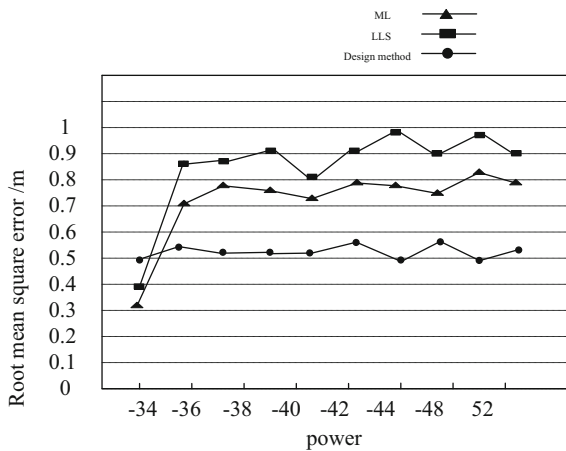


Fig. 7. Positioning error of different algorithms under unknown power

existing ML algorithm and the LLS algorithm both predict the true value of the power in advance, and the value of the value is set to  $-35$  dBm, but the size of the po is actually unknown.

It can be seen from the figure that when the transmission power is unknown, when the difference between the real transmit power and the preset value is small, all the positioning algorithms can obtain better positioning performance. When the difference between the real transmit power and the preset value is gradually increased, the ML algorithm and the LLS algorithm may cause a large positioning error, and the accurate positioning of the target node cannot be achieved. Moreover, as the difference between the real value and the preset value becomes larger, the positioning errors of the two traditional wireless sensor network node control algorithms increase sharply. This is because as the difference between the true value and the preset value, the difference between the RSSI values becomes larger and larger, and the ranging is more and more sensitive. When the RSSI value exceeds  $50$  dBm, and smaller difference will bring larger ranging error, resulting in a sharp drop in positioning accuracy. The control model considers the unknown transmission power, no matter how much the difference between the real value and the preset value, the influence on the positioning performance is very small, and the corresponding positioning accuracy is better.

After two comparison experiments, the optimal control model of the wireless sensor network node can be determined. Through the greedy algorithm and the optimized probability algorithm, the current sensor node is directly regarded as an unknown variable to participate in the node location calculation. The optimization algorithm solves it to obtain the position information of the target node. In the calculation process, the transmission power is directly eliminated to reduce the influence of the transmission power on the positioning accuracy, and the nonlinear positioning problem is transformed into linear optimization by linear approximation method, which can effectively solve the traditional control model. Control problems and increase coverage.

In order to further verify the effectiveness of the method in this paper, the control accuracy of the control model in this paper and the control model in reference [5] are compared and analyzed, and the comparison results are shown in Fig. 8.

According to Fig. 8, the control accuracy of the wireless sensor network node of the control model in this paper can reach up to  $90\%$ , which is higher than that of the wireless sensor network node of the control model in reference [5], indicating that the control effect of the wireless sensor network node of the control model in this paper is better.

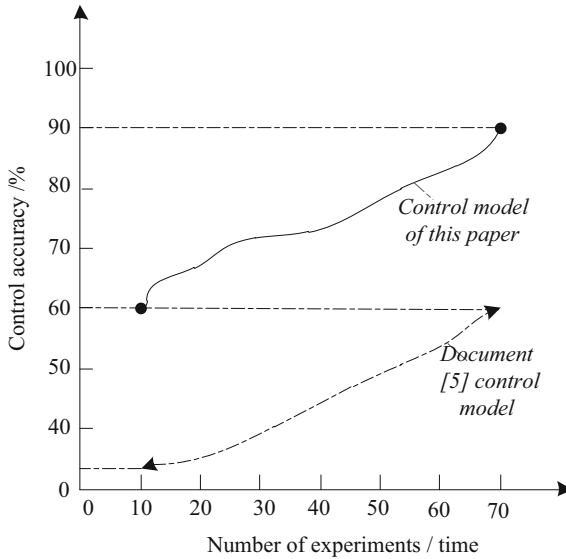


Fig. 8. Comparison of control accuracy of two systems

## 4 Conclusion

This paper introduces the origin of wireless sensor network and the research status at home and abroad. The related research on the coverage of wireless sensor networks at home and abroad is analyzed. The related technologies of wireless sensor networks are succinctly explained, and several characteristics of wireless sensor networks are summarized. The realization of the algorithm lays the foundation. This paper proposes a distributed algorithm based on probabilistic model. Under the condition that the coverage of each discrete grid point reaches  $k$  and the accuracy reaches  $T$ , the matlab simulation program is written. The simulation results of this algorithm are compared with those of average algorithm and random algorithm, the experimental results have significant advantages, and the algorithm is extended to the three-dimensional space. The experiment proves that the control method has practical performance.

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