Wireless sensor networks optimization covering algorithms based on genetic algorithms

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Abstract

This paper starts with two methods applied widely of computational intelligence; Evolutionary computing and swarm intelligence. It makes the Genetic Algorithms (GA) that is classic in evolutionary computing and genetic algorithm that is representative in swarm intelligence as its study foundation. It presents theory and characteristic of the two methods to seek the application of intelligent optimization in engineering practice. In application, in view of the feature that wireless sensor network (WSN) must possess auto-organization, auto-adaptation and robustness, especially, energy of WSN is very limited, this paper fully utilizes the advantages of computational intelligence, marries together both the research focuses. It proposes some methods and ideas for applying computational intelligence to solve optimization problems of WSN. This paper depicts coverage problem of WSN, for the feature that this problem is the problem of multi objective optimization, under the topology control of GA, it applies GA based on sorting to solve the problem, then improves this algorithm to maintain population diversity and obtain high-quality, well distributed solutions. The algorithm it proposes realizes the aim that using the least number of sensor nodes to achieve the best coverage, which is able to save energy of the network, decrease the interference between signals and prolong the network life-time.

Keywords: Wireless Sensor Network (WSN), Coverage rate, Sensor node, Genetic Algorithms

1 Introduction

With the progress of science and the development of the times, problems that people encounter in industrial production and engineering practice, with more and more large-scale, complex, constraint, nonlinearity, uncertainty, etc., in the production practice! Economic management and scientific research in many fields have a lot of questions that people in urgent need of a large and complex space to find optimal or near-optimal solution. Computational intelligence as a new optimization technique solves the difficulties encountered in conventional optimization algorithm, the algorithm is relatively simple and easy to understand, easy to implement, more importantly, and computational intelligence methods mostly have implicit parallelism, Self-organization, adaptive characteristics, effectively promote their application in optimizing the production of various areas of the system efficiency, reducing energy consumption, rational use of resources and improve the economic efficiency has an important role and significance.

WSN (Wireless Sensor Network) is a kind of self-organization network system which consists of large number of inexpensive sensor nodes, and its nodes are characterized by a certain sensing ability, computing power and communication capabilities. It is widely used in the fields of defence and military, environmental monitoring, rescue works and etc. WSN works in such a way that following way: large numbers of sensor nodes are distributed in discrete form within the coverage area, and data is sent to or collected from nodes directly or indirectly. Usually the target node is covered in a manner that sensor nodes are high density deployed to monitor the target area, and to improve the quos of network, information is exchanged among sensor nodes to achieve target node coverage and information processing. But there're some defects, first, deployment of larger number of sensor nodes in target area results in existence of considerable amount of redundant nodes, which consume much network energy and reduce the network Qos.

The second, due to the excessive consumption of node energy, and non-rechargeable feature of nodes, the network tends to collapse quickly. How to distribute sensor nodes in target area reasonably to determine the minimum point set under certain coverage requirement, and how to limit the power consumption maximally, become key problems, which influence the network lifetime directly. In summary, the solving of energy issues and coverage problem means monitoring the given area at the minimum nodes number and low energy cost, meanwhile, the quality of coverage should be guaranteed. It is also the study focus of this paper.

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2 Related works

In the 1990 of the 20th century, Italy scholar M Dorig, who was inspired from the mechanism of biological evolution, Ant routing behaviour by simulating the natural world, proposing a new simulated evolution of Ant Colony algorithm (Ant Colony algorithm ACA). Early was widely used in the travelling salesman problem (Travelling Salesman Problem, TSP) solution. Travelling salesman problem is a typical combinatorial optimization problem, but also a NP hard problem. As the problem grows, ant colony algorithm in a limited number of cycles is difficult to find the exact solution of the problem, and can easily fall into local optimal solution, causing the system to run the cycle is too long, slow convergence and the emergence of stagnation. University of Michigan in 1975, Professor John H. Holland proposed genetic algorithm (Genetic Algorithm, GA) can be initialized from a start node traversal, to avoid initialization from a single node caused the most easy to fall into local optimal solution of the iterative process that converges to a greater probability of the optimal solution, which has a better ability to solve the global optimal solution. However, in solving complex nonlinear problems there too premature, convergence is slow, resulting in a lot of redundant code and other shortcomings, thus making the solution accuracy is too low [1-3]. Wireless sensor network coverage problem in the field of wireless sensor network (WSN) is one of the focuses of research problems. Wireless sensor network characteristics can be summarized as: small size, low cost, low energy consumption, has a certain calculation, processing and communication capabilities. In the process of wireless sensor network coverage, needs to solve two problems: first, the coverage, how to reasonably and effectively reduce the node energy consumption, and try our best to prolong the network life cycle; Second: using mobile node scheduling strategy and parameter dynamic change, reduce the mobile node to cover the amount of work area, to achieve the goal of local area cover effectively, enhanced the topology of the network, reducing redundant data generated at the same time improve the quality of network service. Covered, therefore, how to meet certain conditions, the use of minimum sensor node to specify the local area covered and effectively inhibit the node energy consumption of too fast is a challenging topic.

The methods of deployment of the wireless sensor network nodes can be divided into deterministic deployment and randomness deployment. Usually the deterministic deployment method is adopted when the network is small, and a good monitoring regional condition can be guaranteed. The advantage of this method is that by controlling the position of each node through artificially deployment, the optimal solution meeting the network coverage requirement can be achieved. On the contrary, if artificial way is not feasible, usually aircraft or other tools is used to randomly distribute sensor nodes in a certain area, because of the uncertainty of nodes' positions, more nodes will be needed compared to the deterministic method, then the node redundancy problem comes out. Thus, the problem of energy consumption and node coverage become one of the major research topics in the fields of wireless sensor network. In references [4], by exploiting the Force Filed Theory of mobile network and Round Coverage Thinking in wires sensor network, VFA algorithm is proposed. When the nodes in a wireless sensor network are distributed unevenly, this algorithm can be used to scatter the intensive nodes in order to effectively cover the target area, but the energy consumption problem of whole network is not fully considered. In references [5], a sensor network coverage and connectivity probability model in the case that nodes are random scattered is proposed. By exploiting this model, the node numbers which meet different coverage and connectivity requirement can be calculated and the calculation is simple; but this model is only studied with the complete coverage case, meanwhile, the connectivity rate under multi-network coverage is not considered. In references [6] proposed perception coverage and connectivity restore study in mobile sensor network, the idea is study the coverage area and connectivity issues as a whole, Coverage Conscious connectivity Restoration is used to restore one or more nodes from the failure nodes, thus the connectivity is restored and this node at initial position in coverage area are monitored. Because the energy consumed for data collection every time is not equal, and it is not suitable to re-divide the intersecting coverage set during the recovering process of the failure nodes [7-9]. To this end, by using the Gaussian density function and the coverage area probability function the quantitative comparison between the node-sensing radius and the number of nodes is given in the minimum nodes set theory model, so that the coverage for the target area is done.

3 Mathematical models of genetic algorithms

In practical applications, it is often encountered in multi-criteria or objectives, design and decision making problems, "such as securities investment issues, investors in order to get higher returns, you need to select the best stocks to invest in, in general, an outstanding shares have the following characteristics: good performance, low price-earnings ratio, growth higher, but usually these goals are in conflict, such as the current domestic steel industry generally better performance of listed companies, earnings are relatively low, but the steel industry is not sunrise industry, the company's growth is not high; while some small and medium sized companies although growth is high, but the performance is poor, the high price-earnings ratio, and thus to be able to choose a good stock, you need to make investment decisions among these goals a balanced approach, that more than a numerical target in a given region of the optimization problem is known as multi-objective optimization.

In order to solve multi-objective optimization problem, we need to create a general mathematical model, we must first determine its decision variables, the general case, the decision variables dimensional Euclidean space as a point, namely:

$$x=\left(x_1,x_2,x_3\cdots x_n\right)\in E^n . \quad (1)$$

The second one is the objective function, in general it can be assumed with objective functions and decision variables are all about function, namely:

$$f\left(x\right)=\left[f_1\left(x\right),f_2\left(x\right),\cdots f_p\left(x\right)\right]^T . \quad (2)$$

Finally, its constraints, from a mathematical point of view, there are two constraints: inequality constraints and equality constraints, constraints can be defined as the m inequality constraints and k equality constraints:

$$\begin{cases} g_i\left(x\right)\le 0 \quad i=1,2,3\cdots m \\ h_j\left(x\right)=0 \quad j=1,2,3\cdots k \end{cases} . \quad (3)$$

If all are the minimization of the objective function value, the multi-objective optimization problem can be described as the following mathematical model:

$$\begin{cases} min\ f\left(x\right)=\left[f_1\left(x\right),f_2\left(x\right),\cdots f_p\left(x\right)\right]^T \\ x_i^\alpha \le x_i \le x_i^\beta \end{cases} , \quad (4)$$

where, x is the decision variable, $f\left(x\right)$ is the objective function, X represents the decision vector formed by the decision space x , $g_i\left(x\right)$ and $h_j\left(x\right)$ constraints x feasible decision variables to determine the range, min represents A Minimization Vector, namely, a vector target $f\left(x\right)=\left[f_1(x),f_2(x),\cdots f_p(x)\right]^T$ in certain constraints as far as possible the various sub-objective function minimization. It can be seen when the $p=1$, the mathematical model for a single objective optimization problem mathematical model.

3.1 DEFINITION MULTI-OBJECTIVE OPTIMIZATION

Multi-objective optimization problem is that people in the production or frequently encountered problems in life, in most cases, due to multi-objective optimization problem in all its goals are in conflict, a sub-target improvement may cause the performance of other sub-goals reduced, in order to make optimal multiple targets simultaneously is impossible, and thus in solving multi-objective optimization problem for each sub-goal can only be coordinated and compromise treatment, so that each sub-objective functions are optimal as possible multi-objective optimization problem with a single objective optimization problem is essentially different, in order to properly solve multi-objective optimization problem the optimal solution, we must first multi-objective optimization of the basic concepts of a systematic exposition.

Definition 1: N Viola Space:

$$\begin{cases} x=\left(x_1,x_2,x_3\cdots x_n\right)^T \\ y=\left(y_1,y_2,y_3\cdots y_n\right)^T \\ x=y \quad Iff\ x_i=y_i \quad \forall i=1,2,3\cdots n \\ x>y \quad Iff\ x_i>y_i \quad \forall i=1,2,3\cdots n \end{cases} . \quad (5)$$

Definition 2: Let $X\subseteq R^m$ is a multi-objective optimization model of the constraint set, $f\left(x\right)\in R^p$ is a vector objective function, $x_1\in X$, $x_2\in X$, (a) $f_k\left(x_1\right)<f_k\left(x_2\right)$ better solution called solution, x_2. (b) x_1 weak solution of $f_k\left(x_1\right)\le f_k\left(x_2\right)$ called superior solution x_2 . (c) $f_k\left(x_1\right)\ge f_k\left(x_2\right)$ solution called indifference to solution x_1, x_2.

Definition 3: Let $X\subseteq R^m$ be a multi-objective optimization model constraint set, $f\left(x\right)\in R^p$ is a vector objective function, $x^n\in X$ and x^n than the X all the other points are superior, called x^n is the multi-objective minimization model optimal solution. By definition, multi-objective optimization problem is to make the optimal solution x-vector objective function $f\left(x\right)$ for each sub-goal is to achieve the most advantages of the solution, obviously, in most cases; the optimal multi-objective optimization problem solution does not exist.

Definition 4: Pareto optimal solution: Let $X\subseteq R^m$ be a multi-objective optimization model constraint set, $f\left(x\right)\in R^p$ is the vector of the objective function. If $\xi\in X$, ξ and there is no more than the superiority of x , then ξ is a minimal model of multi-objective Pareto optimal solution, or non-inferior solution.

Definition 5: No inferior set with the front end: Let $X\subseteq R^m$ be a multi-objective optimization model constraint set, $f\left(x\right)\in R^p$ is a vector objective function. $\lambda\in X$ Is a minimal model of multi-objective Pareto optimal solution set, then λ is called non-inferior set of X , $Y=f\left(\lambda\right)$ is called Pareto optimal front.

Seen from the above definition: (a) Multi-objective optimization problem with a single objective optimization problem is essentially different, in general, multi-objective optimization problem Pareto "optimal solution is a collection of the Mu most cases, similar to the single-objective optimization problem in a multi-objective optimal solution optimization problem does not exist, there is only Pareto optimal "multi-objective optimization problem is just a Pareto optimal solution acceptable" not bad "solution, and usually most multi-objective optimization problem with multiple Pareto optimal solution. (b) If a multi-objective optimization problem optimal solution exists, then the optimal solution must be Pareto optimal solution, and the Pareto optimal solution is also the optimal solution by only composed of these, do not contain other solutions, so can be so say, Pareto optimal solution is a multi-objective optimization problem reasonable solution set. (c) For practical application, must be based on the level of understanding of the problem and the decision-makers of personal preference, from a multi-objective optimization problem Pareto optimal solution set of one or more selected solution as a multi-objective optimization problem of optimal solution, so seeking more objective optimization problem the first step is to find all its Pareto optimal.

3.2 NETWORK MODEL AND HYPOTHESIS

The following hypotheses are advanced on the network model:

Hypothesis 1: the monitored area is much larger than the sensor node sensing area, not considering the boundary factors on the monitoring of regional influence.

Hypothesis 2: sensor node sensing radius and radius of communication will appear a disk shape and the communication radius greater than or equal to 2 times the radius of perception.

Hypothesis 3: each sensor node can be through their own information to their location information.

Hypothesis 4: the initial state, and each sensor of node energy is the same, all sensor nodes have the same processing capacity, and equal status.

Definition 6: the distance between any two nodes $d(i,j)$ are called nodes i and j Euclidean distance, when $d(i,j) < 2R$ referred to the neighbour node, node i and j.

Definition 7: in the monitoring of the target area, when a target node is K sensor node coverage, called K heavy cover.

Definition 8: in the monitoring of the target area, all sensor nodes coverage Union and all sensor nodes range and then, called network covering efficiency:

$$EA = \bigcup_{N=1,2...N} S_i \,/ \sum_{N=1,2...N} S_i \,. \tag{6}$$

Definition 9: Covering the region of coverage for:

$$p(s_i,s_j) = \begin{cases} 0 & \text{if } \; R_s \le d(s_i,s_j) \\ e^{-\varepsilon d} & \text{if } \; (R_s - R_e) < d(s_i,s_j) < R_s \\ 1 & \text{if } \; d(s_i,s_j) \le (R_s - R_e) \end{cases} . \tag{7}$$

Among them: ε is sensor node physical parameters; R_e said sensor node monitoring dynamic parameters in the said sensor nodes; $d(s_i,s_j)$ Euclidean distance; when $d(s_i,s_j) \le (R_s - R_e)$, this time node s_i is detected, it is not detected.

Theorem 1: when and only when the three equal circles intersect at one point, and form an equilateral triangle length of a side is $\sqrt{3}$, covering the efficiency of *EA* maximum, That is: $EA \le 82.73\%$

Proof: As shown in Figure1:

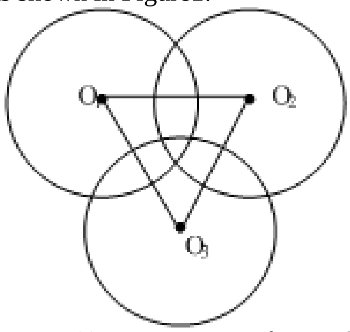
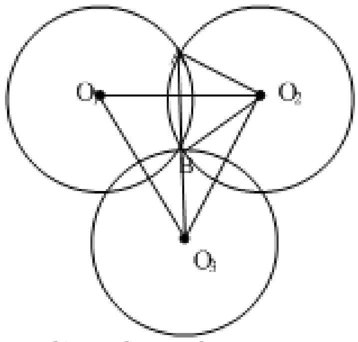


FIGURE 1(a) Any intersection Of two circles



FIGUER 1(b) Any three circles intersect at one point

Firstly, Figure 1(a) was analysed. Two intersect, and the intersection region are equal, so $\triangle O_1O_2O_3$ is an equilateral triangle, with side length O_1O_2 is r, an equilateral triangle $\triangle O_1O_2O_3$ three interior angles are respectively $\pi/3$, $\angle O_2O_1O_3 = \pi/3$, $S_{\triangle O_1O_2O_3} = \frac{1}{2}(r^2 \sin \pi/3)$, since three, round two intersection, and completely covered on the plane the Euclidean distance, $d_i < 2r$, let the equilateral triangle $\triangle O_1O_2O_3$ the maximum length to keep the $S_{\triangle O_1O_2O_3}$ area is the largest, the three circle intersect at a point B, as shown in Figure 1 (b) as shown, connect to the O_3B and extended to two points to A, connecting the O_2A, set three the radius of the circle of 1, $S_{\triangle ABO_2} = \sqrt{3}/4$, $S_{ABO_2} = \pi/6$, according to the formula (1) we get $EA = S_{\triangle ABO_2} / S_{ABO_2}$, $EA = 3\sqrt{3}/2\pi = 82.73\%$ namely in the completely covered cases the maximum coverage of the efficiency value is 82.73%.

Theorem 2: a sensor node monitoring area A, the monitoring of regional node density λ, a monitoring area A node number X subject to node K probability density: $P(X=k)=e^{-\lambda A}\cdot(\lambda A)^k/k!$

Proof: the monitoring area is S, in the monitoring region of arbitrary nodes subordinated to the K node distribution probability of $p=A/S$, when the number of nodes of n probability obeys two type distributions is:

$$P(X=k)=C_n^k p^k(1-p)^{n-k}. \quad (8)$$

According to the node density formula $\lambda=n/S$ into arbitrary node distribution probability of P:

$$p=A\lambda/n. \quad (9)$$

Equation (9) into the formula (8):

$$P(X=k)=C_n^k(A\lambda/n)^k(1-A\lambda/n)^{n-k} = \frac{n!(A\lambda)^k(1-A\lambda/n)^n}{(n-k)!k!(n-A\lambda)^k} \quad (10)$$

When $n\to\infty$ and its limit available:

$$P(X=k)=\lim_{n\to\infty}\left(\frac{n!(A\lambda)^k(1-A\lambda/n)^n}{(n-k)!k!(n-A\lambda)^k}\right) = e^{-\lambda A}(A\lambda)^k/k! \quad (11)$$

That is: $P(X=k)=e^{-\lambda A}\cdot(\lambda A)^k/k!$

4 Coverage control and scheduling of nodes

In order to achieve the efficient coverage on monitoring region by minimal node, the purpose is to better extend network existence period. Make the network lifetime maximization is the basic method to make the network system of the node energy minimization. That is to say, in the network monitoring region to let each sensor node to consume all their energy as much as possible, but in practical application process exists the position difference, the sensor node energy consumption is not the same; for example: in close proximity to the base station node for forwarding a large amount of data and the formation of excessive energy consumption and rapid death. Therefore, the node exists between energy consumption disequilibrium phenomenons, which require the deployment of nodes, considering the different regional deployed nodes is also different. Its purpose is to balance each sensor node's energy has to balance the network deployment, while the network effectively covering algorithm finally, can be achieved on the node energy consumption effectively resist, the lower energy nodes not too quick death, thereby extending the network cycle.

When the target into a cluster head monitoring area, to the neighbour cluster head node sends a packet containing the target information, all the monitoring to the target cluster are dynamically in the target around to form a group, cluster member nodes only with the cluster node communication, the cluster head and between cluster heads can be mutually communication. Involved in tracking the cluster number depends on the size of the radius of the grid. For example, if the access grid side length equal to the radius of communication node, then a maximum of only four cluster capable of simultaneously monitoring to the target. When at the same time two or more than two cluster head and monitoring to the target, we select these clusters in a cluster head node as a leader node, cluster head first to the neighbour hair to send their and monitoring the distance between the target data information, if the cluster head received a distance closer to the target hair to information, give up campaign to become leader node. Selection criteria for: first, choose from the closest cluster head node; second, if there is two or more than two cluster head node and the target and the distance between the same, residual energy larger the lead node. All the monitoring to the target cluster head node will be sent to a leader node data first, and then by the leading node calculation and data fusion are transmitted to a data centre node. As shown in figure 2:

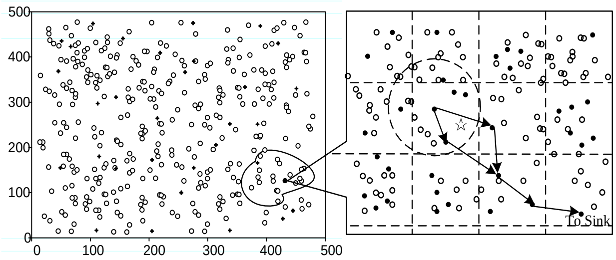


FIGURE 2 The target node coverage area diagram

When the mobile target leading away from the node, because of the need to transmit data over long distances to the leader node, or a new cluster head node monitoring to the target, then a leader node is no longer applicable acts as a leader node, fast the election of a new leader node is very necessary. Here we shall, when there is a new cluster head node joins the mobile target tracking, under the leadership of node selection rules, in all involved in tracking the cluster head node selects a distance to a target the nearest cluster head node as its new leader node, data reported by the new leader node is sent to a data centre.

5 Simulation experiment

In order to evaluate the feature of the algorithm, this paper MATLAB6.5 is adopted as a simulation platform in this paper, the sensor nodes are randomly deployed in different network areas, the parameters are included in table1.

TABLE 1 Simulation parameters

Parameter	Value	Parameter	Value
dimension 1	100*100m^2	ε_{amp}	20(pJ/b)/m^2
dimension 2	200*200m^2	$E_{R\text{-}elec}$	30nJ/b
dimension 3	400*400m^2	E_{min}	0.02J
Number	180	Header	20B
R_s	2m	Initial energy	2J
$E_{T\text{-}elec}$	50nJ/b	broadcast	20B
ε_{fs}	10(pJ/b)/m^2	each round	100ms

The wireless communication models for Sensor node transmitting data and receiving data are respectively the following:

$$E_{Tr}(k,d) = E_{T-elec}k + E_{amp}(k,d) = \begin{cases} E_{T-elec}k + \varepsilon_{fs}d^2k & d < d_0 \\ E_{T-elec}k + \varepsilon_{amp}d^4k & d \ge d_0 \end{cases}. \quad (12)$$

In the above formula, $E_{T\text{-}elec}$ and $E_{R\text{-}elec}$ denote the energy consumption of wireless transmitting module and wireless receiving module; ε_{fs} and ε_{amp} stand for the energy consumption parameters of spatial model and multiple attenuation models; d_0 is a constant.

Experiment I. The first case is, with the same respective parameters, execute 50 times and get the mean value, then execute for 400 to compare with the LEACH protocol the quantitative relationship between number of remaining nodes and the number of turns, as shown in Figure 3.

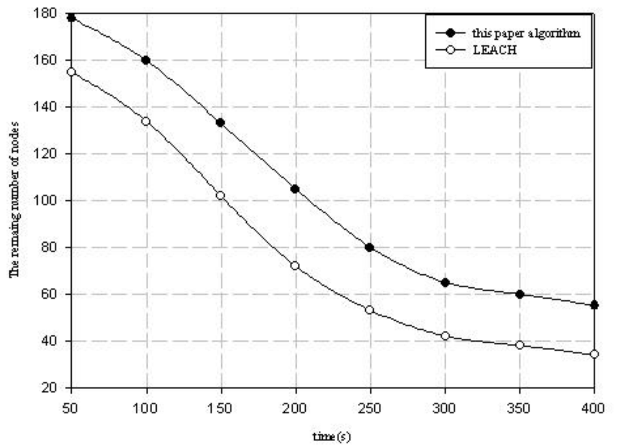


FIGURE 3 Remaining nodes and the round number

As can be seen from Figure 2, with increasing of time, the number of remaining nodes of proposed algorithm is higher than the LEACH protocol, and then the conclusion that with the increasing of time, the energy consumption of the proposed algorithm is lower than that of LEACH protocol, and the network lifetime is extended, also the network resources are optimized.

Experiment II. In order to achieve the scale of network coverage, and thus better evaluate the performance of the model in different sizes, which mainly reflect the minimum number of nodes needs to by deploy in different network coverage, each simulation experiment executed 50 times at average. Curve of node coverage changes is shown in Figure 4.

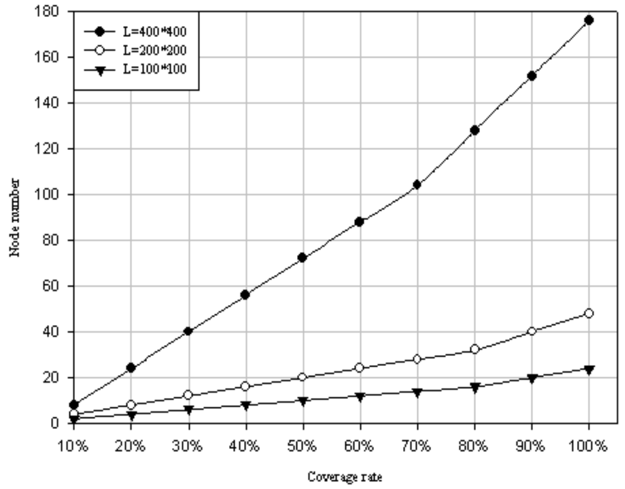


FIGURE 4 Coverage rate for different coverage area

Figure 4 shows the graph of the number of sensor nodes needed to deploy to achieve different node coverage under different network dimensions. The figure shows that, with the expansion of the network, to meet the demand for network coverage, the number of nodes required to be deployed will increase, and the higher the coverage of the network, the number of nodes need to be deployed increases can be obtained from Figure more fast, so that the concern target node can achieve complete coverage.

Experiment III. Figure 5 shows a diagram of the number of sensor nodes need to be deployed for the same network size 400 * 400m^2 under different node coverage requirement, and compare with the experiments of literature [10] SCCP algorithm, to meet certain demand for network coverage, the number of nodes deployed will be gradually increased as time progresses, and the network coverage will also increase, so that completely coverage is achieved for the same coverage area and different nodes coverage for target area, as shown in Figure 5.

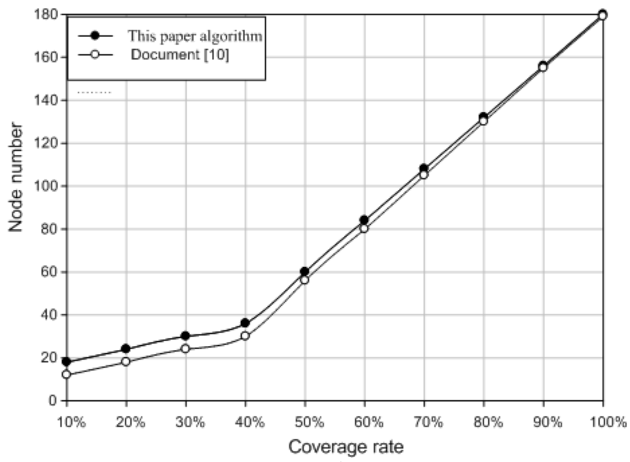


FIGURE 5 Coverage comparison of proposed algorithm and [10]

5 Conclusions

Computational Intelligence approach is that people learn and use a variety of principles and mechanisms of natural phenomena in nature or organisms developed a new method of adaptive environmental capacity and has, because of its efficiency to optimize performance, no problem specific information, etc., in has been successfully applied in many fields. coverage problem for WSN are described, for it has the characteristics of multi-objective optimization, genetic algorithm based on Pareto applied to solve this sort of problem, "in algorithm design, the choice of the operator has been improved, Meanwhile, the introduction of external groups to save Pareto optimal solutions generated by each generation, and using quick sort method based on Euclidean distance to external groups to be updated to maintain population diversity and individual differences between algorithm to achieve the ultimate purpose of using as few sensor nodes in order to achieve the greatest possible degree of target coverage, so WSN energy consumption can be balanced.

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