Incorporate Intelligent Computation into Coverage Optimization for Wireless Sensor Networks

Lun Zhang , *Member of IAENG*, Lan Chen, Yan Lu, Decun Dong

***Abstract*—Due to the fact that it plays an important role to improve the connectivity and coverage of Wireless Sensor Networks, it is considered to be efficient to improve the coverage by artificially deploying the critical Sink nodes. In this paper, we use Particle Swarm Optimizer algorithm to find out the best position of sink nodes deployment in the whole network area and then optimize the Wireless Sensor Network by adding sink nodes after generating a quantity of nodes to constitute Wireless Sensor Networks at random. Hereafter, by simulation based on a random network to prove that : (1) intelligent algorithms are worthy of considering and efficiently to be utilized in the network topological deployment and keeping the network integrity, (2) the Partial Swarm Optimization is much algorithmically easier and reliable, (3) Intelligent computation is a kind of optimal methodology to improve the network integrity.**

***Index Terms*— Network Integrity, Particle Swarm Optimizer, Topology Control, Wireless Sensor Networks,**

I. Introduction

Recently, there has been a great attraction of interests in researches of Wireless Sensor Networks (WSN) since it is a combination of short-distance wireless telecommunication technology, Topology Control issues, Self-organizing mechanism , Micro-embedded technology, optimized network management and other modern scientific technology, comprising a set of mutually connected main sensor nodes and sink nodes of sensor based on Ad Hoc telecommunication.

This paper aims at finding an optimum sink node which can cover the most nodes so as to promote connectivity or fill up the "blind zone" of networks. The paper firstly introduces the method of finding the optimum sink node with cluster as a unit and proposes the best calculating method by PSO. Then emulation is applied to check whether the calculating method is feasible. Finally, the paper demonstrates the adaptability of the calculating method in changeable topological structure networks.

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Lun Zhang is with School of Traffic Engineering, Tongji University, No.4800,Cao An Road, 201804, Shanghai, China (phone: 86-21-69589881; fax: 86-21-65980212; e-mail: Lun_zhang@ mail.tongji.edu.cn).

Lan Chen is with School of Traffic Engineering, Tongji University, No.4800, Cao An Road,201804,Shanghai, China (e-mail: clanxning@126.com).

Yan Lu is with School of Traffic Engineering, Tongji University, No.4800, Cao An Road,201804,Shanghai,China(e-mail: xvela630@hotmail.com).

Decun Dong is with School of Traffic Engineering, Tongji University, No.4800,Cao An Road,201804,Shanghai, China (e-mail: ddc58@sohu.com).

II. PROBLEM DESCRIPTION

A. *Network Topology Control [1][2][3]*

We can get a rough concept literally that network topology frame is the connection modes of nodes Topology control means to choose the cheapest and most suitable method of connection, coverage, line capacity, and flow distribution etc. on the condition of given nodes' positions, definite reliability, time delay, and throughput. We can consider a WSN as a planar Euclidean Coordinate. We use R^2 to denote this coordinate. V is the network nodes set in R^2. The distance between two nodes (x and y) is expressed as $dist(x,y)$. Since wireless communication area is weaken by the increasing of distance, we use the following model to define the minimal energy used to make correct communication between x and y.

$$\lambda(x,y) = c \times dist(x,y)^d \tag{1}$$

In Formula1, c is a constant; d is a parameter which is influenced by environments and the value of d usually is between 2 and 4. The energy level of node x is a function of time, which is expressed as $B_x(t)$. T denotes time, t≧0. $B_x(0)$ is a given value, which denotes the initial energy of node x. This value determines this node's communication transfer cover area. This node can communicate with all nodes in his cover area. Then we will introduce the energy consumption model. Suppose node x has an energy level Bx(t) at time t and x needs to consume energy Ps to communicate. Then, after Δt, the residual energy of node x is

$$B_x(t+\Delta t) = B_x(t) - (P_s \times \alpha_x \times \Delta t + P_r \times \Delta t). \tag{2}$$

In formula2, α_x is the transmission quantity during Δt, P_r is the energy consumption during data reception. Note that P_s maybe a parameter, while P_r should try to be constant. For example, during time t, we need connect two nodes (x and y), the minimal consumption energy of two nodes is λ(x, y), and the connection can be maintained within the following time.

$$\min\{\frac{B_x(t)}{\lambda(x,y)\times\alpha_x + P_r}, \frac{B_y(t)}{\lambda(x,y)\times\alpha_y + P_r}\} \tag{3}$$

Connect all the nodes in their transmission areas, then we can get the network topology frame.

B. *Coverage [4][5][6]*

In two dimensional surfaces R^2, the cover area of node Si is a circle with a center of node, radius of inductive radius R_i, which is called "inductive circle". Formula4 denotes this situation.

$$S_i = \{ p \in R^2 \mid dist(p, S_i) \le R_s \} \tag{4}$$

The cover area C of whole WSN is the union of all nodes in cover area, which is expressed as:

$$C = \bigcup_{i=1}^{n} S_i \tag{5}$$

P is covered by nodes, which is equal to Formula6.

$$dist(p, S_i) \le R_s \tag{6}$$

The objective area R is covered completely by WSN, which means that each node in R is covered by a node at least. The direct communication area of Node S_i is a circle of the center S_i and radius R_c. Every node only can communicate directly with nodes in the district.

Define2.1 Given a set S of nodes in WSN, the communication network $G_c = (V_c, E_c)$ which is consisted of all the nodes in this set is an undirected graph. In which $V_c = S, \forall S_i, S_j \in S, (S_i, S_j) \in E_c$, if and only if $dist(S_i, S_j) \le R_c$

Then we call communication graph is exported by set S. A communication path $P = \{S_1, S_2, S_3 ...\}$ of Graph G_c is composed by a series of nodes. Every pair of neighbor nodes is communication neighbor. If there exists a communication path between two random nodes in G_c, this communication graph will be considered as interconnected.

Define2.2: Give a set S of WSN nodes and objective area R, if each node in R is covered by a node at least, we will call S as the coverage set of R. If the communication graph which is exported by S is interconnected, a set S will be call as connected cover set (CCS) of R.

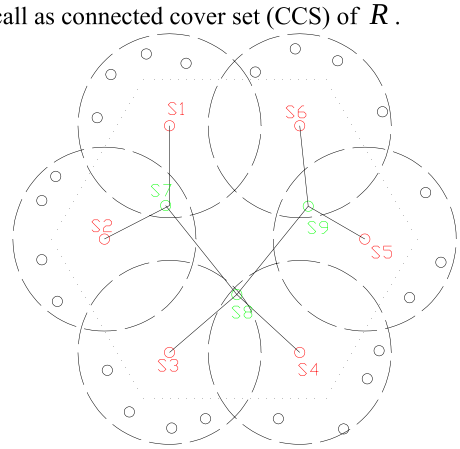

Fig.1 Connected coverage sets

In Fig.1, set $\{S_1, S_2, S_3, S_4, S_5, S_6\}$ is a coverage set of objective area. While this coverage set is not connected. A connected coverage set formed when S_7, S_8, S_9 are joint.

Considering to deploy a sensor network S in objective area R, MCCS (Minimal Connected Coverage Set Problem) is to find a minimal subset $S' \subseteq S$, S' can cover area R completely, namely $R \subseteq \bigcup_{S_i \in S'} S_i$, and the communication graph G_c' which is exported by S' is connect.

Then, we will give related arithmetic to solve MCCS.

III. ARITHMETICAL DESCRIPTION

On the background of the WSN's rapid developments, it's important to research the optimization of actual networks. This paper is started in this point, to develop actual network performance through increasing sink nodes. The keystone of this paper is to find how to increase sink nodes.

A. *Best Sink Nodes*

Firstly, we think that increasing sink nodes can connect some discrete nodes in networks. Best sink nodes are those can connect most nodes, as Formula 7 and 8

$$S_0 = \max(N) \tag{7}$$

In Formula 7, S_0 is the best sink node. N is the amount of connect nodes.

$$N = count(L) \tag{8}$$

In Formula 8, L is the area which is connected by sink nodes. L must conclude two gathers.

This is different from the traditional methods, which consider the more nodes sink node includes, the better sink node is, namely as formula 9.

$$S_0 = \max(N), N = count(C) \tag{9}$$

C is the amount of nodes covered by sink node.

This way often leads to the redundancy, low payoff connection and low optimization efficiency of sink nodes. So this paper is divided into units by gathers, and considers the planning of sink nodes by gathers. This way can solve the problems well in traditional researches.

B. *Arithmetical Applicability*

This paper adopts Particle Swarm Optimizer (PSO) algorithm to optimize the coverage,. PSO is an evolutionary computation. It comes of the behavior research of birds' prey. PSO is familiar with genetic arithmetic. It's an optimal tool based on iterance. System initiation is a set of random solution, and then finds the optimal value through iterance. However, the arithmetic follows the optimal particle to search in the particle space rather than the crossover and mutation of genetic arithmetic. The main reason to apply PSO is for its simplicity and there're few parameters to adjust. There're below 300 nodes for most WSN, so PSO arithmetic is applicable absolutely.

C. *3.3. Arithmetic flow*

The actual flow chart for calculating the best sink node and optimizing random networks is showed as Fig.2.

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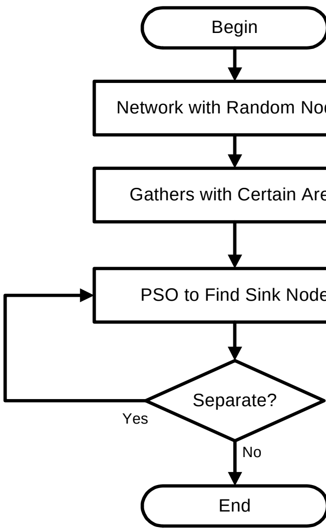

Fig.2 PSO arithmetic flow chart

1) Create N nodes in a certain area, such as N=100;

2) Fix up each node's energy and connect all nodes which can be connected.

3) The set of nodes which can be connected called a cluster, namely divide N nodes into M clusters.

4) For the randomicity and the finity of nodes, commonly M≧2. It namely means the low feasibility between random two nodes in a plane. In this case, networks exist needs of optimization. The actual optimal methods have been mentioned before. It is increasing a sink node, and the principle to fix it up is to connect more nodes and to consume the minimal energy.

5) Find the best sink position through PSO. Firstly we design some particles with a certain speed. Secondly, we let them choose the working direction freely through PSO.

Finally, particles reach optimal point, namely that best sink node. Fig.3 is the result of arithmetic.

6) After finding the first sink node, we consider two ways to extend cover area.

. Deleting nodes which covered by sink node, then iterate this arithmetic to extend the connect area.

. Reduce the weighing of nodes which covered by sink node. The weighing of this node will be reduced once when it is covered again. Then we iterate this arithmetic to extend the connect area.

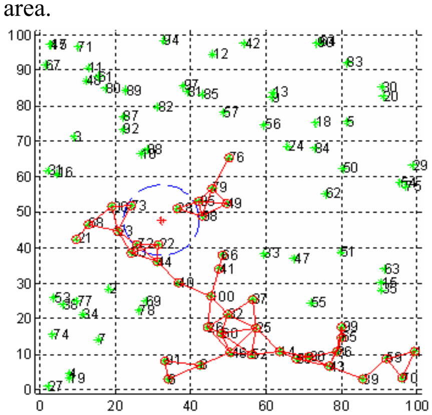

Fig.3 Gathers and nodes connected by sink

Two ways each has his strong point. First method can complete iteration with fewer nodes. However maybe there exist some "dead zones". For example, if there's gathers' division of a WSN which showed as Fig.4. There're five gathers in it. We can find best sink node to connect gather1 and gather5 through PSO. If we delete gather1 and gather5 directly, left three gathers will use great energy nodes to be connected. "Dead zones" is the main drawback of this arithmetic.

Although second method can conquer the drawbacks above, it can lead to the repeated coverage of sink nodes in the case of mass gathers. So, we should consider the actual disturbing situations to use which ways in the progress of application. For examples, we should adopt second method in the application of urban roads because the control nodes often distribute as crossing. When the arithmetic is applied in railways, control nodes often distribute as band, so we should adopt first method.

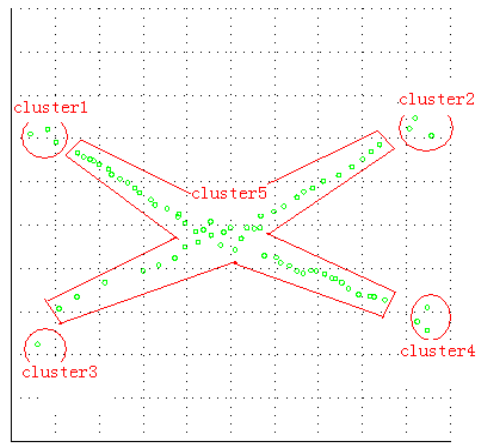

Fig.4 Situation "dead zones" occurred in deleting optimal nodes directly

This paper adopts a more scientific way to avoid "dead zones" caused by first method and the redundant nodes caused by second method.

The way in this paper is that join the connectivity of best sink nodes into original frame after it is found. Then a new topology frame formed. In this new topology frame, we continue to find best sink nodes. In this way, we didn't delete any factors during consideration, so this way won't lead to extra "dead zones". In the process of finding sink nodes in new network frame, it can be materialized completely in the new frame for the before sink node. So this way won't lead to the energy redundancy of sink nodes.

IV. PARTICLE SWARM OPTIMIZER ALGORITHM

A. *Introduction of PSO [7][8][9]*

Recently, there has been a surge of interests in articles of Particle Swarm Algorithm (PSO) since it was originally designed by Kennedy and Eberhart. Some of the attractive characteristics of PSO include the ease of implementation and the fact that no gradient information is required. It is widely used to efficiently find optimal or near-optimal solutions in large search spaces. It involves in non-liner, multi-peaks or multi object problems, complex system optimization issues or other artificial intelligence tools.

In PSO algorithm, this kind of technique simulates the particles' social behaviors among individuals "flying" through a multidimensional search space in order to find the "best" solution. the particle utilizes its goal (fitness) to evaluate their current positions at every iterative generation and thus gradually moves to higher fitness position in order to adjust them to approach their final expectation .Each Particle in a local neighborhood shares memories of their "best" position in its local history and has an idea of the global best position of all the members in the group, and then decides their own velocities by calculating with those memories, subsequently flying to a new position. Through the iteration of certain amount generations, all particles shall fly aggregately and converge to a fix point, which we call the optimized result.

In Kennedy's original versions of the algorithm (standard version of PSO, SPSO), the formulas are represented as:

$$v_{id} = v_{id} + \varphi_1 \cdot rand(\cdot) \cdot (p_{id} - x_{id}) + \varphi_2 \cdot rand(\cdot) \cdot (p_{gd} - x_{id}) \quad (10)$$

$$x_{id} = x_{id} + v_{id} \quad (11)$$

Where, $X_i = (x_{i1}, x_{i2}, ..., x_{iD})$ denotes the current position of every particle i. Xi holds personal previous "best" record which here expressed as P_{id} (we call it as cognition component) and the highest fitness in local neighborhood, designated P_{gd} (here named social component). Furthermore, different dimensional velocities $V_i = (v_{i1}, v_{i2}, ..., v_{iD})$ are iterated with time going. Constants φ_1 and φ_2 determine the relative influences of the social and cognition components respectively. At each iterative step, particles are able to evaluate their fitness according to their own positions. And the best fitness of all the neighborhoods is regarded as the global "best" position in the d^{th} dimension.

B. *Concrete realization and optimize*

In the paper, according to the compute rules of Fitness Value, we establish the following optimization：

1) When we consume one unit of power， we decrease the power weight according to the fitness.[10]

2) The priority which relate on the nodes covered——

When we add a node covered，we increase the cover weight according to the fitness；

If the cluster of the node is not calculated, mark it uncalculated and increase the weight according to the number of the node in the cluster.[11]

The actual arithmetic flow is showed as Fig 5.

C. *Module*

We divide PSO into three parts in general：

1, Initialize the nodes and network (born the nodes ,connect the nodes).

2, Display the output module (display the content of simulation according to the data).

3, Use PSO to compute the position of sink nodes:[12]

(1) Initialize particle swarm: position, power, velocity(x,y,e) , optimization value , fitness value , compare with the overall optimization value, decide the first optimization position.

(2) According to the main thoughts of PSO, all the particles begin to find the optimization position.

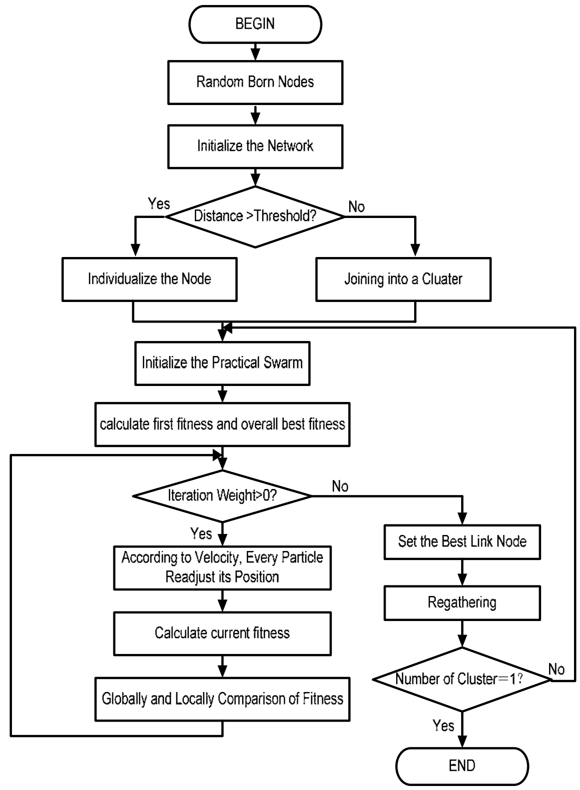

Fig.5 The flow Chart of PSO algorithm

(3) When the velocity weight is below zero(we can adjust this end condition of judgment),we can stop the PSO, and current optimization position is the result.

(4) One sink node has been chosen. We divide the nodes into new cluster. if num of the rest cluster is one(every node has been connected)，then PSO is over, jump to (5) .otherwise, jump to (1) continue to execute next PSO.

(5) The structure of network has been all connected, PSO end, all the sink nodes marked is the optimization result in the paper.

V. SIMULATION

A. *Simulation result*

The simulation of this paper is made by VC++. There's some randomicity in the result because WSN is created randomly. The concrete simulation result shows as follows.

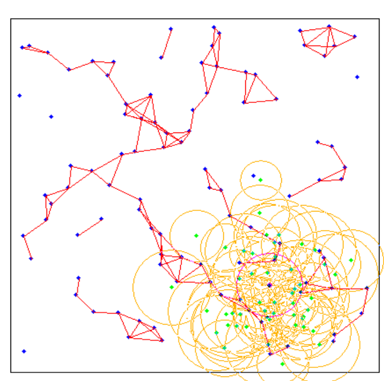

Fig.6 PSO algorithm (1)

Connect all nodes which can be communicated, then clusters are formed. We can find optimal sink node through the PSO algorithm of this paper.

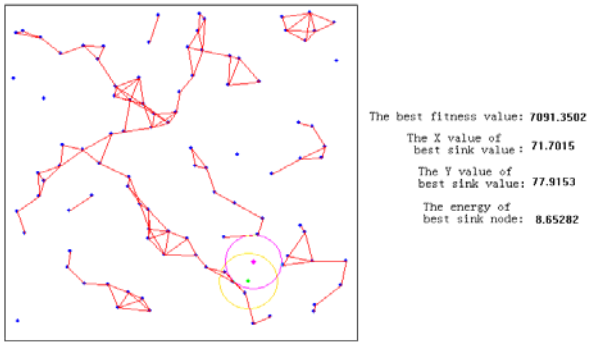

Fig.7 PSO arithmetic (2)

Here, a best sink node is found which can connect most nodes through PSO algorithm. We call it as local optimization.

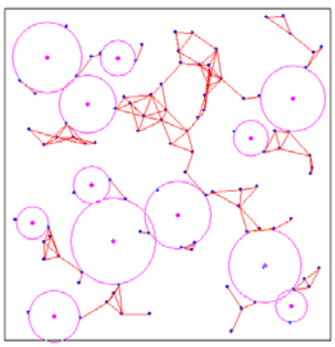

Fig.8 PSO algorithm (3)

Thus, make this process repeated until all nodes in networks are connected.

B. *Simulation analysis*

We can realize the optimizing process of WSN and get corresponding simulation results through using PSO algorithm,. If we put up N nodes randomly, through the optimal process of sink nodes, we can find out that sink nodes are no more than ten percent of the whole nodes through the optimal process. This is accpetable for the network optimization of WSN. The new added nodes can make network connected, and there are no doubt that the algorithm can get massive optimal results by using few calculation. So, this algorithm has practical engineering value.

1) Algorithmic precision and efficiency is the characteristic feature of PSO. We can get different computing velocity and precision through self-changing final condition and the changing velocity, initial value, study parameter Cx of velocity weight.

2) **Parameter adjustment**. There're different requirements for algorithmic precision and efficiency in practical application. The arithmetic should adjust parameter to meet the practical requirements. If precision is preferred, then we can use more particles and longer time to calculate sink nodes. If efficiency is preferred, we can use less particles and shorter time to calculate sink nodes. All in all, particle numbers and proceeding time is the main parameter we should adjust.

3) **Algorithmic optimization**. In Figure 9, we can see that there should be a certain number of sink nodes if we want to connect the whole network. If there're many clusters of a single node, the whole network will have the hidden trouble of many sink nodes. Whether it is necessary to set up so many sink nodes to make the network connected, or to use other optimal strategy, we can judge it from network function evaluation. The algorithm in this paper is only limited to find best way to connect all the known nodes.

VI. CONCLUSION AND FUTURE WORKS

After the research above, we can get the conclusion as follows.

1.We can use PSO to find best sink nodes with least energy consumption until all nodes in WSN are in communication. PSO is a new theory applied into coverage optimization and proved to be fast and efficient.

2.The advantage of this way is that main control elements in this algorithm are operating time and number of particles. We can adjust the value of these parameters so as to control the precise and efficiency directly.

3.The application of this algorithm is very wide. Almost every WSN can use this way to complete coverage optimization.

4.Another advantage of this optimization method is easy to carry out. We only need to add sink nodes through PSO to complete optimization. This means that we can complete optimization without changing the network frame

Meanwhile, there're many difficulties for us to solve.

First of all, this paper discussed optimization of the WSN without sleeping nodes. So, electricity waste is an unavoidable problem. If nodes are sleeping alternately, topology frame will change all the time, and then the best sink nodes will change constantly. How to control the adaptability during the sleeping situation is a problem. We suggest considering this problem synthetically through two aspects: control the rules of sleeping and add the sink nodes properly.

Next, mobile nodes should be considered. How to put up sink nodes in this situation, we give two algorithmic anticipations here:

1. Make sink nodes move accordingly. Divide the process of nodes motion into many time slices. We can regard every time slice as a changeless wireless sensor network, and every WSN has a certain topology frame. According to every topology frame, we can compute the best sink nodes which are corresponding to this time slice. Finally, link all these nodes; we can get the rough rule of the sink nodes' motion. The application of nodes is a repeated and regular process, so we can set up some adjacent nodes in mobile facilities after finding the motion rules of sink nodes.

2. Continue to use improved PSO. The motion of nodes can be described as motion models in a certain extent, so the best sink nodes computed by the algorithm of this paper is moving according to some rules. This way maybe becomes a valuable research aspect in the future.

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