Coverage Optimization Techniques in WSN using PSO: A Survey

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ABSTRACT
Focus of this study is the sensor coverage problem which is a crucial issue, where a high coverage rate will ensure a high quality of service (QoS) of the Wireless Sensor Network (WSN). The coverage strategies are categorized into three groups based on the approaches used, namely; force based, grid based or computational geometry based. PSO is a popular multidimensional optimization technique. The objective of this paper is to present a state of the art survey on these strategies used to optimize sensor coverage using Particle Swarm Optimization (PSO).

Keywords
Wireless Sensor Network (WSN), Particle Swarm Optimization (PSO), coverage, force based approach, grid based approach, computational geometry based approach.

1. INTRODUCTION
Advancement in wireless communication have enabled the development of low-cost, multifunctional, tiny sensor nodes that can sense the environment, perform data processing and communicate with each other untethered over short distances [1]. These sensor nodes are deployed either randomly or according to some predefined statistical distribution, over a geographic region of interest (ROI). A sensor node has severe resource constraints, such as low battery power, limited signal processing, limited computation and communication capabilities and a small amount of memory; hence it can sense only a limited portion of the environment [2]. That is why coverage optimization is a critical issue in the design of a WSN.

WSN issues such as node deployment, localization, energy-aware clustering, and data aggregation are often formulated as optimization problems. Particle swarm optimization (PSO) is a popular multidimensional optimization technique [3]. Ease of implementation, high quality of solutions, computational efficiency and speed of convergence are strengths of the PSO [4]. Connectivity and coverage problems are caused by the limited communication and sensing range. To solve both problems the solution lays in how the sensors are positioned with respect to each other [5].

Following are the strategies used during deployment phase where the coverage is calculated based on the placement of the sensors on the region of interest (ROI). They are categorized into three groups based on the approaches used, namely; force based, grid based or computational geometry based approach [5]. Force based methods use attraction and repulsion forces to determine the optimal position of the sensors while grid based methods use grid points for the same objective. As for the computational geometry approach, Voronoi diagram and Delaunay triangulation are commonly used in WSN coverage optimization algorithm [5].

The aim of this paper is to compare these different strategies for WSN coverage which are implemented with PSO. Coverage types and optimization strategies are discussed in next section. Section III discusses role of PSO in WSN. Different coverage optimization strategies using PSO for WSN coverage are discussed in Section IV. Finally, the concluding remarks are given in Section V.

2. COVERAGE & STRATEGIES OF COVERAGE

2.1 Coverage Classes
According to [6], coverage can be classified into three classes namely area coverage, point coverage and barrier coverage.

2.1.1 Area Coverage
Area coverage is on how to cover an area with the sensors. The objective here is to maximize the coverage percentage. Coverage problem can also be seen as a minimization problem [6]. From this point of view, the objective is to make sure the total area of the coverage holes in the network is as small as possible.

2.1.2 Point Coverage:
Point coverage is the coverage for a set of points of interest. This type of coverage concentrates on how to cover a set of targets or hotspots in an area, instead of the whole area as in area coverage.

2.1.3 Barrier Coverage:
Barrier coverage is about covering the barrier of an area. The barrier coverage focuses on decreasing the probability of undetected penetration to a protected area. Therefore, the sensors need to be deployed along the area's border.

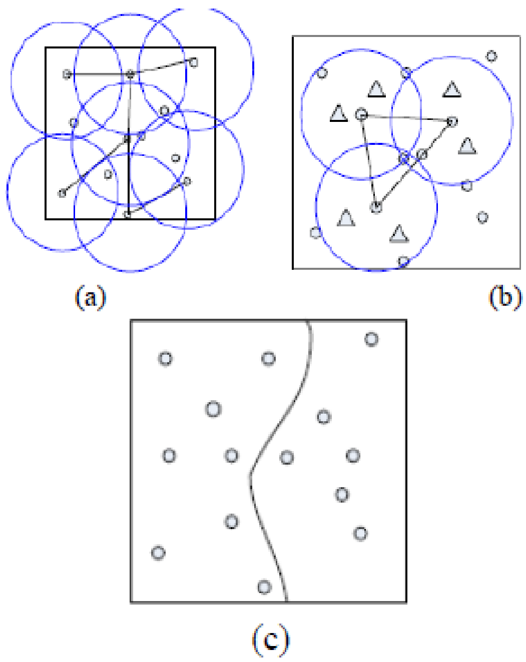

Fig. 1 (a) Area Coverage (b) Point Coverage (c) Barrier Coverage

2.2 B. Coverage Strategies

The strategies used in solving coverage problem in WSN which are done during deployment stage are divided into three categories force based, grid based and computational geometry based.

2.2.1 Force Based:

It uses virtual repulsive and attractive forces. The sensors are forced to move away or towards each other so that full coverage is achieved. Force based deployment strategies rely on the sensor's mobility The sensors will keep moving until equilibrium state is achieved where repulsive and attractive forces are equal thus they end up cancelling each other[8].

2.2.2 Grid Based:

Grid points are used in two ways in WSN deployment

1) To measure coverage

2) To determine sensors positions.

Coverage percentage is defined as ratio of area covered to the area of ROI. In sampling methods, only a set of points inside the ROI is used to evaluate the coverage. The coverage is calculated as ratio of grid points covered to total number of grid points in the ROI. The cost of grid based method is calculated by number of grid points; n×m and amount of sensors deployed, k [7].

2.2.3 Computational Geometry Based:

This method is frequently used in WSN coverage optimization. The most commonly used computational geometry approaches are Voronoi diagram and Delaunay triangulation [5].

3. PSO: A BRIEF OVERVIEW

PSO models social behaviour of a flock of birds [3]. It consists of a swarm of *s* candidate solutions called particles, which explore an *n*-dimensional hyperspace in search of the global solution (*n* represents the number of optimal parameters to be determined). A particle i occupies position Xid and velocity Vid in the *d*th dimension of the hyperspace, $1 \leq i \leq s$ and $1 \leq d \leq n$. Each particle is evaluated through an objective function $f(x1, x2, . . . ,xn)$, where $f : Rn \rightarrow R$. The cost (fitness) of a particle close to the global solution is lower (higher) than that of a particle that is farther. PSO thrives to minimize (maximize) the cost (fitness) function. In the global-best version of PSO, the position where the particle *i* has its lowest cost is stored as (*pbestid*). Besides, *gbestd* is the position of the best particle. In each iteration *k*, velocity *V* and position *X* are updated using (1) and (2). The update process is iteratively repeated until either an acceptable *gbest* is achieved or a fixed number of iterations *k*max is reached.

$Vid(k + 1) = wVid(k) + \square 1\ r1\ (k)(pbestid - Xid) + \square 2r2\ (k)(gbestd - Xid)$ (1)

$Xid(k + 1) = Xid(k) + Vid(k + 1)$ (2)

where □1and □2are constants, and $r1\ (k)$ and $r2\ (k)$ are random numbers uniformly distributed in [0, 1]. Popular themes of PSO research are: choice of parameters and their ranges, iterative adaption of parameters, particle interaction topologies, convergence acceleration, adaption to discrete, binary and integer domains, and hybridization with other algorithms.

4. COVERAGE AND ENERGY OPTIMIZATION TECHNIQUES

4.1 Force Based

4.1.1 VF

The effectiveness of WSN depends on the coverage and target detection. Probability provided by dynamic deployment, which is usually supported by VF algorithm. In the VF algorithm, the virtual force exerted by stationary sensor nodes which hinder the movement of the mobile sensor nodes [9].

4.1.2 PSO

PSO is introduced as other dynamic deployment algorithm, but in this case the computation time required is the big bottleneck [9].

4.1.3 VFPSO

A dynamic deployment algorithm combining the VF algorithm and PSO is proposed, which is so-called VFPSO, where VF uses judicious combination of attractive and repulsive forces to determine virtual motion paths and the rate of movements of sensors and PSO is suitable for solving multi-dimension function optimization in continuous space. In this algorithm, the deployment of mobile sensor nodes are determined by PSO, and the velocity of each particle are updated according to not only the historical local & global optimal solutions but also the virtual force of sensor nodes. It is found that VFPSO has better performance on regional convergence and global searching than PSO algorithm and can implement dynamic deployment of WSNs more efficiently and rapidly [10].

4.1.4 VFCPSO

This paper proposes a dynamic deployment algorithm which is named ―virtual force directed co-evolutionary particle swarm optimization‖ (VFCPSO), since this algorithm combines the co-evolutionary particle swarm optimization (CPSO) with the VF algorithm, whereby the CPSO uses multiple swarms to optimize different components of the solution vectors for dynamic deployment cooperatively and the velocity of each particle is updated according to not only the historical local and global optimal solutions, but also the virtual forces of sensor nodes. Simulation results demonstrate that the proposed VFCPSO is competent for dynamic deployment in WSNs and has better performance with respect to computation time and effectiveness than the VF, PSO and VFPSO algorithms [11].

4.2 Grid Based

4.2.1 Grid based Strategy using PSO

In order to solve coverage problem in Wireless Sensor Network (WSN), Particle Swarm Optimization (PSO) is employed to locate the sensors in a two dimensional square area as region of interest and the coverage performance of sensor nodes will be determined by applying grid based strategy. A homogeneous network is considered where sensing radius for all sensors is similar and the sensors know their position respectively. Grid based strategy divides the target field into grids. Here, sampling methods are used, where only a set of points inside the ROI is used to evaluate the coverage. Besides that, coverage percentages in WSN are calculated based on the following equation:

% Coverage= (Grid points covered / Total Grid Points) x100% (3)

After an initial random placement, the algorithm is executed at a base station. The base station will transmit the sensors' final optimal positions to the sensors then they will move to their optimal positions based on this information. The main objective here is to minimize the total area of coverage holes. The coverage is measured based on grid diagram computation according to the sensors positions encoded in a particle. The computational complexity of this fitness function is due to the number of grid points that not covered [12].

Here, coverage percentage for wireless sensor network can be increased by adding more sensors or using small region of interest (ROI). However, these techniques are only worthy for small surveillance areas such as in a room or hall. Adding more sensors are costly and using small ROI is not practical for some heavy surveillance applications. Therefore, PSO algorithm can be utilized to work out on coverage problem for wireless sensor network without effecting number of sensor nodes and ROI [12].

4.2.2 MDPSO using Grid Based Placement
Distributed sensor network can arrange in two ways, one as a random placement and the second as a grid-based placement. When the surrounding is unknown the random placement is used but when the properties of the network were known before then the sensor placement could be done with great investigation so that we could guarantee the quality of services. The strategy of sensor placement depends on the application of the distributed sensor network (DNS). In this paper the focus is on the grid-based placement and the sensor network is considered as a two or three dimensional network. The modified binary PSO algorithm is applied to solve the problems like coverage and cost [9].

4.2.3 BPSO
A binary version of the algorithm moves particles in a probabilistic space using the velocity of the particle. Thus, both the space and the fitness functions have a binary probability associated with them. Here, the particles try to train themselves during different iterations, hence position themselves in a probabilistic space such that the probability either 0 or 1 is higher for a particular dimension. The swarm tries to maximize the probability of a certain binary variable by maximizing its probability.

The algorithm has been applied to optimize the different grid areas with a fixed numbers of sensor nodes.

Minimum number of sensors nodes required to be deployed to cover the entire grid points keep on increasing with the increase in number of grid points. It may further be emphasized that if the number of sensors nodes for deployment are sufficiently more than the required optimized value to achieve 100% grid coverage then the excess number of sensors are located in an overlapping formation. This formation is achieved to cover not only all grid points but also to cover the entire area [13].

4.2.4 DBPSO
The proposed discrete binary PSO technique has better temporal efficiency in comparison to genetic algorithm technique to solve such problems. A minimum number of sensors are required to cover the entire grid area; below which it is not possible to cover the entire ROI. With the increase in grid node density and the number of sensors used, the placement of sensors using PSO for optimum coverage improves the computational efficiency.

The proposed discrete binary particle swarm optimization algorithm for deployment of wireless sensor network is governed by the number, locations and types of sensors within the network. The performance of the proposed PSO is better in terms of its optimality rate and temporal efficiency in comparison to genetic algorithms. This algorithm is capable of very efficiently deploying the sensors with an objective of maximizing the coverage and minimizing the network cost [13].

4.3 Computational Geometry Approach:
4.3.1 WSNPSOvor
The main aim of WSNPSOvor is to enhance mobile WSN coverage after random deployment. There are few assumptions made:

1. The ROI is a two-dimensional square area.
2. The WSN is homogeneous (i.e., all the sensors have similar sensing radius).
3. The sensors know their positions.

The algorithm designed is to be executed at a base station after an initial random deployment. The final optimal position found will be transmitted by the base station to the sensors. Based on this information the sensors will move to their optimal position. The coding of the particle is straightforward. A particle encodes the positions of the sensors.

WSNPSOvor utilizes Voronoi diagram in the fitness function to measure the coverage. Voronoi diagram is a partition of sites (shown as ◊'s in Fig. 4) in such a way that points inside a polygon are closer to the site of the polygon than any other sites, thus the farthest point of the polygon to its site lies on one of the vertices of the polygon.

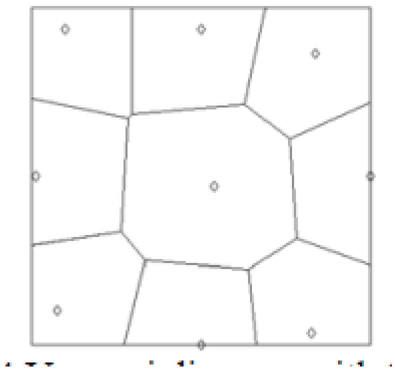

Fig. 4 Voronoi diagram with 9 sites

However, in WSNPSOvor the algorithm aims to minimize the area of the coverage holes (i.e., areas not covered by the sensing field of any sensor) where the Euclidean distance is used as the radius of the holes [14].

4.3.2 WSNPSOper
WSNPSOvor focuses on maximizing the sensor coverage. However, it does not consider the energy consumed in repositioning the sensors. Therefore, here a second phase algorithm is proposed to take the cost of moving the sensors into consideration. The algorithm aims to reduce the distance moved so that the energy is saved. The purpose of WSNPSOper is to minimize the maximum distance moved; dmaxmov by any sensor through its better assignment to their final positions. This is a permutation task, where WSNPSOper need to achieve its objective without reducing the coverage found by WSNPSOvor. The flow of WSNPSOper is as follows; WSNPSOper takes as input the following information about the sensors: the sensor IDs, their initial positions and the final positions of the sensors as found by WSNPSOvor. WSNPSOper assigns the sensors to the final positions such that the maximum distance moved (dmaxmov), is kept at a minimum. The swarm update process continues until the maximum number of iterations is reached. [14].

4.3.3 WSNPSOcon
WSNPSOper is not suitable for limited mobility WSN, therefore the third algorithm is aiming for this type of WSN where the maximum distance travelled (dmaxmov) is limited to a threshold value; Dmax. WSNPSOcon uses the same particle encoding as WSNPSOvor. In every iteration, the maximum distance moved by any particle dmaxmov is passed to the fuzzy system to compute a new value of the penalty parameter γ. This value is passed to PSO to be used in the fitness function for the particles fitness evaluation. The stopping criteria are either; the maximum number of iterations is reached or 100% coverage with

dmaxmov≤ Dmax– is met [14].

5. COMPARISON OF OPTIMIZATION METHODS

If VF based algorithms are compared e.g. VF, PSO, VFPSO & VFCPSO then it is observed that VFCPSO is more effective in terms of effective coverage area, computation time and stable performance as the number of wireless sensor nodes increases. It is fast, effective and robust algorithm for dynamic deployment in WSNs.

If Computational geometry based Voronoi Diagram methods combined with PSO are compared with respect to maximum distance, moved parameter then it can be concluded that for smaller network size WSNPSOper is better than WSNPSOcon. But for larger network size WSNPSOcon is better than WSNPSOper. Hence, most preferred method out of these three can be WSNPSOcon for larger networks and WSNPSOper for smaller networks.

If Grid Based methods e.g. WSN without PSO, WSN with PSO, MDBPSO, Grid Scan Scheme to calculate basic k-coverage rate and Grid Scan based re-deployment scheme for sensor nodes are compared then it is observed that in the first three methods MDBPSO is the best and in Grid Scan based methods re-deployment scheme for sensor nodes is the best.

There is no method which is implemented based on computational Geometry with Delaunay Triangulation that is combined with PSO and implemented for coverage optimization.

6. CONCLUSIONS

There is no common platform on which these all discussed methods can be compared. But if some common parameters are considered for WSN such as coverage area, number of SNs, number of iterations of PSO then it may be the scenario that Grid Based Strategies will yield better results because they divide the ROI into grids and deploy the SNs in the ROI so as to have maximum coverage to be achieved.

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