PSO Based Deployment of Hybrid Sensor Networks

Thesis submitted in partial fulfilment of the requirement for the degree of

Bachelor of Technology

in

Computer Science and Engineering

by

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Certificate

This is to certify that the thesis **PSO Based Deployment of Hybrid Sensor Networks** submitted by **Sushil Pal** and **Annwesh Barik** in the partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Computer Science and Engineering at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance. To the best of my knowledge the matter embodied in the thesis has not been submitted to any other university/institution for the award of any Degree.

Dr. Bibhudatta Sahoo
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Abstract

With the rapid increase in the usage of wireless sensor networks, it is emerging as a technology for monitoring various physical activities. The essential characteristics of wireless sensor network are coverage, cost, connectivity and lifetime which are dependent upon the number and type of sensors being used for the required task. A random deployment strategy of sensor nodes may cause coverage holes in the sensing field. The work presented here shall mainly focus on deployment strategy of WSNs which will improve the coverage area that poses the biggest challenge to the developers. Most of the problems related to WSNs are modelled and approached as multi objective functions through various genetic algorithms. PSO is one such technique that is efficient and computationally efficient in addressing various issues such as optimising sensor deployment and localization of sensor nodes. A modified particle swarm optimization (PSO) technique using grid based strategy has been proposed for sensor deployment which is capable of efficiently deploying the sensors with an objective of maximizing the coverage ratio. It will determine the optimum location of the mobile nodes after the initial random deployment .The optimality rate of this approach is also higher as compared to other genetic algorithms.

Keywords: [Wireless Sensor Networks, particle swarm optimization, area coverage, optimal deployment]

Contents

List of Figures

List of Tables

List of Abbreviations

WSN……Wireless Sensor Network

ROI…….Region of Interest

PSO ……Particle Swarm Optimization

QoS…….Quality of Service

GA …….Genetic Algorithm

GPS ……Global Positioning System

Chapter 1

Introduction

Wireless sensor networks are a group of spatially dispersed and dedicated sensor nodes which are used for monitoring and recording data of various physical conditions such as light, temperature, sound, pressure, humidity etc. and organizing these collected data in a central data sink. Each of the sensor node is composed of a battery, radio transreciever, memory, processor and a sensor. These low-cost, battery operated nodes are targeted to achieve certain tasks, and depending on the type of application they are responsible for sensing, computation and communication tasks. Major applications of wireless sensor networks are structural monitoring, habitat monitoring, disaster management, healthcare as well as other tactical and surveillance applications.

One of the vital points in the fabrication phase of a WSN that pertains to the sensing attribute of the sensor is the coverage of the ROI. The way area coverage protocol is used to maximize area coverage of the ROI similarly the target coverage assumes the sensing field to be divide into a number of target points based on grid based topology. In context to target coverage, coverage can also be referred as the ability of the sensor nodes to reach the data sink. If there is no route for the sensor node to reach the data sink, the data collected by the sensor node cannot be processed. Each node in the WSN has a communication range which defines the area within which another node can be placed. In this a swarm of sensors are deployed in such a manner such that the data from any node can be routed to the destination sink node .Therefore the major objective in the thesis is to maximize the target coverage.

The coverage issue depends on various parameters such as the topology of the network, sensing model and the most important is the deployment strategy. The sensors can be deployed using any deterministic algorithm (predefined manner) or randomly. In most situations the only option available is random deployment. However random deployment of sensors may lead to coverage hole formulations and our required objective of efficiency in terms of coverage may not be achieved. Therefore in this paper we mainly focus on deployment of sensors in order to maximize the coverage.

Such problem solving has both theoretical and practical significance. Since aerial deployment to cover a required region is very expensive, deploying the necessary sensors for desired connectivity and coverage is of utmost importance for various economic reasons.

1.1 Motivation

Wireless Sensor Networks (WSNs) in practice are hybrid in nature. They consist of both mobile sensor nodes and stationary sensor nodes to reduce cost and energy consumption [14]. A WSN consisting of both mobile and stationary nodes is called a Hybrid Wireless Sensor Network. The position of the sensor nodes play a very important role in deciding how effective the WSN is. The positioning of the sensor nodes is referred to as the deployment of the network. The main objective of sensor network deployment is to determine the positions of the sensor nodes which in turn affects the coverage of the region of interest (ROI). In dynamic deployment of sensors, initially they are deployed in a random manner in the ROI and the mobile sensors change their position by moving from one place to another by using the position knowledge from other neighbouring sensors. The purpose of this movement is to increase the coverage ratio of the sensors. The initial random deployment generally does not result in effective coverage. Many deployment strategies based on Genetic Algorithms (GA) have been proposed. But the algorithmic simplicity of Particle Swarm Optimization (PSO) gives it an edge over GA and other biologically inspired techniques. Therefore we are motivated towards finding an efficient deployment strategy based on PSO which results in maximum coverage for a given number of sensors.

1.2 Objective

The present work focuses on the deployment of sensor nodes in wireless sensor network which seeks to maximize the coverage for a given number of sensors. First the problem is analysed and a mathematical model is given to depict the coverage problem in wireless sensor networks. The main objective of this work is to give a PSO based deployment strategy for hybrid sensor networks that maximizes the coverage.

1.3 Organisation of the Thesis

This thesis is organised into 6 chapters:

Chapter 1: Chapter 1 provides basic overview of the Wireless Sensor Networks and its application, with our main focus being the maximization of coverage area in the sensing field and the limitations associated with it during deployment. Here we also represent our basic Problem statement and our main objective.

Chapter 2: Chapter 2 discusses the related work done in this field and points out major factors that need to be taken into consideration while defining the system and the proposed algorithm.

Chapter 3: Chapter 3 discusses the various assumptions which are made in the current work. It also presents a mathematical model for the system based on the probabilistic sensing model which takes into account the environmental conditions and gives a probabilistic distribution function for coverage. It then formulates the given problem in the form of an optimization problem. It also specifies the objective function that needs to be maximized in the optimization problem.

Chapter 2

Related Work

WSNs have recently become a popular research area because of their promising application in numerous areas, especially in district monitoring. Each sensor has a sensing range, and with some sensors combined as WSNs, they can then detect an extended area. Therefore, WSNs are widely used in environment monitoring [6, 1].

However, there are some challenges in using WSNs because of their properties. For example, each sensor has a limited communication range and lifetime [2]. There-fore, the sensors need to be placed within a certain range for communication. For area monitoring, coverage is a problem. The sensors in WSNs are used for monitoring a region of interest (ROI). Therefore, an increase in the number of points detected in the ROI ensures better coverage effect of the sensors deployment. Meanwhile, the deployment algorithm should have an appropriate convergence speed considering about the computation time.

Numerous studies have been conducted to optimize sensor deployment. PSO algorithms are frequently used as an optimization algorithm to solve the deployment of WSNs [9]. Parallel particle swarm optimization (PPSO), which divides the ROI and the sensors equally into several parts, is proposed in [17], and it is used when there are large numbers of sensors to be deployed. Thus, the dimension of the searching space is partitioned to save time. In [13], a

PSO-LA algorithm is proposed, and the velocity is changed by using learning automata (LA). In [16], an improved co-evolutionary PSO algorithm is proposed that combines virtual force and PSO with a co-evolutionary mechanism.

There are some computational geometry methods based on Delaunay triangulations and Voronoi diagrams [1, 2, 8]. In [12], a grid deployment algorithm is proposed with environmental factors in order to minimise the number of mobile nodes needed for deployment.

Earlier most researchers assumed the sensor nodes to be static for the coverage area problem. However, these days the mobile nodes used, have limited repositioning abilities after deployment, due to limited power supply. Various algorithms, such as [10, 7, 18, 5] have been proposed to optimize the coverage and time. One such is the method proposed by Howard et al. [7], which uses the iterative method for determining the positions each node in the WSN should move , for better coverage.

In this paper, the coverage problem is discussed, and an improved algorithm based on PSO is proposed. Because in most of the papers, they have implemented the binary model which is not practical because it does not take the interference due to environmental noise and the decrease of the signal intensity into account. Some important issues investigated are coverage rate and convergence speed.

Chapter 3

System Model

This work deals with optimization of sensor node deployment in wireless sensor networks with the aim to achieve maximum coverage of the ROI. In this section we show how the sensor node deployment can be optimized by optimization of the coverage ratio. First we formulate the given problem and then we propose a mathematical model. The central idea is to find a better solution to the problem using PSO.

3.1 Assumptions

The following assumptions have been taken into consideration while developing the model for the proposed system:

1. The wireless sensor network consists of sensor nodes and a cluster head sensor node which acts as a base station – collects data from all the sensors and passes out commands to them.
2. All sensor nodes remain in the communication range of the cluster head after the initial random deployment.
3. The cluster head is able to execute the proposed algorithm and manage the one-time movement of mobile sensor nodes to the desired locations [19].

4. All the sensors in the network have similar sensing radius.

5. Each sensor uses a mechanism such as Global Positioning System (GPS) by which it can find its location.

6. The ROI is assumed to be a two-dimensional plane that is divided into uniform square grids. The grid points are either used in the measurement of coverage.

7. In a two-dimensional plane the sensing area of the sensor is assumed to be circular.

3.2 Sensing Model

Two types of sensing models are used in WSNs: the Binary Sensing Model [4] and the Probability Sensing Model [15]. The Binary Sensing Model considers only the sensing radius of the sensor with the assumption that an event can be detected if it occurs within the sensing radius of a particular sensor. But in actual practise the sensing ability of the sensor is affected by environmental noise and signal strength. Therefore we have used the Probability Sensing Model in this work which takes these factors into consideration.

Assume that n sensors are deployed in the ROI with each sensor s_i positioned at point (x_i, y_i) with sensing radius r_i. The probability that a point P positioned at (x, y) will be detected by a sensor s_i is given as [15]

$$c_{x,y}(s_i) = \begin{cases} 0 & \text{if } r_i + r_e <= d(s_i, P) \\ e^{-(\alpha_1 \lambda_1 \beta_1 / (\lambda_2 \beta_2 + \alpha_2))} & \text{if } r_i - r_e < d(s_i, P) < r_i + r_e \\ 1 & \text{if } r_i - r_e >= d(s_i, P) \end{cases}$$

Where $d(s_i, P)$ denotes the Euclidean distance between the point P and the location of the sensor s_i.

$$d(s_i, P) = \sqrt{(x_i - x)^2 + (y_i - y)^2}$$

$r_e (0 < r_e < r_i)$ is the uncertainty in sensor detections.$\alpha_1, \alpha_2, \beta_1, \beta_2, \lambda_1$ and λ_2 are parameters related to characteristics of sensor nodes [15]:

$$\lambda_1 = r_e - r_i + d(s_i, P)$$

$$\lambda_2 = r_e + r_i + d(s_i, P)$$

The use of this model results in different probabilities of coverage at different points. Low coverage will result at a point that is covered by only one sensor. In order to compensate for the low coverage the points that are at a greater distance from a sensor node need to be covered by multiple sensors whose sensing area overlap in that region. The coverage of the overlapped area S_{ov} which is overlapped by a set of k_{ov} sensors is given as [15]:

$$c_{x,y}(S_{ov}) = 1 - \prod_{s_i \in S_{ov}} (1 - c_{x,y}(s_i))$$

The objective function of the PSO can be determined as: [11]:

$$\text{Objective Function, CR=Coverage Ratio=} \frac{N_{effective}}{N_{all}}$$

where $N_{effective}$ is the number of points in ROI that are effectively covered and N_{all} is the total number of points in the whole ROI.

3.3 Problem Definition

The coverage problem can be defined as; given a set of N number of hybrid sensors, $S = \{s_1, s_2, ..., s_N\}$ and a ROI, the coverage problem is how to position the sensors in the ROI so that the coverage percentage is maximized and coverage holes is minimized [3].

The optimization problem can therefore be stated as:

$$\text{Maximize: CR=Coverage Ratio=} \frac{N_{effective}}{N_{all}}$$

Chapter 4

Proposed Work

4.1 Method

The basic PSO is easily trapped into a local minimum and has some problems such as premature convergence or the curse of dimensionality. A non-linear dynamic adaptive control inertia weight PSO improves to better balance global search ability and local development capability of the particle swarm. Therefore we dynamically control the variation range of inertia weight according to the best and worst coverage values obtained by the particles after each iteration and this inertia weight value is used for updating the velocity of the particles in the next iteration.

In this work, we use a probabilistic deployment model for the mobile sensor nodes of the WSN, that gives the best locations that these nodes should move after their initial deployment, to improve the network coverage of the WSN. This algorithm will overcome the disadvantages of the PSO algorithm with early convergence and time consumption. This algorithm is a modified version of the traditional PSO but with improved, faster and more optimized global solution.

In our proposed work , we assume that there are n sensors in the region of interest(ROI) .The location of each sensor is described using coordinate system as (x_i, y_i). Therefore each particle in the PSO can be represented as

$(x_1, y_1, x_2, y_2, x_3, y_3, ..., x_n, y_n)$.Therefore if there are n sensors , then each particle in it is $2n$ dimensional.

The velocity update function in the PSO is represented as follows:

$$v_{id}(i+1) = w * v_{id}(i) + c_1 * rand() * (p_{ibest} - x_{id}) + c_2 * rand() * (p_{gbest} - x_{id})$$

$$x_{id}(i+1) = x_{id} + v_{id}(i+1)$$

where, v_{id} represents the velocity of the i_{th} particle in the d_{th} dimension.
c_1 and c_2 are the cognitive and social factor which corresponds to local and global best solutions.
$rand()$ is a random number between 0 and 1 to give the algorithm a stochastic approach.
w is the inertia weight factor which indicates that the direction of motion of the particle is affected by its former velocity .The value of W is given as follows:

$$w_{(i+1)} = \frac{Coverage_{best(i)} - Coverage_{worst(i)}}{Coverage_{best(i)}}$$

Where, $Coverage_{best(i)}$ is the coverage obtained by the best particle in the i^{th} iteration and $Coverage_{worst(i)}$ is the coverage obtained by the worst particle in the i^{th} iteration.

We used the probability sensing model and the area coverage is used as a terminating condition or when the maximum iteration is reached. We initially divide the sensing field into a number of grid points .Each grid point denoting a potential sensing position of data.

To get the coverage rate:

1. Calculate the coverage rate of each grid point to each sensor node.
2. Calculate the overall coverage rate of each grid point using equation 4.
3. Repeat Step 1 and Step 2 to calculate the overall coverage rate of each grid point .
4. 4. Calculate the area coverage using equation 6.

4.2 Deployment Flowchart

The optimization algorithm is described as follows:

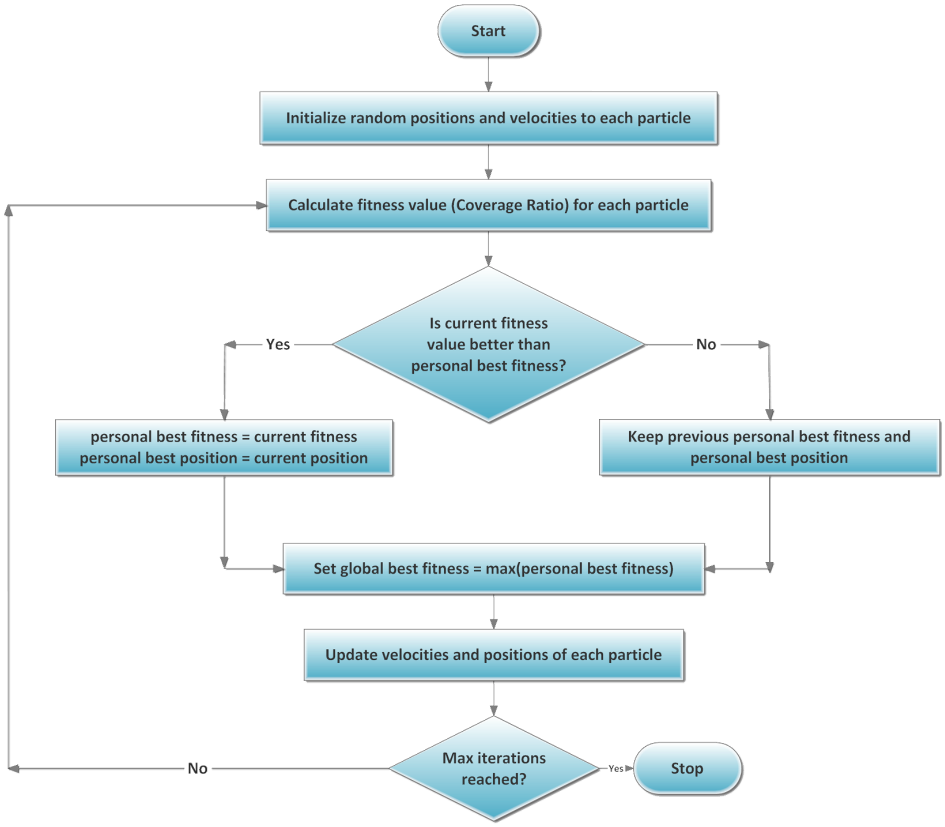

Figure 4.1: Algorithm Flowchart

Chapter 5

Simulation and Results

5.1 System Specifications

In order to test the performance of our algorithm, we performed several simulations using MATLAB. For this purpose, we implemented it using a Intel Core i7-2670 CPU (3.2 GHz) PC using MATLAB R2013a.

5.2 Deployment Performance

We have assumed the sensing field to be a $20*20$ square meter area, in which each intersecting grid point is a potential sensing point. We have initially considered $n = 20$ sensors, which means the dimensions of each particle in PSO will be $d = 2 * n = 40$. The parameters for simulation experiments are:

Number of Sensors	Number of Particles	Area	α_1	α_2	β_1	β_2	r_e	Iterations
20	10	20x20	1	0	1	0.5	$0.5 * r$	200

Table 5.1: Simulation Parameters

5.3 Simulation Results

As the result of our simulation, our deployment algorithm ran successfully each time finding the best optimal solution. Our goal for maximizing the coverage area of the sensing field by our deployment algorithm is fulfilled.

As shown in Table below we can observe that the as the sensing radius of the sensor nodes increase, the coverage rate of the sensing field also increases. Even, when the sensing radius increases, the number of iteration required to calculate the optimal coverage area decreases.

Radius of Sensor Nodes	1.5	2	2.5	3	4	5
Initial Random Coverage %	20.1	31.4	41.9	51.8	66.7	75.9
Coverage % Standard PSO	29.7	45.793	70.986	81.668	97.524	99.962
Coverage % Modified PSO	30.2	50.205	72.669	91.433	99.825	100

Table 5.2: Simulation Results

One more fact that we observe from the result is that, as we increase our radius from $r = 1.5$ to $r = 2.5$, the coverage rate increases with an increasing slope. While as we move from $r = 3$ to $r = 5$, the coverage rate increases with a decreasing slope, and it continues decreasing for the rest of the datasets (for $r > 3$, slope of the coverage rate decreases).

Since the initial positions of the node are declared randomly, there may be a slight probability that our initial configuration might turn into our optimal solution. However, our objective is met by implementing the algorithm, which is to find the best deployment strategy to improve our coverage rate.

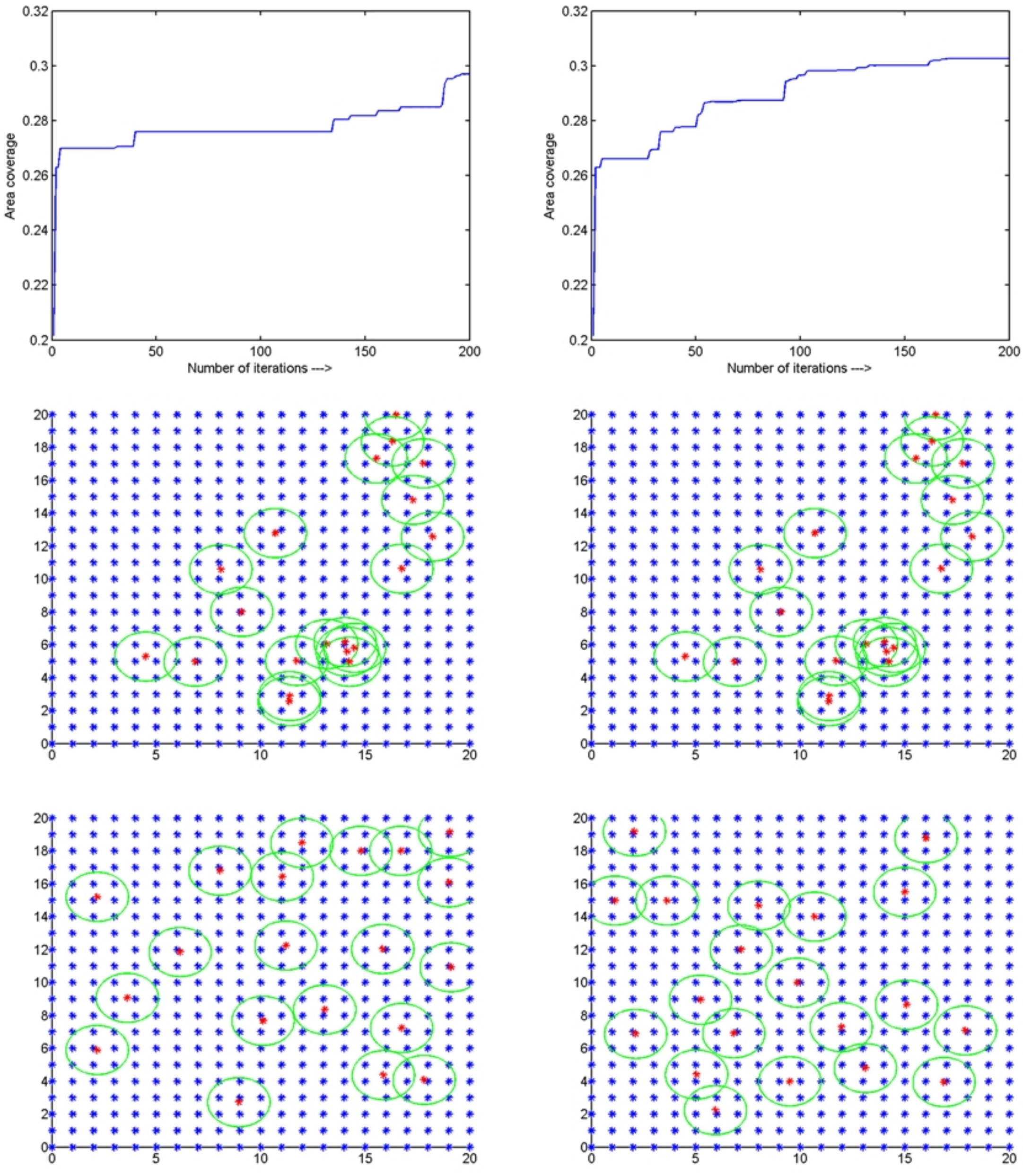

Figure 5.1: Standard PSO vs. Modified PSO for r=1.5

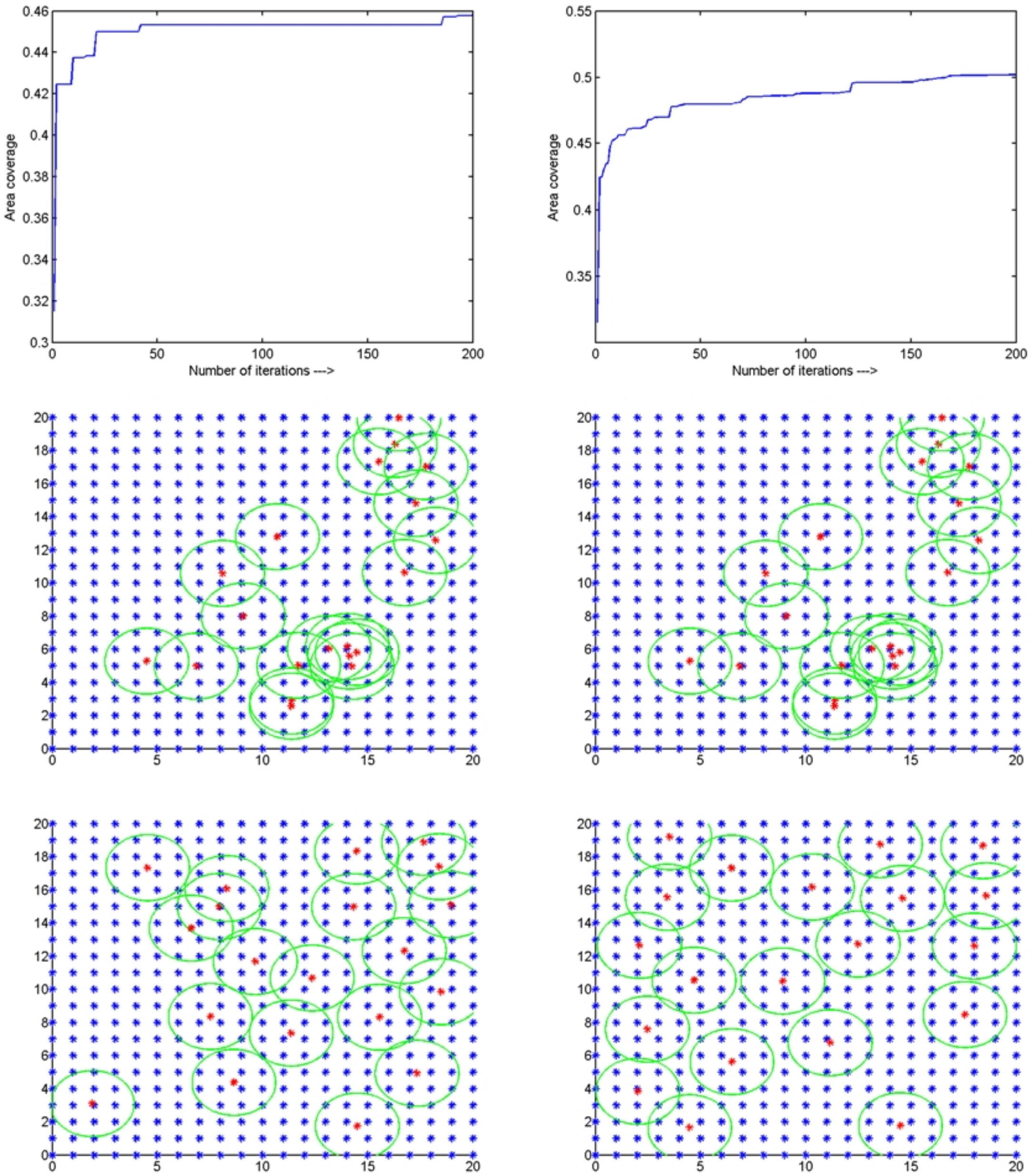

Figure 5.2: Standard PSO vs. Modified PSO for r=2

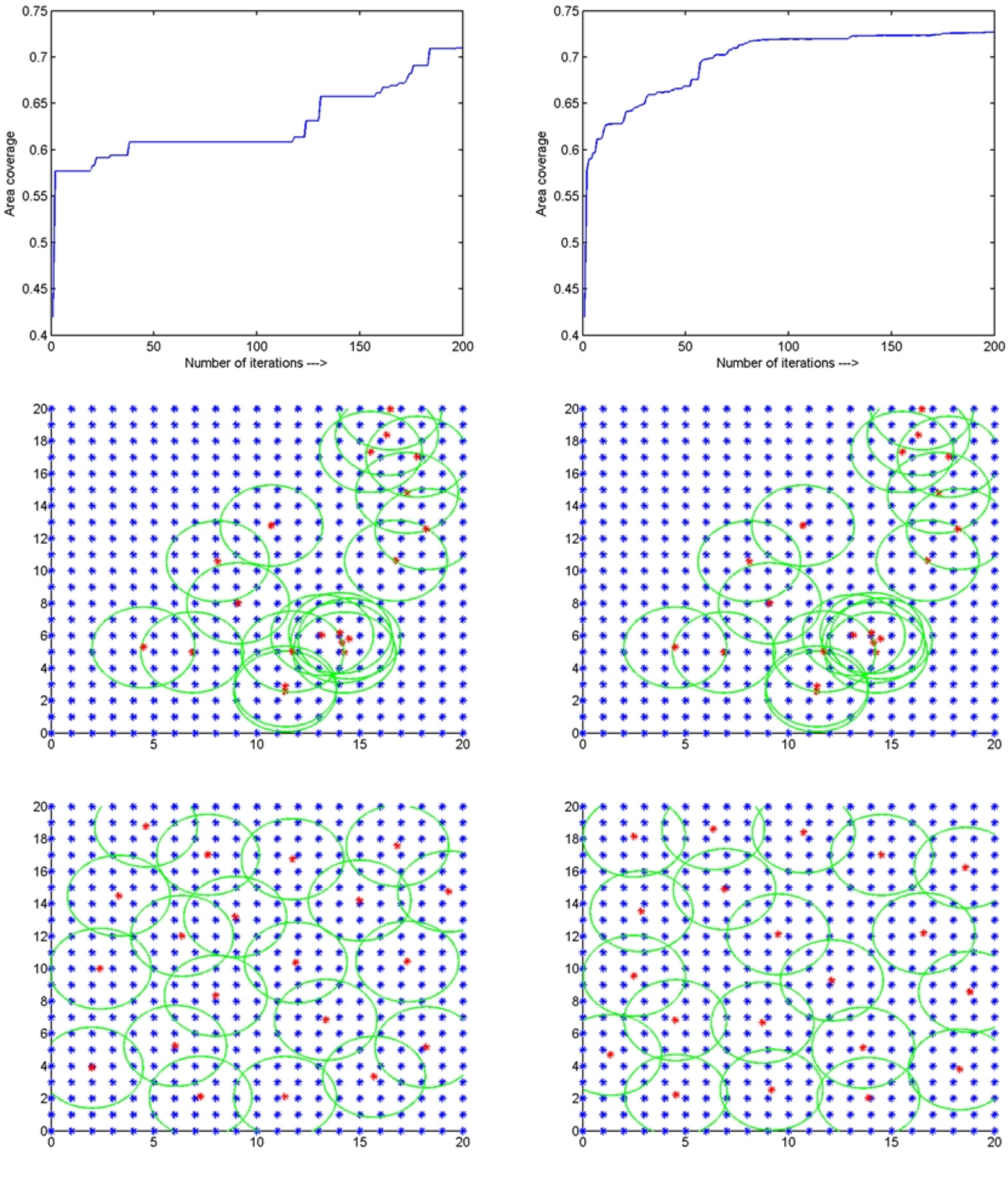

Figure 5.3: Standard PSO vs. Modified PSO for r=2.5

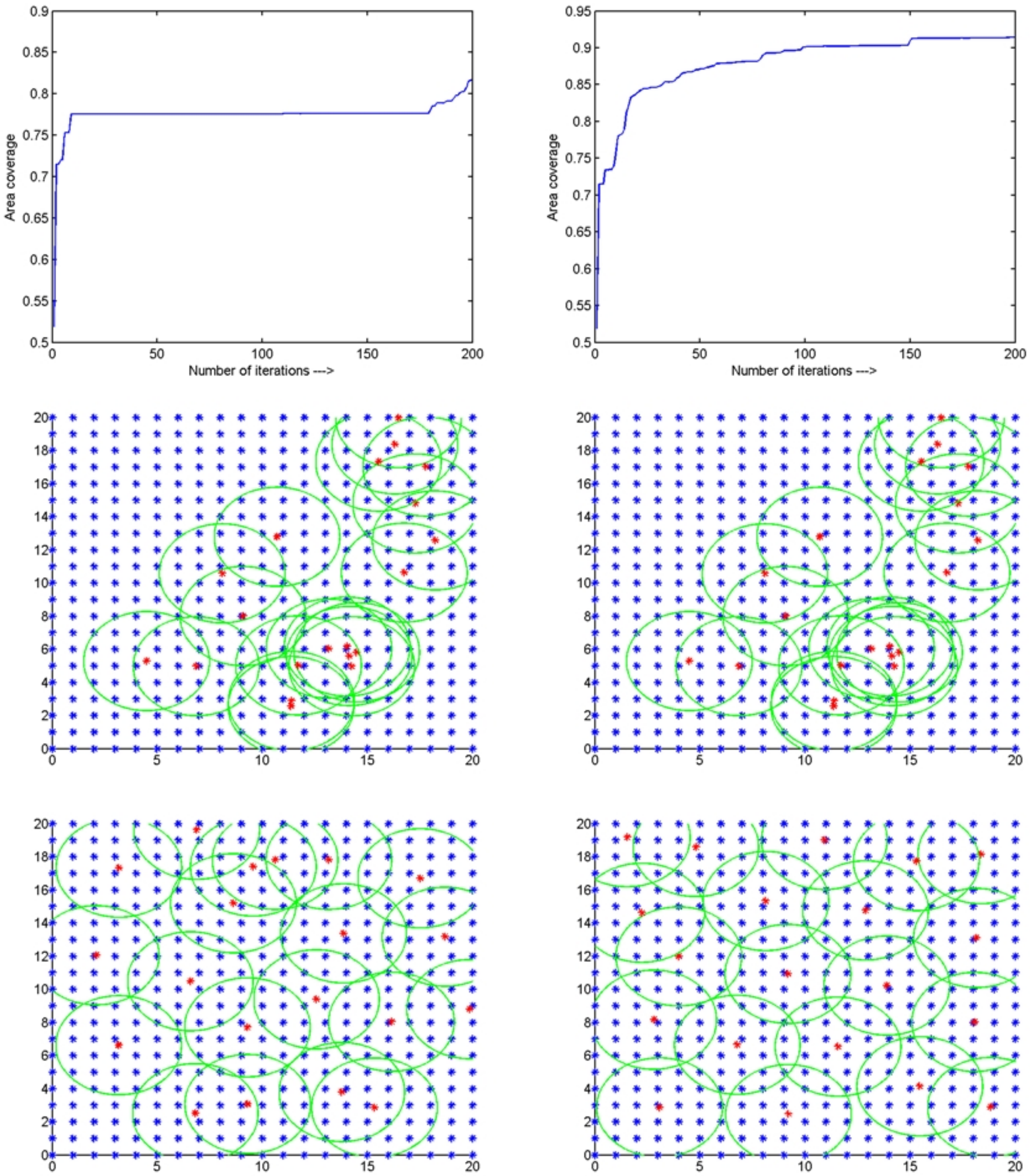

Figure 5.4: Standard PSO vs. Modified PSO for r=3

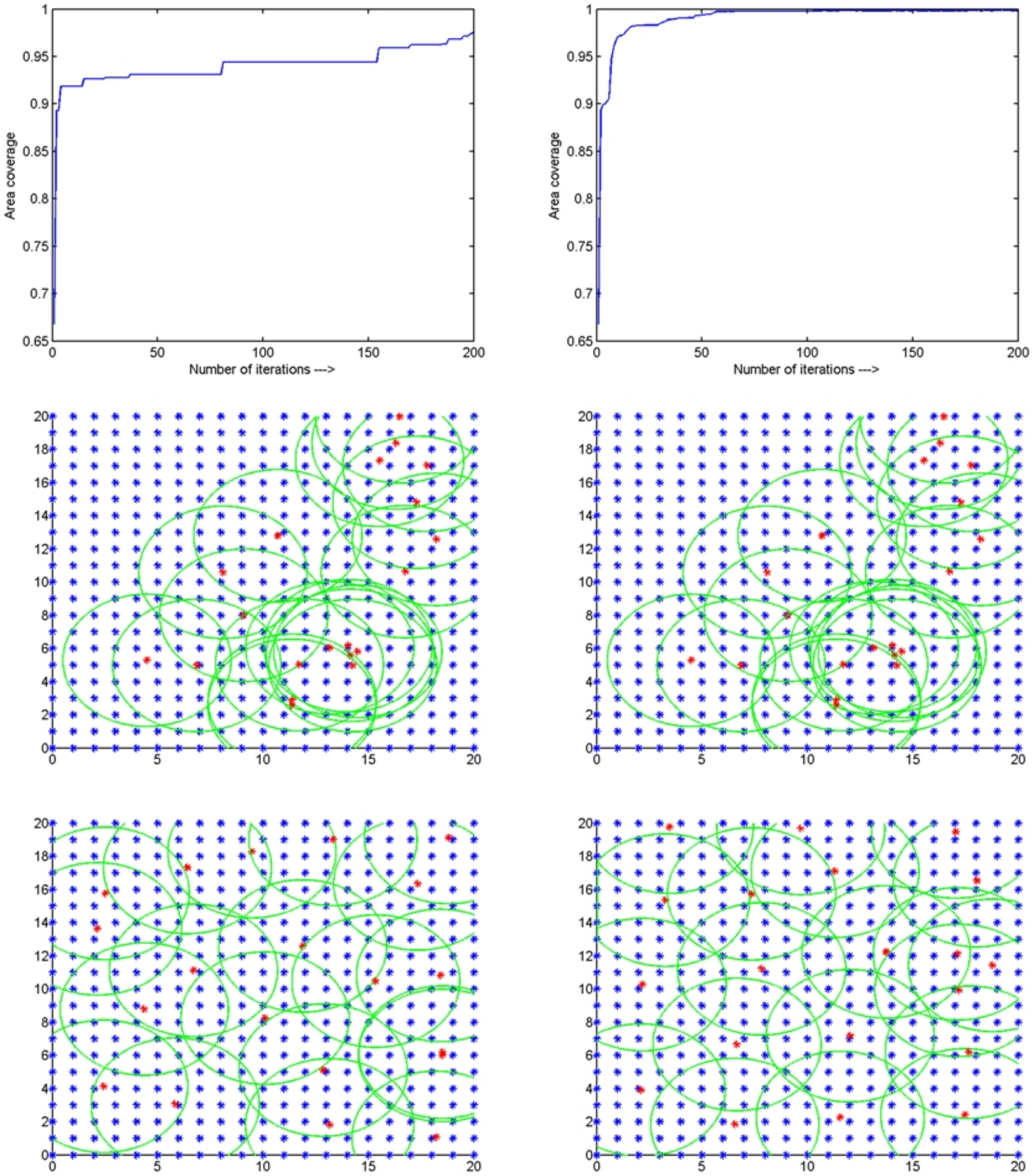

Figure 5.5: Standard PSO vs. Modified PSO for r=4

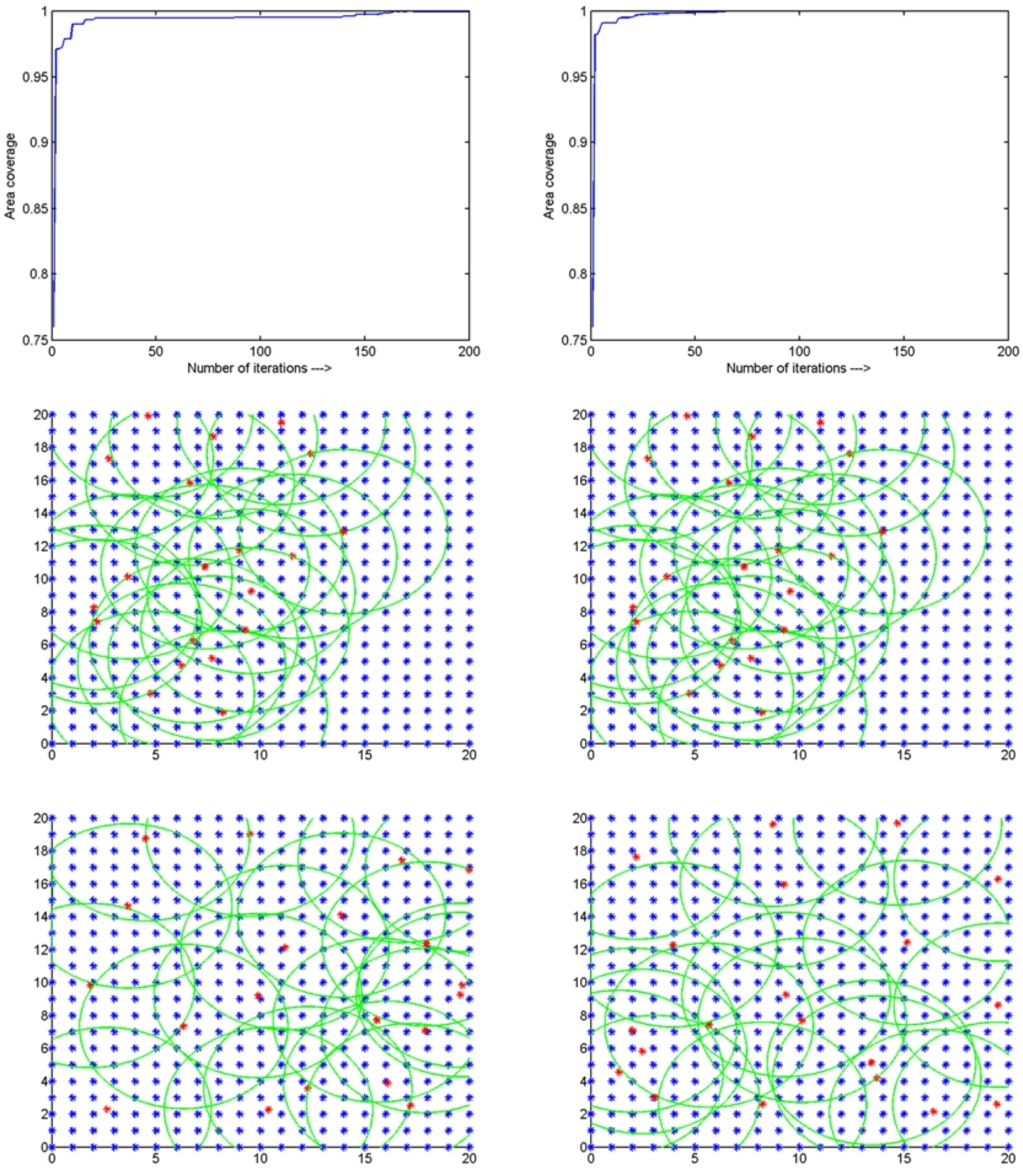

Figure 5.6: Standard PSO vs. Modified PSO for r=5

Chapter 6

Conclusion and Future Work

Wireless sensor networks have provided a basis to future technologies and has made a huge influence on our day to day life. As developers face various challenges which arises due to coverage holes, limited energy and computational constraints needs to be addressed.

Therefore we used Particle swarm optimization which is a bio-inspired optimization technique and has been a popular technique that is preferred for solving various WSN problems due to its simplicity, highly optimal solution and negligible computational burdens.

This thesis presented an approach to tackle the area coverage problem using PSO. We have considered the probability sensing model to evaluate the performance of the network. We found that the optimal coverage result is found using the PSO deployment strategy to search the global. Finally, the effectiveness was proved with the simulation conducted by MATLAB.

This thesis presented a deployment strategy with a motive towards improving it, in the context to convergence. Although this algorithm provides an optimal deployment positions, but the sensing model still needs to be optimized. However due to high computational overhead and iterative nature of PSO, it can prohibit its use for high-speed real-time applications, especially if optimization needs to be carried out frequently. Our future work shall be related to optimizing our algorithm so that the solution can be achieved with minimum iterations and quick convergence.

Bibliography

[1] N Azlina Bt A Aziz, Ammar W Mohemmed, and Mohammad Yusoff Alias. A wireless sensor network coverage optimization algorithm based on particle swarm optimization and voronoi diagram. In *Networking, Sensing and Control, 2009. ICNSC'09. International Conference on*, pages 602–607. IEEE.

[2] NABA Aziz, Ammar W Mohemmed, and BS Daya Sagar. Particle swarm optimization and voronoi diagram for wireless sensor networks coverage optimization. In *Intelligent and Advanced Systems, 2007. ICIAS 2007. International Conference on*, pages 961–965. IEEE.

[3] Nor Azlina Ab Aziz, Kamarulzaman Ab Aziz, and Wan Zakiah Wan Ismail. Coverage strategies for wireless sensor networks. *World Academy of Science, Engineering and Technology*, 50:145–150, 2009.

[4] Krishnendu Chakrabarty, S Sitharama Iyengar, Hairong Qi, and Eungchun Cho. Grid coverage for surveillance and target location in distributed sensor networks. *Computers, IEEE Transactions on*, 51(12):1448–1453, 2002.

[5] Bogdan Cărbunar, Ananth Grama, Jan Vitek, and Octavian Cărbunar. Redundancy and coverage detection in sensor networks. *ACM Transactions on Sensor Networks (TOSN)*, 2(1):94–128, 2006.

[6] Ahmed M Elmogy, Fakhreddine Karray, and Alaa M Khamis. Auction-based consensus mechanism for cooperative tracking in multi-sensor surveillance systems. *JACIII*, 14(1):13–20, 2010.

[7] Andrew Howard, Maja J Matarić, and Gaurav S Sukhatme. An incremental

self-deployment algorithm for mobile sensor networks. *Autonomous Robots*, 13(2):113–126, 2002.

[8] Fan Jing, Wu Qiong, and Hao JunFeng. Optimal deployment of wireless mesh sensor networks based on delaunay triangulations. In *Information Networking and Automation (ICINA), 2010 International Conference on*, volume 1, pages V1–370–V1–374. IEEE.

[9] Raghavendra V Kulkarni and Ganesh Kumar Venayagamoorthy. Particle swarm optimization in wireless-sensor networks: A brief survey. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, 41(2):262–267, 2011.

[10] Mo Li, Peng-Jun Wan, and Ophir Frieder. Coverage in wireless ad hoc sensor networks. *Computers, IEEE Transactions on*, 52(6):753–763, 2003.

[11] Zhiming Li and Lin Lei. Sensor node deployment in wireless sensor networks based on improved particle swarm optimization. In *Applied Superconductivity and Electromagnetic Devices, 2009. ASEMD 2009. International Conference on*, pages 215–217. IEEE.

[12] Ren C Luo and Ogst Chen. Mobile sensor node deployment and asynchronous power management for wireless sensor networks. *Industrial Electronics, IEEE Transactions on*, 59(5):2377–2385, 2012.

[13] Roghayeh Soleimanzadeh, Bahareh J Farahani, and Mahmood Fathy. Pso based deployment algorithms in hybrid sensor networks. *Int. J. Comput. Sci. Netw. Secur*, 10:167–171, 2010.

[14] Xue Wang, Jun-Jie Ma, Sheng Wang, and Dao-Wei Bi. Prediction-based dynamic energy management in wireless sensor networks. *Sensors*, 7(3):251–266, 2007.

[15] Xue Wang and Sheng Wang. Hierarchical deployment optimization for wireless sensor networks. *Mobile Computing, IEEE Transactions on*, 10(7):1028–1041, 2011.

[16] Xue Wang, Sheng Wang, and Jun-Jie Ma. An improved co-evolutionary particle swarm optimization for wireless sensor networks with dynamic deployment. *Sensors*, 7(3):354–370, 2007.

[17] Xue Wang, Sheng Wang, and Junjie Ma. *Dynamic deployment optimization in wireless sensor networks*, pages 182–187. Springer, 2006.

[18] Guoliang Xing, Xiaorui Wang, Yuanfang Zhang, Chenyang Lu, Robert Pless, and Christopher Gill. Integrated coverage and connectivity configuration for energy conservation in sensor networks. *ACM Transactions on Sensor Networks (TOSN)*, 1(1):36–72, 2005.

[19] Yi Zou and Krishnendu Chakrabarty. Sensor deployment and target localization based on virtual forces. In *INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies*, volume 2, pages 1293–1303. IEEE.