

41. Area Coverage Optimization in WSN using Modified PSO

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ABSTRACT

Wireless sensor network found immense uses in the daily life. Also, the random deployment of nodes is a preferable option in many applications such as earthquake observation, military applications, forest fire detection etc. It is expected that deployed nodes should be able to monitor the field of interest (FoI) with the optimum capacity. In order to maximize the coverage of area, each node should be repositioned to an optimal position inside the FoI. A Modified Particle Swarm Optimization (PSO) algorithm has been proposed to achieve optimum coverage while keeping the number of nodes minimum. It introduces the concept of negative velocity in order to avoid premature convergence of the algorithm. The simulated results show a significant improvement in the performance with compared to the standard PSO.

Index Terms— WSN, FoI, Particle swarm optimization, coverage, coverage rate.

INTRODUCTION

The modern age requires a mixture of sophistication and simplicity in technology. Wireless sensor network (WSN) is a leading solution of modern age requirement[1]. WSN is a group of spatially distributed sensor nodes capable of sensing environment, processing information, transmission of gathered data[2]. The WSN consists of mainly four components viz: a group of spatially dispersed sensor nodes, an interconnection network between nodes, a central point of information gathering and a set of computing resources at the central point (or beyond) to handle data correlation, event trending, status querying, and data mining.

The coverage problem[3] in WSN can be stated as “how to deploy and relocate sensor nodes in order to maximally cover the field of interest (FoI) while keeping number of sensing nodes minimum”. There are several categories of coverage techniques: Forced-based, grid-based, computational geometry based and metaheuristic based. Each category has its own prerequisites and constraints[4].

The concept of Particle Swarm Optimization (PSO) was first given by James Kennedy and Russell Eberhart in year 1995. It is a very efficient optimization technique inspired by the behavior of bird flocking. The particles involved in the swarm have very limited computational capability but working in a unison they provides a powerful optimization tool. The authors of [5] proposed an algorithm based on PSO and Voronoi diagram where PSO provides an optimal locations for sensor nodes and afterward Voronoi diagram checks the optimality of the solution. The authors of [6] has proposed an algorithm which optimize the coverage of a FoI in terms of energy and lifetime of the WSN in presence of obstacles. Another paper [7] uses PSO to optimize the information coverage rate using the minimum number of sensor nodes and using minimum energy[8].

Though PSO offers a great ease to optimize any multiobjective fitness function, its suffers from premature convergence[9]. Standard PSO can fall easily to a local maxima or minima rather than to a global solution. The presented algorithm introduces the concept of negative velocity and shows the improvement in the maximum coverage of the FoI in compared to standard PSO. It also shows faster convergence in compared to the standard PSO. The remaining paper has been organized in following manner: section II briefs the coverage mathematical models. Section III describe the standard PSO algorithm. Section IV elaborates the proposed algorithm. Section V simulation results are explored and finally in section VI the paper has been concluded.

WIRELESS SENSOR NETWORK COVERAGE MATHEMATICAL MODEL

A. PROBLEM DESCRIPTION

The field of interest is a restricted 2-dimensional plane, and a fixed number of sensor nodes are randomly deployed within the FoI. The objective is to attain the maximum coverage of the FoI using the deployed nodes. Some constraints and assumption has made:

- The sensing range of a node is in a form of disc centered at the nodes' position.
- The nodes are mobile in nature and they have enough energy to relocate to the final position from initial position.
- All the nodes are isomorphic with same sensing and communication radius.
- One node can know the location of every other node present in the FoI.
- There are no obstacles present inside the FoI.

B. COVERAGE MATHEMATICAL MODEL

Coverage ratio is the measure of what percentage of total area is being covered. Let the N be the total number of sensors dispersed in the FoI of area A and every node may sense an area A_s , thus the coverage ratio C_R can be given in (1) :

$$C_R = \left(\bigcup_{i=1,2,\dots,N} A_{s_i} \right) / A \quad (1)$$

But the above expression of coverage ratio may become cumbersome and complicated for randomly dispersed nodes. A better option is provided by the authors of [10] for evaluating coverage ratio represented in (2).

$$C_R = \frac{m}{n} \quad (2)$$

Where, m denotes the number of grid points covered by sensor nodes and n represent total number of grid points present in FoI. The value of m is defined by the coverage model being used. For binary sensing model as shown in (3):

$$m = \text{cardinality} \left(\bigcup_{i=1,2,\dots,N} Q_i \right) \quad (3)$$

Where, Q_i is the set of grid points lying inside the coverage range (r_s) of the sensor s_i . Whereas for probabilistic sensing model, the value of m is given by the number of grid points satisfying the following criteria described in (4):

$$C_{xy}(\rho, S_N) = 1 - \prod_{i=1}^N (1 - (C_{xy}(\rho, s_i))) \geq C_{th} \quad (4)$$

Here, $C_{xy}(\rho, S_N)$ is the joint coverage probability, C_{th} is a predetermined threshold and $C_{xy}(\rho, s_i)$ is the probability of detection the node s_i of a grid point $\rho(x,y)$ and given by the probabilistic sensing model as in (5):

$$C_{xy}(\rho, s_i) = \begin{cases} 1 & \text{if } d(s_i, \rho) \leq r_s - r_e \\ e^{\left(\frac{-\alpha_1 \beta_1 \lambda_1}{\beta_2 \lambda_2 + \alpha_2} \right)} & \text{if } r_s - r_e < d(s_i, \rho) < r_s + r_e \\ 0 & \text{if } d(s_i, \rho) \geq r_s + r_e \end{cases} \quad (5)$$

Where, r_e ($0 < r_e < r_s$) is the uncertainty radius present in the sensing capability of the nodes and $\alpha_1, \alpha_2, \beta_1, \beta_2$ are constant related to nodes' characteristic, the value of λ_1, λ_2 are given in (6) and (7):

$$\lambda_1 = r_e - r + d(s_i + \rho) \quad (6)$$

$$\lambda_2 = r_e + r + d(s_i + \rho) \quad (7)$$

In all the above equation $d(s_i, \rho)$ represent the Euclidian separation amidst a sensor node s_i and point $\rho(x, y)$ given in (8):

$$d(s_i, \rho) = \sqrt{((x_i - x)^2 + (y_i - y)^2)} \quad (8)$$

PARTICLE SWARM OPTIMIZATOIN

Particle swarm optimization[11] is a simple yet a very powerful optimizing tool. In PSO a total of N particle is dispersed randomly inside the search space. These swarm particle traverse through the search plane to give the local best solution and global best solution of the objective function. Let N be the total swarm size, x_i and p_i are the position and local best position of the sensor node s_i (where $1 \leq i \leq N$). Velocity of the particle is given by v_i . p_g denotes the global best particle and d is the dimension of the search space. Equation (9) and (10) describe the standard equations of the PSO.

$$v_{id}(t+1) = w * v_{id}(t) + c_1 * r_1 * (P_{id} - x_{id}(t)) + c_2 * r_2 * (p_{gd} - x_{id}(t)) \quad (9)$$

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \quad (10)$$

In (9), the first part on the right hand side is *inertia part* and w denotes the inertia weight, the second part is the *cognitive part* with c_1 and r_1 being cognitive constant and random number ($0 < r_1 < 1$). The third part is the *social part* with c_2 and r_2 being social constant and random number ($0 < r_2 < 1$). Equation (10) updates the position of the node s_i . The velocity of any particle is governed by its own velocity, position of the best position achieved by it and the global best position.

PROPOSED ALGORITHM: MODIFIED PSO

A. OBJECTIVE FUNTION FOR THE COVERAGE PROBLEM

Suppose the WSN has the total N sensor nodes dispersed randomly over a square area. The aim of proposed work to enhance the coverage ratio by using a fixed amount of nodes and minimizing the movement of sensor nodes.

This optimization can be modeled as described in (11)

$$\text{Min}[F_1(x), F_2(x)] \quad (11)$$

This is the multi-objective function where $F_1(x)$ and $F_2(x)$ are described in (12) and (13). Here, $x \in \text{Search space}$.

$$F_1(x) = \left(\frac{1}{N}\right) \sum_{i=1}^N \sqrt{(x_{i_{initial}} - x_{i_{new}})^2 + (y_{i_{initial}} - y_{i_{new}})^2} \quad (12)$$

$$F_2(x) = 1 - C_R \quad (13)$$

Where, $(x_{i_{initial}}, y_{i_{initial}})$ is the initial position of the nodes when they were deployed and $(x_{i_{new}}, y_{i_{new}})$ is the position of the node s_i after any iteration. To solve multi-objective function is to convert it into a weighted-sum problem as in (14).

$$\text{min} \sum_{i=1}^2 \omega_i \cdot F_i(x) \quad (14)$$

In (14) ω_i is the weights associated with function F_i with two criteria viz: $\sum \omega_i = 1$ and $\omega_i > 0$ for $i=1, 2$.

B. IMPROVED PARTICLE SWARM OPTIMIZATION

Assume that N have been deployed randomly in the area A and the search dimension is 2 ($d=2$). Let x_i and p_i are the position and local best position of the sensor node s_i (where $1 \leq i \leq N$). Velocity of the particle is given by v_i . p_g denotes the global best.

Step 1. *Initialization*: Deploy N number of sensor nodes to random positions in the area A ($d=2$). Assign zero initial velocity to every node. Assign the current position of nodes as the local best position.

Step 2. *Global best calculation*: Calculate the Euclidian Distance of each node's best position with respect to the origin of the area *i.e.* $(0,0)$. The particle having largest value gives the global best position.

Step 3. *Position and Velocity updation*: The velocity and position one node (starting from 1st node) is to be updated using (15) and (16).

$$v_i(t+1) = w * v_i(t) + c_1 * r_1 * (P_i - x_i(t)) + c_2 * r_2 * (p_g - x_i(t)) \quad (15)$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (16)$$

Step 4. *Local best calculation*: If the fitness value (using (14)) of the i^{th} particle for current iteration is better than the previous iteration then, update the local best position for that particle with the current position otherwise no changes will be done in the local best position.

Step 5. Repeat step 3. and step 4. for every node in the swarm.

Step 6. If ending criteria is not met, traverse to step 2. Otherwise the present result is the optimized result. End of the algorithm.

The above steps describe the complete working of the proposed algorithm. Negative velocity of the particle ensures that algorithm will not converge prematurely.

SIMULATION RESULTS AND DISCUSSION

For observing the functioning of the presented algorithm, MATLAB 2019a software has been used.

A. SIMULATION PARAMETERS AND RESULTS

The parameters used for this simulation has been listed in table 41-1.

Table 41-1 Simulation Parameters

N	20
A	20×20 m ²
<i>Max iteration</i>	400
c_1	1.467
c_2	1.467
α_1	1
α_2	0
β_1	1
β_2	0.5
d (<i>dimension of search space</i>)	2
w	0.9 – (iteration / (2*Max iteration))

For simulation 20 sensor nodes has been deployed in 20×20 m² area in a random fashion The sensing radius is being varied for each simulation.

The optimization of coverage ratio of nodes having sensing radius $r_s = 1.5m$ & $r_e = 0.25m$ has been shown in Fig. 41-1 and Fig. 41-2.

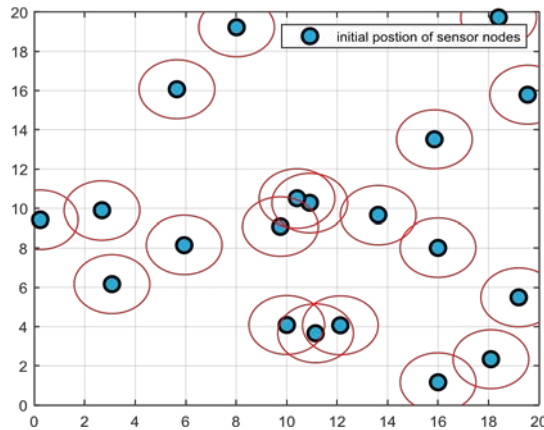


Figure 41-1 Initial placement of sensor nodes with $r_s = 1.5m$ & $r_e = 0.25m$

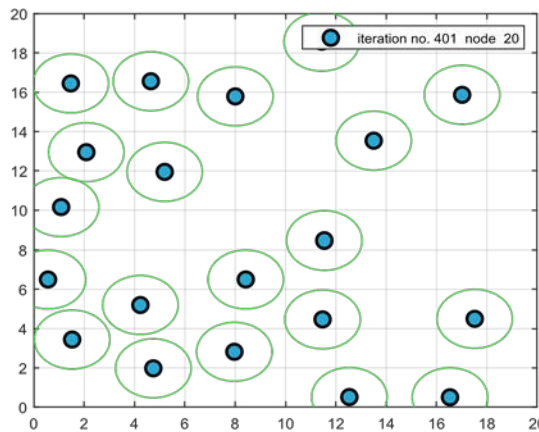


Figure 41-2 Optimised position of nodes ($r_s = 1.5m$ & $r_e = 0.25m$) after applying improved algorithm

The Fig. 41-2 shows the nodes acquire better position after algorithm. The initial coverage ratio was around 34.5% which becomes 45% after 270 iterations i.e. 10.5% increase. The improvement in coverage ratio can be seen in Fig. 41-3.

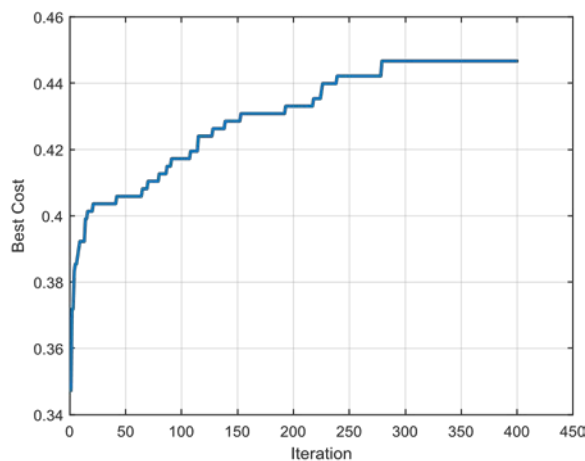


Figure 41-3 Coverage ratio vs. iteration for $r_s = 1.5m$ & $r_e = 0.25m$

Similarly, simulation has been done a WSN with the nodes having $r_s = 2m$ & $r_e = 0.5m$ and has been depicted in Fig. 41-4 and Fig. 41-5.

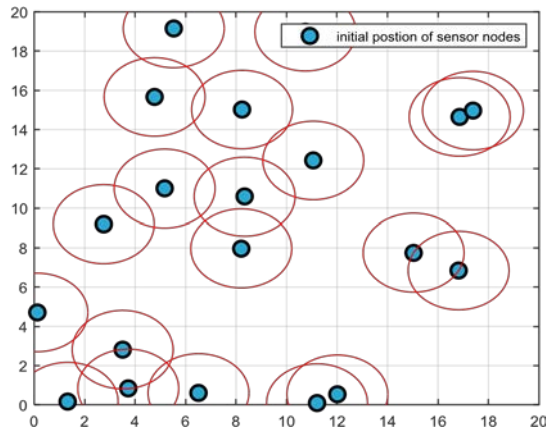


Figure 41-4 Initial placement of sensor nodes with $r_s = 2m$ & $r_e = 0.5m$

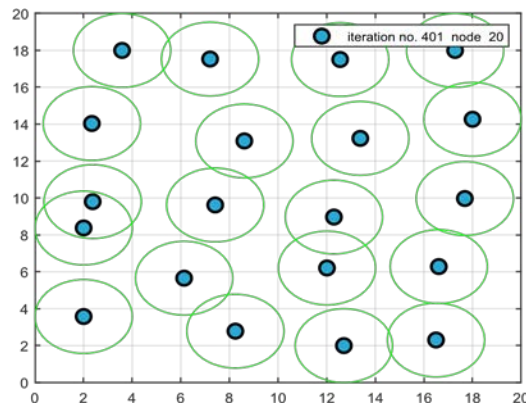


Figure 41-5 Optimised position of nodes ($r_s = 2m$ & $r_e = 0.5m$) after applying improved algorithm

The Fig. 41-5 gives a better proof that the nodes have better position after going through proposed algorithm. The initial coverage ratio was around 54% which becomes 73% after 240 iterations which is 20% increase. The improvement in coverage ratio can be seen in Fig. 41-6.

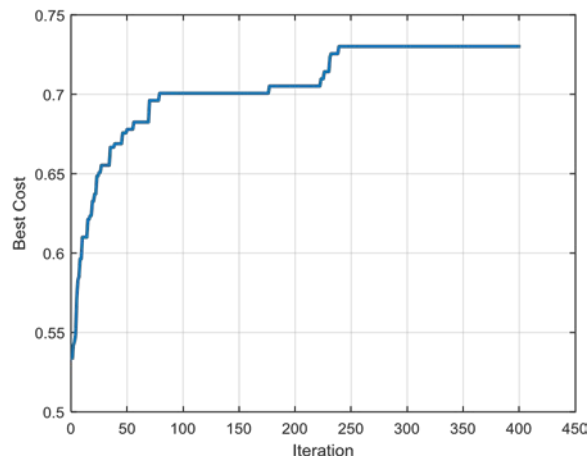


Figure 41-6 Coverage ratio vs. iteration for $r_s = 2m$ & $r_e = 0.5m$

Another simulation has been done to a WSN with the nodes having $r_s = 3m$ & $r_e = 1.25m$ and has been depicted in Fig. 41-7 and Fig. 41-8.

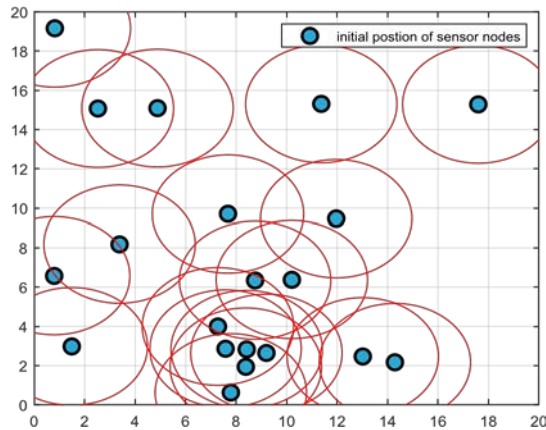


Figure 41-7 Initial placement of sensor nodes with $r_s = 3m$ & $r_e = 1.25m$

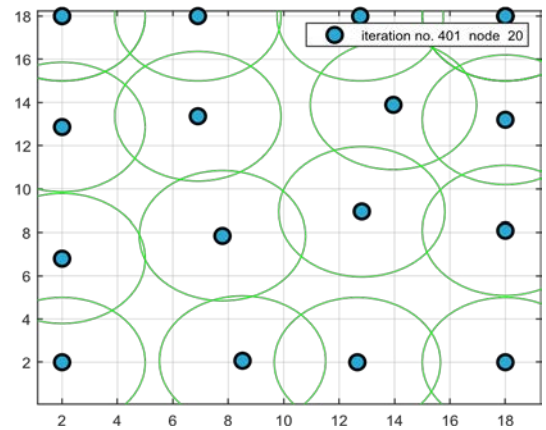


Figure 41-8 Optimised position of nodes ($r_s = 3m$ & $r_e = 1.25m$) after applying improved algorithm

The Fig. 41-8 shows that the nodes have a much better arrangement inside the FoI after the proposed algorithm. The initial coverage ratio was around 81% which becomes almost 100% after 50 iterations which is 19% increase. The improvement in coverage ratio can be seen in Fig. 41-9.

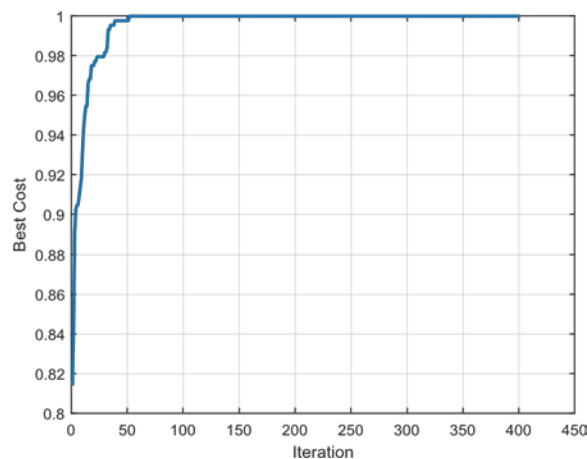


Figure 41-9 Coverage ratio vs. iteration for $r_s = 3m$ & $r_e = 1.25m$

B. COMPARISON WITH STANDARD PSO

For a clear comparison of the proposed and standard PSO algorithm [12] Table 41-2. is to refer.

Table 41-2 COMPARISON BETWEEN STANDARD AND MODIFIED PSO

Radius (m)	Max Coverage Ratio		No. of iteration taken	
	Standard	Modified	Standard	Modified
1.5	23%	45%	240	270
2	40%	73%	180	240
3	75%	Almost 100%	250	55

Table 41-2. signifies that there is a significant improvement in the coverage ratio of the WSN in comparison to standard PSO. The percentage increase in the maximum coverage ratio in for $r_s = 1.5m, 2m, 3m$ is 95%, 82.5%, 33.3% respectively, which shows a fair performance increase of this algorithm with respect to standard PSO. Also, the concept of negative velocity in the algorithm reduces the premature convergence of conventional PSO.

CONCLUSIONS

The presented paper aims to improve coverage of FoI using minimum number of sensors using a modified version of Particle swarm optimization. With the help of simulations for different scenario it can be seen that proposed algorithm shows a significant improvement in coverage of FoI. The obtained results have also been compared with that of standard PSO and the improvement in performance can be observed using the same number of nodes. The modified position updation in the algorithm makes it easier to search for global optimum rather than local optimum. The future goals of this work would be to optimize the coverage when obstacles are present inside the FoI and make it more energy efficient.

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