A NEW APPROACH FOR AREA COVERAGE PROBLEM IN WIRELESS SENSOR NETWORKS WITH HYBRID PARTICLE SWARM OPTIMIZATION AND DIFFERENTIAL EVOLUTION ALGORITHMS

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ABSTRACT

One of the most important and basic problems in Wireless Sensor Networks (WSNs) is the coverage problem. The coverage problem in WSNs causes the security environments is supervised by the existing sensors in the networks suitably. The importance of coverage in WSNs is so important that is one of the quality of service parameters. If the sensors do not suitably cover the physical environments they will not be enough efficient n supervision and controlling. The coverage in WSNs must be in a way that the energy of the sensors would be the least to increase the lifetime of the network. The other reasons which had increase the importance of the problem are the topologic changes of the network which are done by the damage or deletion of some of the sensors and in some cases the network must not lose its coverage. SO, in this paper we have hybrid the Particle Swarm Optimization (PSO) and Differential Evolution (DE) algorithms which are the Meta-Heuristic algorithms and have analyzed the area coverage problem in WSNs. Also a PSO algorithm is implemented to compare the efficiency of the hybrid model in the same situation. The results of the experiments show that the hybrid algorithm has made more increase in the lifetime of the network and more optimized use of the energy of the sensors by optimizing the coverage of the sensors in comparison to PSO.

KEYWORDS

Wireless Sensor Networks, Coverage Problem, Particle Swarm Optimization, Differential Evolution

1. INTRODUCTION

WSNs are used in research, operation and business fields vastly. The WSNs include many sensors which are applicable in the supervision and security environments [1]. WSNs are able to supervise the aimed environments and control them and process the gathered information. In WSNs we must consider the coverage and energy use problems to increase the lifetime of the network so the data sending and lifetime of the network would not face considerable decrease [2]. The energy use and network coverage are very important factors in designing the WSNs. And according to the environmental situation of these networks, it is not possible to change the battery of the thousands of the sensors [3, 4]. So, the coverage problem in WSNs is in direct relation to the increase of the lifetime of the sensors. The best situation for the WSNs is the time that all nodes are located in a suitable sensor radius distance. And this means that the network has the

DOI : 10.5121/ijmnct.2013.3606

longest lifetime [5]. So, to increase the lifetime of the network, the sensor distribution must be steady.

The most important factor for developing and scaling the WSNs is to consider the coverage problem and decreasing the energy use of the sensors [6]. To increase the serious factors in WSNs it is possible to name these fields [7, 8, and 9]: First the redundant sensors must be deactivated to save their energy. When the redundant sensors are deactivated, the active sensors gather the information and send them to the Base Station (BS). It means that if just the active sensors gather the information, surely the energy use will decrease. So, the coverage must be in a way that all active sensors be able to overall points and also the minimum number of the sensors will be used [10]. Second, we must set the coverage area according to the size of the neighbor sensors and then the distance to the neighbor sensor is needed to sense and transfer the information. So, coverage problem is the most important and basic case in creation of the WSNs. Different classifications are identified for coverage in the sensor networks any of which affect the problem from another point of view.

- **Area Coverage**: The most important problem in area coverage is the coverage kind of an area by the sensors. The main goal of area coverage in WSNs is to cover and supervise en environment completely [11]. Any point of under coverage environment in area coverage must be covered at least by one sensor. In [12] the under coverage area is assumed as a circle and all points under coverage are covered by *K* sensors. In [13] two *K* joints and *K* coverage states are studied among the sensors and there is no relation between the under coverage points and the sensors are diffused randomly in the environment. When an area is covered, any point must be covered by a group of the sensors. So, in this method of coverage we consider a place coordinates and distribute the sensors randomly or manual to cover the aimed environment totally. In area coverage the best coverage takes place when the aimed area is covered by the least number of the sensors completely [14, 15]. Area coverage is often used for the areas in which the probability of events exists in all coordinates. Also the existence of the redundant sensors in this model cause the multi coverage which lead to the high density of the network. In Figure (1) the area coverage is shown.

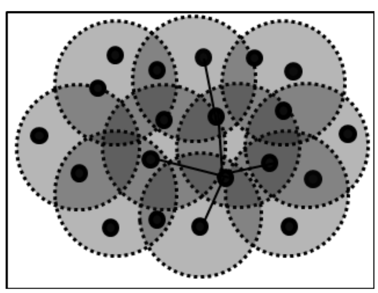

Figure 1. Area coverage

- **Point Coverage**: The goal is to cover a specific point of the environment in this method. And these points are diffused in the area [16]. It is possible to say that this method is a sub set of the area coverage method. So, if the total area is not covered by the sensors just some points are covered and this means the point coverage. In point coverage just the points which are applicative are covered. So, in point coverage some of the goals are identified by some specific points which must be controlled are considered. Medium numbers of the sensors are diffused around the goals and then are activated according to specific scheduling in relation to specific responsibilities and send the gathered information to the BS [17]. In Figure (2) the point coverage is shown.

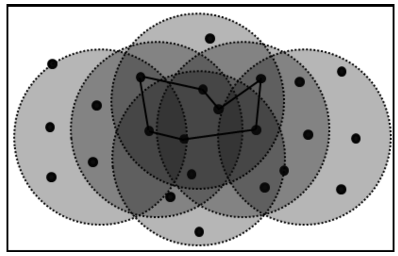

Figure 2. Point coverage

- **Barrier Coverage:** the total area is not covered by the sensors in barrier coverage. The barrier coverage is a suitable model for penetration diagnosis applications. In this model the coverage operations take place in a way that if the penetration takes place from the width of the under coverage area, the sensors must diagnose them [18]. In barrier coverage the goals are controlled at least by one sensor and all existing goals in that area are under control of that area [19, 20]. In Figure (3) the barrier coverage is shown.

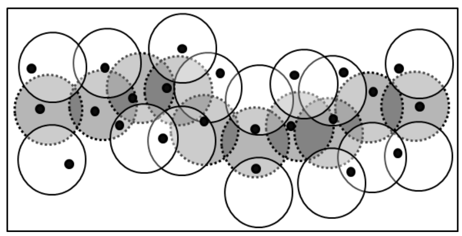

Figure 3. Barrier coverage

Now, the population algorithms based on swarm search are used for optimization. An important class of these algorithms are aspired the natural processes and the behavior of the creatures. These algorithms are inspired by the swarm behavior of the animals like the insects and are applicative in optimization problems vastly [21, 22]. In other words the group behavior is used as a powerful tool for solving the optimization problems. In this paper the problem of area coverage in WSNs is studied which is one of the most important factors in increasing the lifetime of the network using the hybrid of PSO and DE algorithms.

This paper is organized as follows: in Section 2, we have introduce the related works; in Section 3, meta-heuristic algorithms are introduced; in Section 4, the proposed model is described; in Section 5, the evaluation and results of the proposed model are presented and at finally in Section 6, we have presented the conclusion and future works to be done.

2. RELATED WORKS

One of the most important research fields in wireless communications, is WSNs. WSNs includes a set of the sensors which are diffused in supervising environments and process the sensed data and finally send the favorite information to the BS. Many different methods are presented for improving the coverage problem till now any of which has caused many advances in the coverage and its quality in the WSNs.

Using the Multi-Objective Particle Swarm Optimization (MPSO) in coverage problem for energy efficiency and the increase of the lifetime of the WSNs is studied in [23]. The main goal of MPSO is to find the best position for the sensors for better coverage. According to the results of the experiments it is possible to say that MPSO is efficient in coverage and increasing the lifetime of the network. In [24] studied the K-coverage problem in WSNs using the Harmony Search (HS). In this reference it is said that the two coverage and energy efficiency are very important parameters in wireless sensor nodes distribution. In this reference the HS algorithm is used for better joint of the sensors, K-coverage and minimizing the energy use. In K-coverage the area is covered by k sensors. The results of the experiments in this reference show that the HS algorithm is very efficient in coverage and minimizing the energy use of the sensors. In [25] a distributed algorithm with efficient energy use and optimized coverage goal is proposed. In proposed algorithm the sensors are divided into active and inactive subsets and create a graph model which leads to the balance energy use of the sensors. In this reference, only the active sensors are used for coverage and the rest of the sensors go deactivated. Turning off the unnecessary and redundant sensors, the other sensors of the network use less energy and as a result the lifetime of the network increases. The results of the simulations show that the efficiency of the suggested algorithm is more than the under comparison algorithms and it is able to increase the lifetime of a network up to multi times more.

In [26] has studied the positioning method of the sensors in WSNs according to the point coverage. In point coverage which is shaped by some goal points, the establishment of the sensors is very affective on the number of the needed sensors for coverage of the points. In this reference, the point coverage takes place according to the position of the goal and angle of the goal points. Z. Bin et al [27] use the Fish Swarm (FS) and PSO algorithms hybrid to study the WSNs coverage problem. PSO algorithm is used in hybrid algorithm for more efficiency and FS for covering the sensors. The results show that the hybrid algorithm is efficient enough in deployment of the sensors of network and has improved the coverage problem. In some researches [28], the sensing coverage of any sensor is set in a specified space for increasing the efficiency of the energy of the sensors. In this reference, two heuristic algorithms are used for the results of the experiences. The results of the experiments show that Greedy is more efficient in energy consumption and network coverage in comparison to Linear Programming. The researches of [29] proposed a heuristic algorithm to fully cover a region having arbitrary (opaque) obstacles, which allow neither the sensor to be placed inside nor the signals to pass through. They first deploy an optimal pattern for covering a plane over the region, and then locate and efficiently cover the uncovered holes formed by the obstacles.

Reference [30] has presented a dynamic algorithm for area coverage problem in WSNs. In coverage, the most important challenge is the distribution of the sensors and the lifetime of the network. In this reference, the sensors are distributed according to the supervision area and the shape the most important establishment. Also the sensors can dynamically have topological changes in the environment. The most important specifications considered in this reference is the energy used by the sensors. The results of the experiments show that the proposed algorithm is more efficient than the other algorithms from establishment of the sensors point of view. Researchers [31], use the Ant Colony Optimization (ACO) Algorithm in WSNs coverage problem. The best radius for the sensors is identified using the ACO algorithm. When it is needed to have an active network for long time and the sensing limits of the any sensor is identified or when the quality and stability of supervision are the most important factors, the use of ACO algorithm is suitable. They have evaluated the improvement of the energy use problem in sensor networks using the area coverage and have showed that ACO is efficient in lifetime of the network. According to the results of their simulation, ACO algorithm is efficient in lifetime of the network.

Researchers [32] have used the heuristic algorithms for the coverage problem in large scales. For optimization of coverage problem in large scales, the Greedy algorithm is utilized. The goal of them is to use the heuristic algorithms to establish the sensors in the points of the spaces which cover the network in the best manner and have the best lifetime. Any point could have many redundant sensors and if they are active, more energy is used. So, the sensors which are not used are deactivated by the Greedy algorithm a just the sensors which are in relation to the base station are activated. The results of the experiments show that the Greedy algorithm is the best solution for coverage problem of the sensors in large scale. X. Wang et al [33] have proposed a new protocol based on the dynamic structure of the sensors for coverage problem. In the proposed protocol, the sensors are activated or deactivated for energy saving. Also, the position of the sensors is dynamically identified and any sensor can cover its radius well. They have proved that the propose algorithm is more efficient in coverage. In [34] first studied the barrier coverage of two-dimensional plane and two-dimensional strip sensor networks using percolation theory results. The barrier coverage of a two-dimensional plane network is related to the existence of a giant sensor cluster that percolates the network. However, the strength of the barrier coverage, i.e., the number of disjoint barriers, was not obtained. For a two-dimensional strip network of finite width, it is proved that there always exist crossing paths along which an intruder can cross the strip undetected. Furthermore, the probability that an intruder is detected when crossing a strip is characterized.

3. META-HEURISTIC ALGORITHMS

Meta-Heuristic algorithms are based on population to the optimization problems and are tools for finding the near to optimized solutions. These algorithms utilize the diversity and cooperation concepts and make the optimization space better in achieving the most optimized status. So, the more the power of an algorithm in controlling the two parameters, the more algorithms is capable in finding the most optimized stage. In this section we talk about PSO and DE algorithms which are the most important population algorithms.

3.1. Particle Swarm Optimization

PSO algorithm was first introduced Kennedy and Eberhart in 1995 inspiring the social behavior of the birds living in large and small groups [35]. PSO is a simulation of the social behavior of the birds which search for food in and environment. None of the birds have information about the place of the food but they know in each stage how far they are from the food. On this basis, the best procedure to find food is to follow the nearest bird to the food.

PSO algorithm is a population algorithm in which a number of the particles which are the solutions for a function or problem shape a population. A population of the particles moves in the problem space and tries to find the most optimized answer in the searching space according to their own experience and also the population's. PSO algorithm is an optimization algorithm which provides a search based on the population in which any particle changes its position by the time. In PSO algorithm the particles move in a searching space of multi dimension including the possible solutions. In this space an evaluation factor is defined and the quality evaluation of the solutions of the problem takes place by it. Any change of a particle in a group is affected by the self or other's experience and the searching behavior of a particle is affected by the other particles. This simple behavior causes finding optimized areas of the searching space. So, in PSO algorithm, any particle which finds the optimized situation, informs the other particles in a suitable manner and any particle decides for the cost function according to the achieved values and searching takes place using the ex-knowledge of the particles. This cause the particles do not get near each other more than the normal and solve the optimization problem effectively.

In PSO algorithm, first the group members are created randomly in problem space and the searching process for the optimized answer starts. In the total structure, the search of any member follows the other which is the most optimized suitable value of the function and it does not forget its experience and follows the state in which he suitability function value was the most for itself. So, in each repetition, any member changes its situation according to the two values, one of them is the best situation of the member till then (pbest) and the other is the best situation the total population has had till then. In fact it is the pbest in the total population (gbest). In concept, pbest for any member is in fact the biologic memory of the member. gbest is the general knowledge of the population and when the members change their situation according to gbest, in fact they try to heighten the knowledge level up to the general knowledge of the population. From the concept view, the best particle of the group relates all other particles to each other. The identification of the next situation of any particle is done by the equations (1) and (2).

$$v_{i+1} = w.v_i + c_1.r_1.(P_{best_i} - x_i) + c_2.r_2.(g_{best_i} - x_i), \tag{1}$$

$$x_{i+1} = x_i + v_{i+1} \tag{2}$$

In equation (1), c_1 and c_2 are the learning parameters. *rand()* is a function for producing the random numbers in [0, 1]. x_i is the present situation and v_i is the moving speed of the members. W is a control parameter which controls the present speed (v_i) with the next one and creates a balanced state between the ability of the algorithm in local and global searching and then reaches the answer in a shorter time. So, for optimized operation of the algorithm in the searching space, parameter w is introduced as follows [36, 37]:

$$w = w_{Max} - \frac{((w_{Max} - w_{Min}) \times i)}{i_{Max}} \tag{3}$$

In equation (3), i_{max} shows the maximum number of the repetitions of the algorithm and parameter i is the counter of the repetitions of finding optimized answer. In equation (3), the w_{max} and w_{min} are the primary value and the final value of inertia weight in algorithm execution time, respectively. Inertia weight value changes from *0.9* to *0.4* linearly in execution time of the program. Large values of w lead to the global search and the small values lead to local search. To balance the local and global search it is necessary to reduce the inertia weight in algorithm execution time. So, by reducing the w, the search takes place locally and around the optimized answer.

3.2. Differential Evolution

DE algorithm was innovated in 1995 by Storn and Price [38]. DE algorithm is a probable searching which is based on population. This algorithm uses the distance and direction from the existing population information to continue searching. He advantages of this algorithm are speed, parameter setting, efficiency in finding the optimized solution, parallelization, high care and no need for ordering and matrix coefficient. DE algorithm is able to search in direction of the coordinates of the optimization variables and changing the coordinates for finding the optimized solution. DE algorithm starts the evolution of the searching process from a random initial population. Three mutation, crossover and selection controlling parameters include the population, index coefficient and the crossover probability which are important in DE Algorithm. DE algorithm stages include the followings:

- **Creating initial population:** The initial population or the solution vectors are selected randomly from the problem domain in DE algorithm. The solutions position vector is introduced by equation (4).

$$X_i = (x_{i,1}, x_{i,2}, ..., x_{i,D}) \tag{4}$$

$$x_{ik} = x_k^{\min} + rand(0,1).(x_k^{\max} - x_k^{\min})$$
$$with \quad i \in [1, Np], k \in [1, D]$$

(5)

The selection of the random numbers x_{ik} from the problem domain takes place by equation (5). In equation (5), D means the dimensions of the solutions. Np is the number of the initial population. Rand (0, 1) function produces the random numbers (uniform distribution) in (0, 1). It is clear that if the equation (5) is used, the values for x_{ik} is in $[x_i^{\max}, x_i^{\min}]$ and the position vector of the solutions would be one of the potential answers of the optimization problem.

- **Mutation:** In mutation stage three vectors are selected randomly which differ each other. For any *x* vector in population a new answer in each repetition is created according to equation (6).

$$v_{i,G+1} = x_{r_1,G} + F.(x_{r_2,G} - x_{r_3,G})$$

(6)

In equation (6), r_1, r_2 and r_3 which are three non-equal random numbers are located in [1, N_p]. *G* is the number of the produced generations and *F* is a constant and real number which is often considered 0.5.

- **Crossover:** Crossover operator causes increase in diversity of the population. This operator is similar to the crossover operator in genetic algorithm [39]. In this operator the new vectors are created by hybrid of the *x* and *v* vectors as equation (7).

$$u_{ji,G+1} = \begin{cases} v_{ji,G+1} & if \quad (r_j \le CR) \quad or \quad j = j_{rand} \\ x_{ji,G+1} & otherwise \end{cases}$$

(7)

In equation (7), parameter *CR* is located in [0, 1). Parameter r_j is randomly created in [0, 1]. Also the value is j=1, 2 … D.

- **Selection:** To select the vectors of the highest propriety, the vectors created by the mutation and crossover operators are compared to each other and any of them holding more suitability is transferred to the next generation. The selection operator takes place by equation (8).

$$x_{i,G+1} = Fitness \ \ Value(u_{i,G+1}, x_{i,G})$$

(8)

- **Stop:** The searching process continues till the stopping factor of the algorithm is met. Usually the stopping facto of the algorithm could be based on the non-changing propriety of the best answer or algorithm repetition.

4. PROPOSED MODEL

The most important factor in WSNs is to minimize the energy use of the sensors and the coverage problem. Sensors usually use a battery for providing the energy which is not chargeable or changeable in many cases. So, the reduction of energy use in increase of the lifetime of the sensors is very important. In coverage problem, the sensing radius of the sensors which shows the capability of diagnosing the phenomena or physical signals by the sensors is very important.

Setting the parameter of sensing radius of the sensors is very important but the minimization of the energy used by the nodes is also very important. Of the problems to be cited in WSN is the distribution type of the sensors in an optimized coverage. In this paper a new hybrid model using the PSO and DE algorithms for distribution of the sensors for area coverage is proposed. In Figure (4) the hybrid algorithm flowchart is showed.

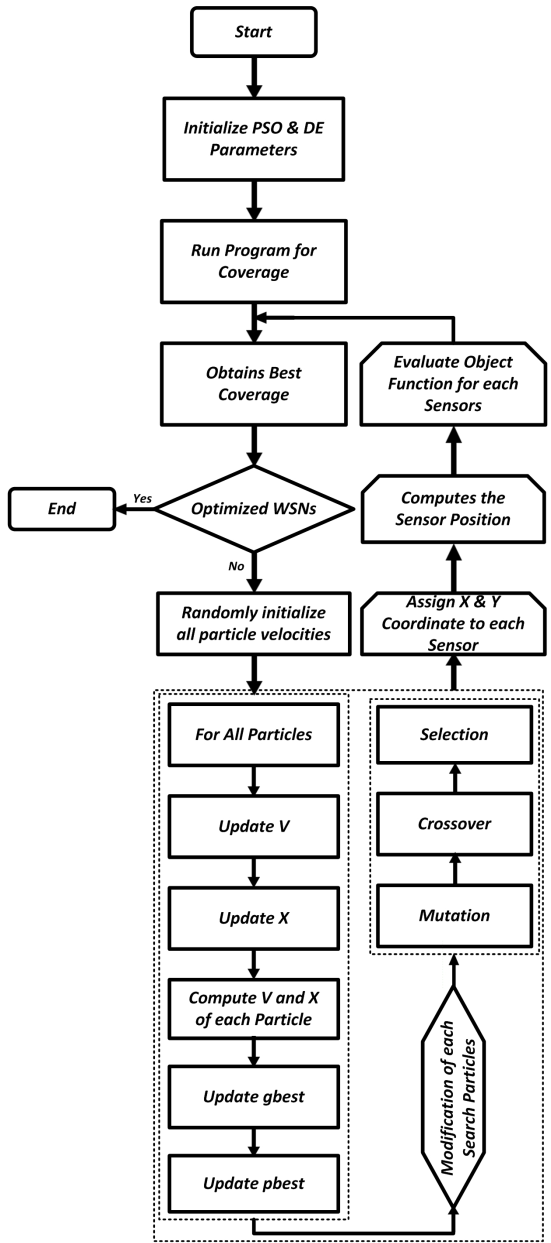

Figure 4. The hybrid algorithm flowchart

In Figure (5), the quasi code of the hybrid algorithm is shown.

1. Initialization Phase
1.1. Start
1.2. Initialize PSO & DE parameters
2. Coverage Phase
2.1. Loop
2.2. Run program for coverage
2.3. Obtains best coverage
- *Randomly initialize all particle velocities*
- *for all particles*
- *Update V*
- *Update X*
- *Compute V and X of each particle*
- *Update gbest*
- *Update pbest*
- *Modification of each search particles*
- *Mutation vector particles*
- *Crossover vector particles*
- *Selection vector particles*

2.4. Assign X & Y Coordinate to each sensor
2.5. Sensor (i) = Optimum Location (X_i, Y_i)
2.6. Computes the Sensor Position
2.7. Evaluate Object Function for each sensor
2.8. While (Max Iteration)

Figure 5. The quasi code of the hybrid algorithm

In hybrid algorithm the most optimized points for *n* sensors are searched according to PSO algorithm for covering *p* aimed points. Searching takes place based on the particles which are near the goal and are able to cover the around suitably and then the mutation and crossover operations on n sensor take place using DE algorithm. One of the most important goals of mutation operation and crossover is finding more optimized points for the sensors. The hybrid algorithm acts for increasing the lifetime of the network and reducing the energy use and covering all points in an optimized manner. The particles in PSO algorithm is affected by the situation in the neighbor. In hybrid model any particle has a two dimensional vector of *x* and *y* coordinates which is in relation to the neighbor particles. In hybrid model any particle is longing for following the best point in its neighborhood. In Figure (6) the position vector of the sensors is shown using the PSO algorithm.

S_1	S_2	…	S_n

Figure 6. The position vector of the sensors

One of the most important parts in the hybrid algorithm is the evaluation of goal function. In goal function evaluation the most important parameter is the overlap rate of the sensing radius of the sensors. The sensing radius of the sensors must be set in a manner to create the best coverage. For sensing radius coverage of two sensors in p_1 and p_2 the equation (9) is used. Equation (9) is updated in each repetition using PSO algorithm and the most optimized points are found according to the global knowledge.

$$d(s_1, s_2) = \sqrt{(xp_1 - xp_2)^2 + (yp_1 - yp_2)^2} \tag{9}$$

In equation (9), if the sensors are located in non-optimized points, the position of the particles is updated in hybrid algorithm and the most optimized points are found for the sensors. And the sensors coverage is repeated till the optimized suitability is achieved. To calculate the energy use of the sensors in this paper the [40] model is used. In this model the value of used energy for receiving *k* bits of information is introduced by equation (10).

$$Rx = \varepsilon_{elec} \times k \tag{10}$$

The energy used for sending one message from a sensor to another sensor located in distance *d*, is introduced by equation (11).

$$Tx = \varepsilon_{elec} \times k + \varepsilon_{amp} \times d^2 \times k \tag{11}$$

In equations (10) and (11) the value of ε_{elec} and ε_{amp} are $50nJ/_{bit}$ and $100pJ/_{bit \times m^2}$ respectively. In Figure (7), simulation of area coverage problem in WSNs using the hybrid of the PSO and DE algorithms in C#.NET 2008 programming environment is shown.

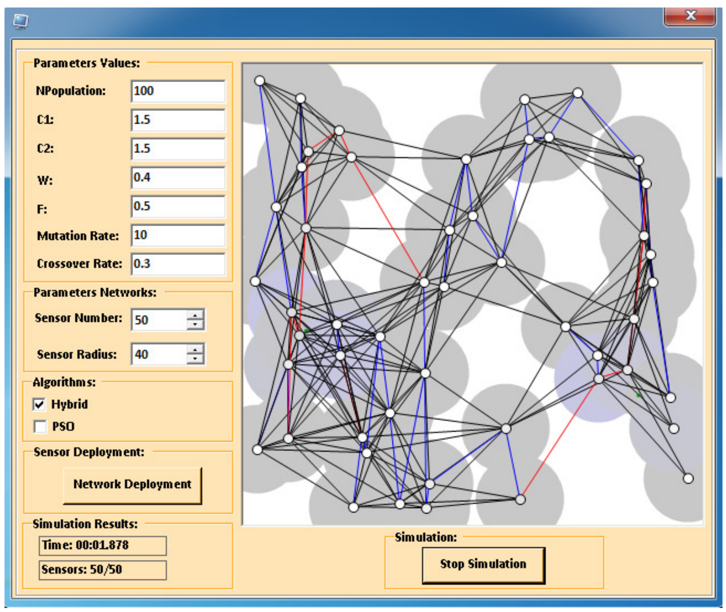

Figure 7. Simulation of area coverage problem in C#.NET 2008

5. Evaluation And Results

In this section the coverage problem in WSNs which is introduced as one of the quality factors is studied using the hybrid algorithm of PSO and DE. And also the sensing radius problem in sensing coverage of the sensors and the lifetime of the sensors are studied. Simulation has taken place in a 450*450 meter place. In hybrid algorithm there are many parameters which affect the operation of the algorithm. In Table (1), *P* parameter is the number of the population (particles). Parameter *W* is the inertia weight to balance the speed of the particles and the value of the C_1 and C_2 parameters contributes the particles' learning in finding the optimized points. Parameter *F* is a constant positive and real number which is used for convergence rate of mutation. P_m parameter is the rate of mutation, and parameter P_c is the crossover rate. Also the initial population in PSO and hybrid algorithm is considered 1000.

Table 1. The value of the parameters

Parameters	Value
P	100
C_1	1.5
C_2	1.5
W	0.4
F	0.5
P_m	10
P_c	0.3

5.1. The Effect of the Number of the Sensors on the Lifetime of the Network

In this section the effect of the number of the sensors on the lifetime of the network is studied. The radius area of any sensor is considered as 40. Figure (8) shows the effect of the number of the sensors on the lifetime of the network is studied. As it is clear from Figure (8), the lifetime of the network in hybrid algorithm linearly increases by the size of the networks.

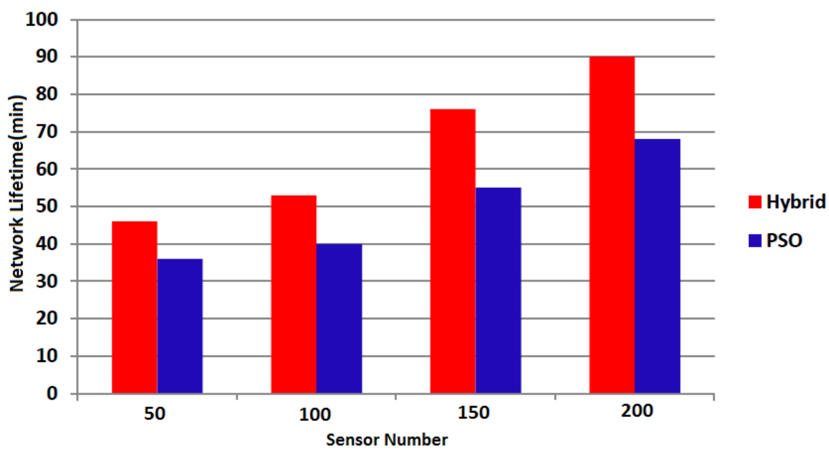

Figure 8. Evaluation of lifetime of the network

5.2. The Effect the Sensing Radius of the Sensors on the Lifetime of the Network

In this section the effects of the sensing radius area of the sensors on the lifetime of the network are evaluated. 50 sensors are considered for the results of the simulation. As it could be seen in Figure (9), the hybrid algorithm is more efficient on the lifetime of the network. Because the hybrid algorithm sets the radius of any sensor better and causes less energy waste in the coverage area.

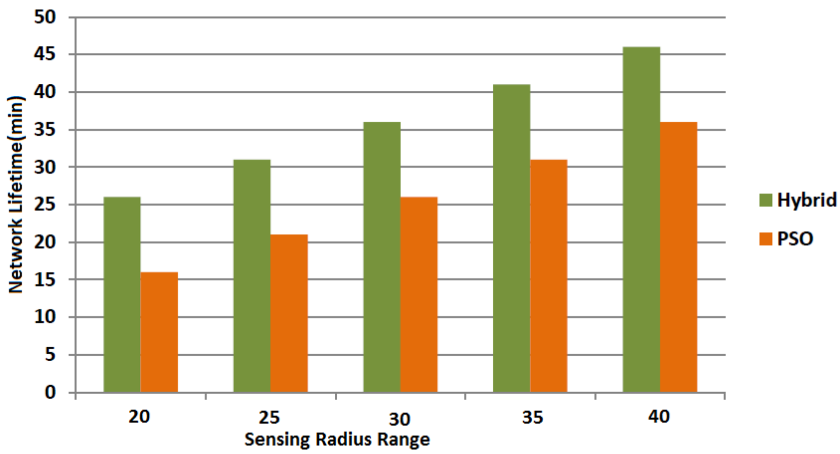

Figure 9. The effects of the sensing radius area of the sensors

If the distance of two sensors is high, more energy is used for the information transfer between them. So, as it can be seen, the more sensors cover each other, the less the distance between the two sensors and finally the less the used energy. The results of the simulations show that the hybrid algorithm acts better than the PSO algorithm from convergence speed and reaching the optimized answer points of view. The hybrid algorithm uses the mutation and crossover parameters for better coverage for the sensors.

5.3. The Comparison of the Sensor Coverage Percent

Figure (10) shows the coverage percent comparison of the hybrid and PSO algorithms. As can be seen in Figure (10), as the hybrid algorithm is more able to set the sensing area of the sensors, it covers more efficient.

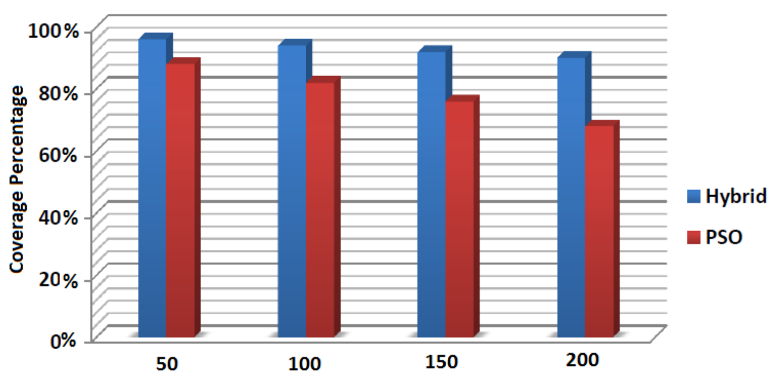

Figure 10. The comparison of the efficiency of the coverage in hybrid algorithm and PSO

6. Conclusion And Future Works

Coverage problem is one of the most important research fields of WSNs. Creating the optimized coverage in WSNs it is possible to increase the lifetime of the network. In this paper we have used a hybrid of the PSO and DE algorithms for area coverage in WSNs and to increase the lifetime of the network. For this reason in hybrid algorithm the two factors of suitable distribution of the sensors and the energy decrease which lead to increasing the lifetime of the network use are considered. And to show the efficiency of the hybrid algorithm better, it is compared to PSO algorithm and according to the results of the simulations, it can be said that the hybrid algorithm is better. By this paper we hope that we will be able to find better solutions and more optimized answers using other meta-heuristic algorithms for WSNs coverage problem.

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