Deploying a Single or a Double Cluster Head Particle Swarm Optimization Technique based on WSN scenarios

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***Abstract*— Designing a WSN involves taking into account two most important design criterions. One is achieving the energy optimization and other is enhancing the network longevity. Particle Swarm Optimization (PSO) technique is an efficient protocol which is capable of achieving these deign goals. Now PSO algorithm can be designed either having a Single Cluster Head or Double Cluster Heads. This paper deals with the choice to be made out of these algorithms depending upon the Wireless Sensor Network (WSN) scenarios. PSO being a heuristic technique, it is very important to choose the efficient method in order to achieve an improved network lifetime along with reduction in energy consumption.**

Keyword-PSO, Single Cluster Head, Double Cluster Head, WSN

I. Introduction.

A Wireless Sensor Network consists of spatially dispensed independent sensor nodes which are capable of monitoring the physical or the environmental conditions and cooperatively pass the sensed data to the base station or the sink. Recent innovations in micro sensor technology has made it possible for the sensors to be available in large numbers, at affordable cost, compact and are capable to be deployed for various applications such as military, ecological observation and several such real time applications. The sensor nodes are equipped with limited energy sources which are non replenish-able. Hence while designing of WSN, it is very important to take energy consumption into account. An enhanced network lifetime thus strongly depends on the sensor node battery lifetime.

One of the competent design methods in considerably achieving the energy optimization is Clustering. In this system, a group of sensor nodes are created and Cluster heads are elected for each Cluster. The Cluster head transmits the data to the base station which in turn reduces the energy expended by each node for direct communication with the base station. This enhances the resource allocation and the bandwidth reutilization. Particle Swarm Optimization (PSO) is one such centralized clustering technique which is energy proficient. PSO is one of the modern computationally efficient heuristic algorithms available which have gained grounds significantly as an optimization technique. This algorithm was pioneered by Russel Eberhart and James Kennedy in 1995 [1]. It is a population based optimization method which is inspired from the social behaviour metaphor. PSO is very convenient to implement regarding tuning of its parameters and has a very fast convergent rate towards the optimum solution. PSO has found a huge prospect with regards to optimization problems in variety of fields such as robotics, telecommunications, electrical power systems, military applications and many more. PSO algorithm can be designed comprising a Single Cluster Head or Double Cluster Heads with the retention in the basic algorithm steps. Variable WSN scenarios are possible depending on the application requirement. This paper discusses the role of selection of single or double cluster heads depending on the scenarios under consideration. The basic PSO and the Double Cluster Head PSO (D-PSO) is then compared with the basic LEACH and an enhanced version i.e the Energy LEACH (LEACH-L) protocol for two different scenarios.

II. SYSTEM MODELLING

A. Network Modelling

For the simulation purpose we are taking into account N sensor nodes deployed uniformly in a square sensing area. We define the term round as a period which consists of cluster setup phase in which clusters are formed and a steady state phase in which the data transfer takes place. Clustering would lead to creation of Primary Cluster Head (PCH) and the Secondary Cluster Head (SCH) in case of D-PSO and a single Cluster Head in case of the basic PSO. In case of D-PSO, the PCH is responsible for collection and aggregation of data from the cluster member nodes and SCH would be responsible for sending this data to the sink. In case of basic PSO both these jobs would be done by a Single Cluster Head.

We make some assumptions regarding the deploying of the sensor nodes as follows

- The base station (sink) is taken to be located inside the sensor network area and after the deployment; the nodes and the sink are taken to be stationary.
- The nodes are autonomous, homogenous and are outfitted with same capabilities.
- The nodes always have some sensing data to be sent to the base station in each round.
- Each node is aware of its location and is energy constrained.

B. Energy Utilization Modelling

The Energy Utilization Modelling is done as per the First order Radio Energy Model as described in [2].In this model, the transmitter expends energy to run the radio electronics and the power amplifier, and the receiver expends energy to run the radio electronics. Power control can be executed by the radios and hence they use the minimum energy required to reach the intended destination.

Hence the energy expended by the transmitter to transmit L bit data over a distance d is given by

$$E_{TX}(L,d) = \begin{cases} L.E_{elect} + L \in_{fs} d^2, \text{ when } d < d_0 \\ L.E_{elect} + L \in_{tr} d^4, \text{ when } d \geq d_0 \end{cases} \quad (1)$$

Accordingly the energy expended by the receiver is given as

$$E_{RX}(L) = E_{elect}.L \quad (2)$$

Where $d_0 = \sqrt{\in_{fs}} / \sqrt{\in_{tr}}$ (3)

E_{elect} is the consumed energy per bit, $\in_{fs}$ is energy consumed by free space amplifier and $\in_{tr}$ is energy consumed by multipath amplifier.

Along with this, we also take into account the energy consumed for data aggregation and is denoted by E_{DA} .

III. PROTCOLS DESCRIPTION

In this section, the protocols whose performance is to be evaluated for this paper are described in detail.

A. Particle Swarm Optimization

This is the basic Particle Swarm Optimization (PSO) which is designed having a Single Cluster Head. PSO is a centralized, energy responsive, cluster based routing protocol. This protocol selects a high energy node as the Cluster Head and produces Clusters that are scattered uniformly in entire sensor area. The crux is choosing a cluster head which can lessen the intra cluster distance i.e. the distance between itself and the cluster member node as well result in optimization of energy all over the network. In PSO, a swarm means number of potential solutions where every potential solution is denoted as a particle. Aim of PSO is to find such a particle position which would give rise to best estimation of the given fitness function. For the further references we will refer the baisc PSO as S-PSO for the ease of comparison.

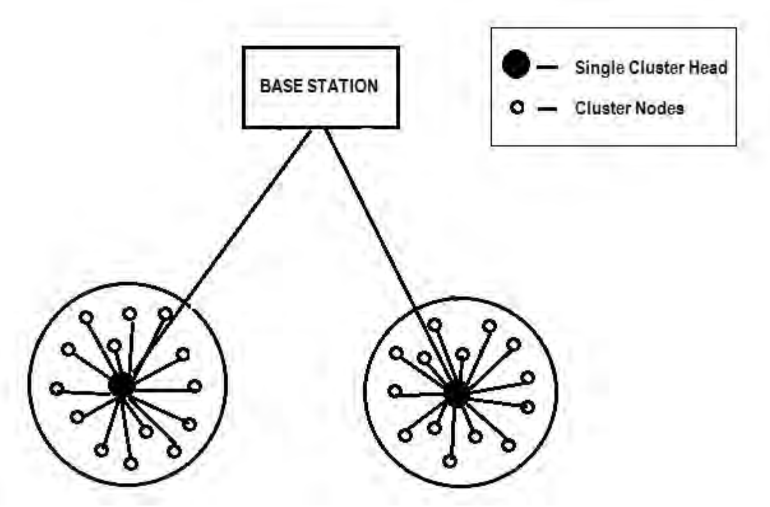

Fig. 1. Cluster representation for S-PSO

1) The Commencing Process: Each particle is provided with the preliminary parameters consisting of position and velocity vectors randomly and the particles are made to wander randomly in the search space. All particles have to be optimized as per the fitness function evaluation. The particles will follow the best particle i.e. the particle which has resulted to finest evaluation of the fitness function to search the next superlative position in the determined solution space. At every iteration the particles revise themselves by keeping a track of optimal solution of the particle itself (p_{id}) and also be keeping a track of the most optimal solution of the current population (p_{gd}).

The velocity update formula is as follows:-

$$v_{id}(t+1) = wv_{id}(t) + c_1\alpha(p_{id} - x_{id}(t)) + c_2\beta(p_{gd} - x_{id}(t)) \quad (4)$$

The position update formula is as follows:-

$$x_{id}(t+1) = x_{id} + v_{id}(t+1) \quad (5)$$

Where v is the particle's velocity, x is the particle's position, t is the time, c_1 & c_2 are learning factors, α & β are random numbers lying between 0&1, p_{id} is particle's best position , p_{gd} is best global position, w is the inertia weight coefficient.

2) The Cluster Setup and Selection of Cluster Head: The functioning of this protocol is based on a centralized control algorithm that is implemented at the base station or the sink. The protocol functions in rounds, where each round begins with a setup phase which consists of cluster formation. The initial clustering is done on the basis of LEACH. This is preceded with a steady state phase. At the commencement of each setup phase, all nodes send information about their current energy condition and locations to the base station. In congruence with this information, the base station carries out the PSO algorithm to determine the best K cluster heads. The algorithm flow chart is as follows-

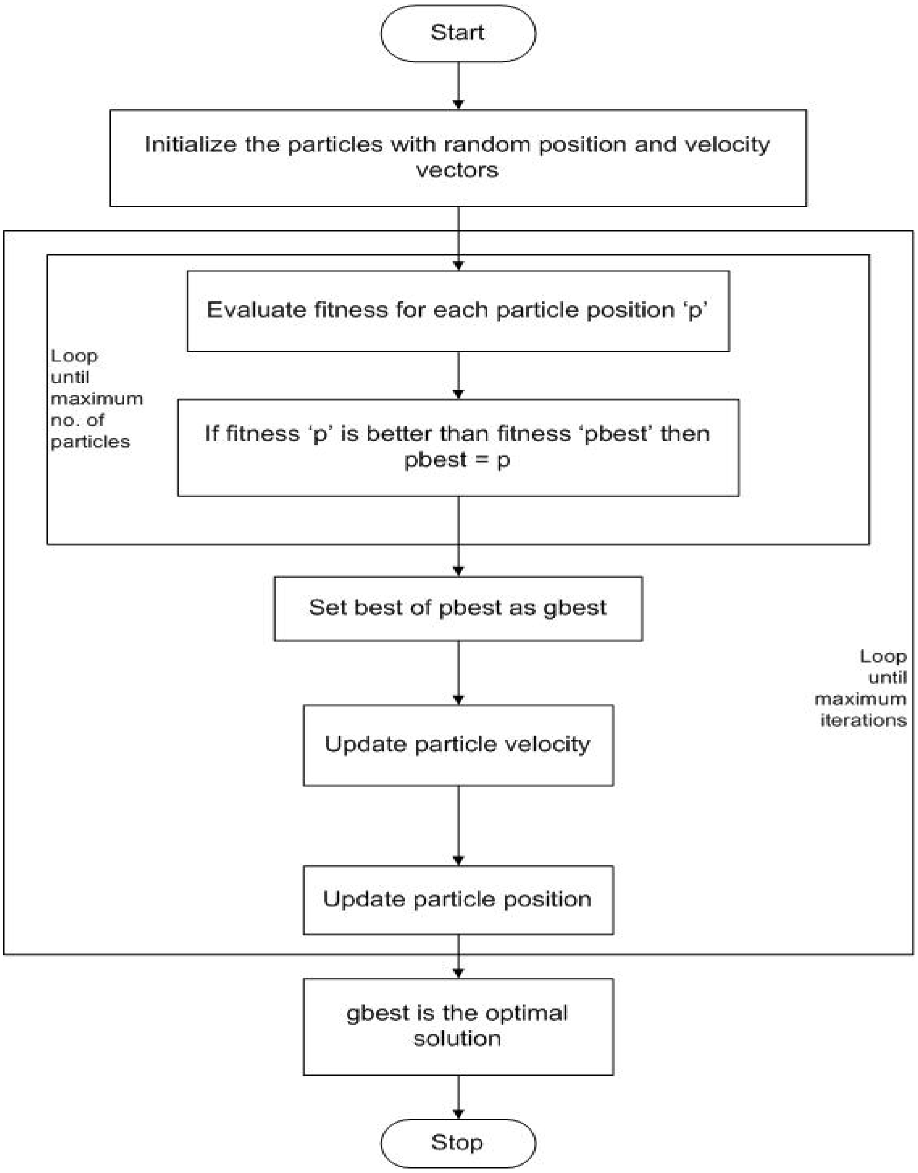

Fig. 2. Flow chart representing working of standard PSO

3) The fitness function: The crux of PSO lies is the fitness function evaluation. The performance of the optimal solution of the algorithm can be efficiently determined by the function. Based on [3] the fitness function is specified as follows-

$$f = \varepsilon \times f1 + (1 - \varepsilon) f2 \tag{6}$$

$$f1(i) = E(i) / \sum_{j=1, j \neq i}^{k} E(j) \tag{7}$$

$$f2(i) = (k-1) / \sum_{j=1, j \neq i}^{k} d(i, j) \tag{8}$$

In the above quoted equation sets function $f1(i)$ is the ratio of node *i*'s energy to the total energy of cluster, k is the number of nodes within the cluster, $E(j)$ is the energy of node *j*. Function $f2(i)$ refers to total Euclidean distance of cluster nodes to node *i*; $d(i, j)$ being the distance between node *i* & node j . ε is a user defined constant which determines the contribution of each of the functions used.

The fitness function satisfies the objective of simultaneously minimizing the intra-cluster distance between the nodes and their cluster head *i*, as calculated by $f2(i)$; and also of optimizing the energy efficiency of the network as calculated by $f1(i)$. The node with the maximum value of $f(i)$ is chosen as the cluster head as it is the most favourable.

B. The Double Cluster Head Clustering Algorithm:

The Double Cluster Head Clustering Algorithm (D-PSO) leads to creation of two cluster heads by using the basic PSO, but using LEACH as the foundation. The further attribute is that this protocol considers the node energy balance in addition to the optimized choice of the cluster head. After the clusters are created the intra cluster data transmission is carried out.

The Primary Cluster Head (PCH) receives and aggregates the data from its cluster members. The data aggregated is sent to the Secondary Cluster Head (SCH). The SCH sends aggregation data to the base station straight away. PCH is not directly in linkage with the base station, which can resort to saving of energy. This methodology better optimizes the network workloads, and certainly paves to extension in the sensor network lifetime.

1) The selection of Primary and Secondary Cluster Head: The algorithm is initiated same as that for PSO. Select the optimal solution as PCH and the suboptimal solution as SCH. When iterations of PSO finish, the global best is the optimal solution, and the global best of the previous iterations is denoted as the suboptimal solution. By taking fitness function into account, it can be stated that SCH has more energy, and the closest distance with the PCH. So we use the suboptimal solution as the SCH. The fitness function used for this process is same as that given by equation (6), (7) and (8).

2) The D-PSO Algorithm steps: D-PSO algorithm has cyclic execution pattern. Process of the specific steps is as follows:

- The initial clustering is carried out using LEACH algorithm.

  All member nodes send out information about their existing energy and locations to the cluster head in each cluster. This cluster head is the initial cluster head.

- Based on this information, the base station runs this algorithm to select the primary cluster head and secondary cluster head using PSO. This step is the core, and the basic steps are as follows:

i) Initialize the particle swarm. Randomly initialize position and velocity of every particle.

ii) Evaluate the fitness of each particle using formula.

iii) Find the personal and global best for each particle. The personal best is the current position of the particle and the global best refers to the position of the particle that has the maximum fitness.

iv) Update each particle's position and velocity using formula.

v) Repeat steps ii) to iv) until the maximum number of iterations are reached. Select the global best as PCH, and the global best of the previous iterations as SCH. The base station transmits the information that contains the PCH ID and SCH ID to all the nodes.

vi) Considering the concept of RSSI, the cluster formation is done.

(3) PCH then sets up a TDMA schedule for its member nodes to avoid collisions among data messages, so that the the radio devices of each member node can turn off at all times, except during their transmission time. Once the cluster head finishes receiving data from its entire members at the end of each frame, the cluster head performs data aggregation and sends the aggregated data to the SCH. The SCH sends the aggregated data to the base station or the sink.

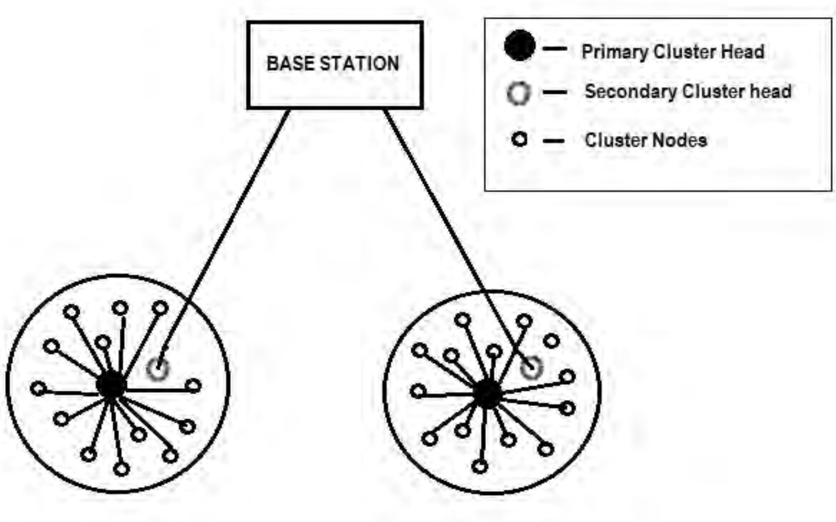

Fig. 3. Cluster representation for D-PSO

C. LEACH Protocol

LEACH Protocol is a pioneering work considering the Clustering techniques employed to resolve diverse energy optimization problems in WSN. It was introduced in [4]. This protocol is carried out in two phases.

1) Set-up Phase: Initially during cluster formation, each node will decide if it has to become a Cluster Head (CH) or not. The decision is made on the basis of number of required cluster heads and the number of times the node has become a CH by far. The judgement is made by node n by selecting a random number between 0 & 1. If this generated number is less than the threshold $T(n)$, node becomes CH for the present round.

$$T(n) = \frac{P}{1 - P \times (r \times \bmod \frac{1}{p})} \quad \text{if } n \in \mathrm{G} \tag{9}$$

$$= 0 \quad \text{Otherwise}$$

Where P is the desired percentage of Cluster Heads, r is the current round and G is the set of nodes which have not been CHs in the last $1/P$ rounds. After the CH is chosen, it sends out an advertisement message to rest of the nodes using CSMA-MAC protocol. After this phase is fulfilled, each node decides to which CH it should belong and this depends on the received signal strength of the advertisement.

2) Steady Phase: The foremost part of this phase is schedule creation in which the CH node generates a TDMA schedule suggesting each node when it can transmit based on the number of nodes within the cluster. After fixing the TDMA schedule the data transmission can begin. The radio of each non cluster head node can be turned off, till its turn arrives, eventually minimizing the energy consumption. When the entire data is received, CH node performs some signal processing to compress the data and then it is directed to the base station. This is the steady state operation.

D. Energy LEACH

This protocol is developed on the basis of LEACH protocol but in LEACH, communication pattern is single hop. So it is definitely not suitable for large networks because if a cluster head is not situated near the Base Station lots of energy will be consumed. So a new modified version of leach was developed called the Energy LEACH (LEACH-L) as in [5].It is characterized as follows-

- When the cluster-heads are in the near vicinity of the base station, they directly communicate with the base station.
- When they are far away from the base station, they telecommunicate by multiple-hop way. The sensor nodes in different areas use variable frequencies for communication.

IV. Simulation results and analysis

This section deals with the performance assessment of all the protocols discussed in the earlier section with the help of simulations. Simulations are carried out with the help of MATLAB. The simulations are run for two network scenarios of 400mx400m and 200mx200m for 300 nodes. The nodes are equipped with same amount of initial energy. The sink position is well within the sensor network area for both the scenarios. Simulation parameters are listed as follows-

TABLE I
SPECIFICATIONS IMPLEMENTED FOR THE SIMULATIONS

Parameter	Scenario1	Scenario2
Scope of network (m^2)	(400,400)	(200,200)
Number of sensors	300	300
Initial Energy	0.5J	0.5J
Packet length	4000	4000
E_{TX}	5×10^{-8}	5×10^{-8}
E_{RX}	5×10^{-8}	5×10^{-8}
$\in_{tr}$	1.3×10^{-15}	1.3×10^{-15}
$\in_{fs}$	10^{-11}	10^{-11}
E_{DA}	5×10^{-9}	5×10^{-9}
ε	0.5	0.5
c_1 & c_2	2	2
α , β	0.5	0.5
w	0.9	0.9

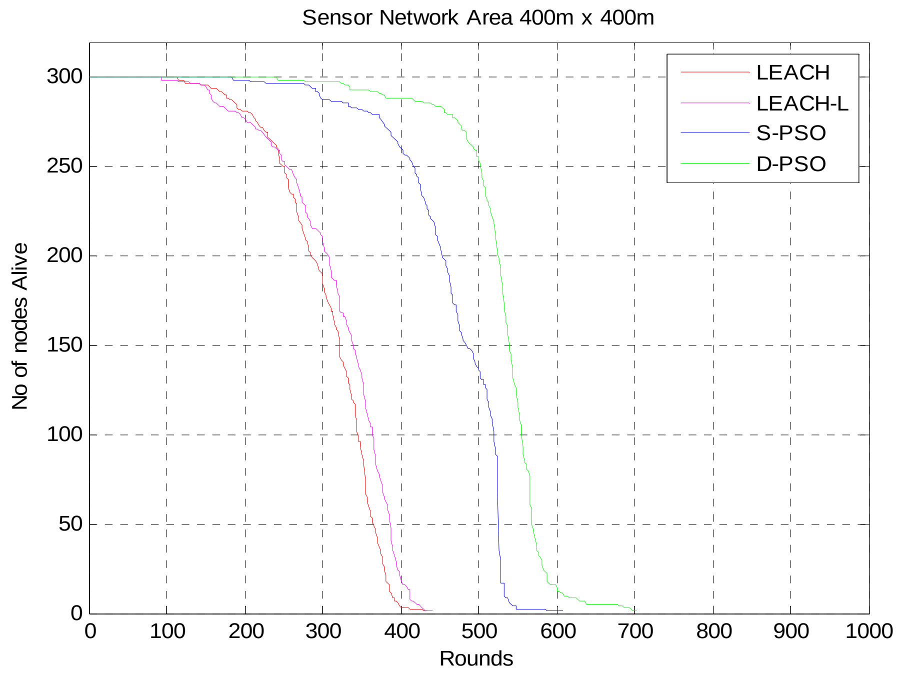

Fig. 4. Rounds vs Number of nodes alive for Sensor network area (400mx400m)

Fig. 4 clearly indicates that for the large sensor network considered i.e. (400mx400m), D-PSO is giving better network lifetime in terms of number of nodes alive vs rounds as compared to S-PSO, which in turn is giving much better results than LEACH-L and LEACH respectively. Thus by the use of Dual Cluster head strategy we can achieve better balancing of workloads for the Cluster Heads, in turn extending the Cluster Head re-election cycle. Thus this division of labour between the two Cluster Heads leads to balanced energy consumption over the wider network thereby resulting in better performance of D-PSO over S-PSO.

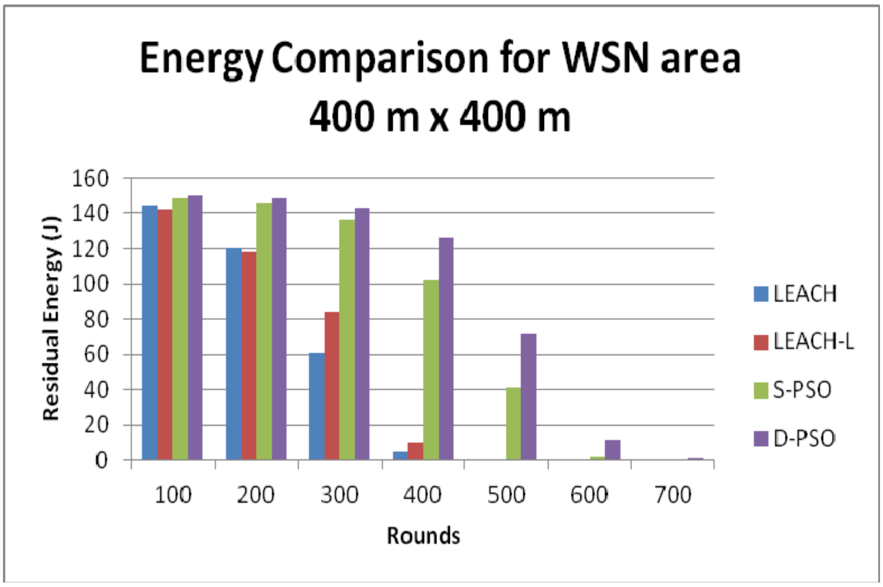

Fig. 5. Rounds vs Residual Energy (J) for Sensor network area (400mx400m)

Fig. 5 represents for the considered protocols a comparison for Rounds vs Residual Energy.It can be seen that S-PSO and D-PSO both show a considerable amount of reduction in Energy consumption as compared to LEACH and LEACH-L. As compared to S-PSO, D-PSO is resulting to better energy conservation, thus considerably enhancing the network lifetime in terms of rounds for the large network area in consideration.

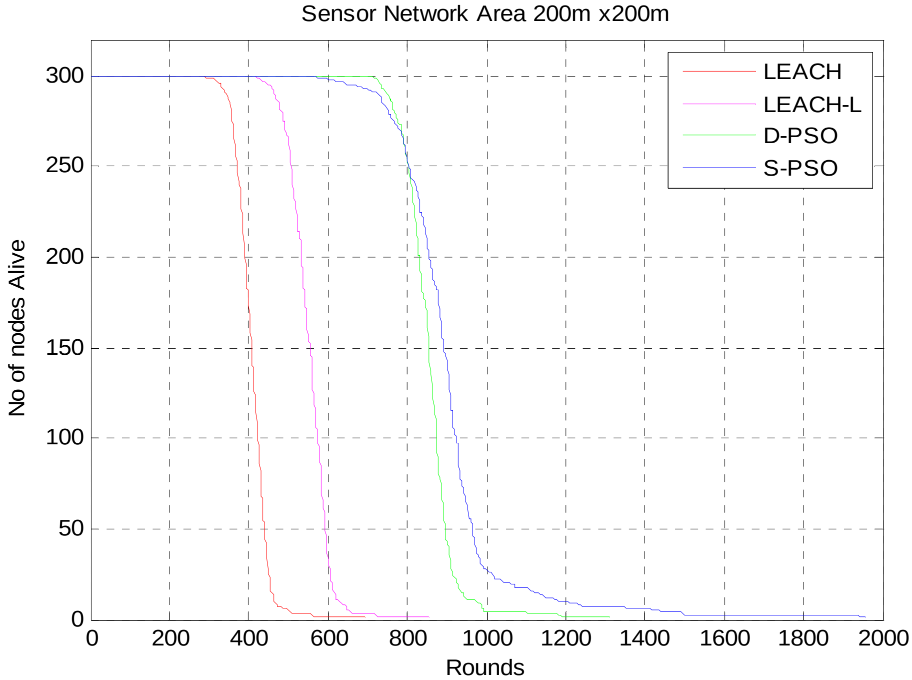

Fig. 6. Rounds vs Number of nodes alive for Sensor network area (200mx200m)

Fig. 6 shows a comparison of Number of nodes alive vs Rounds, but for a much smaller sensor network area (200mx200m). Here, it can be seen that the lifetime of all the protocols in terms of rounds has increased as compared to that of previous scenario. Energy expenditure is reduced considerably for all the protocols because of reduction in the expended energy over a smaller communication distance. In this scenario, S-PSO is giving the best performance which is followed by D-PSO and lastly by LEACH-L and LEACH.

In this case, where the network area is small, D-PSO leads to the additional consumption of energy because of this extra added process of data transfer from PCH to SCH. As the distance of communication is significantly reduced, Single Cluster Head is capable of performing both the tasks of data collection from the member nodes and transferring it eventually to the sink.

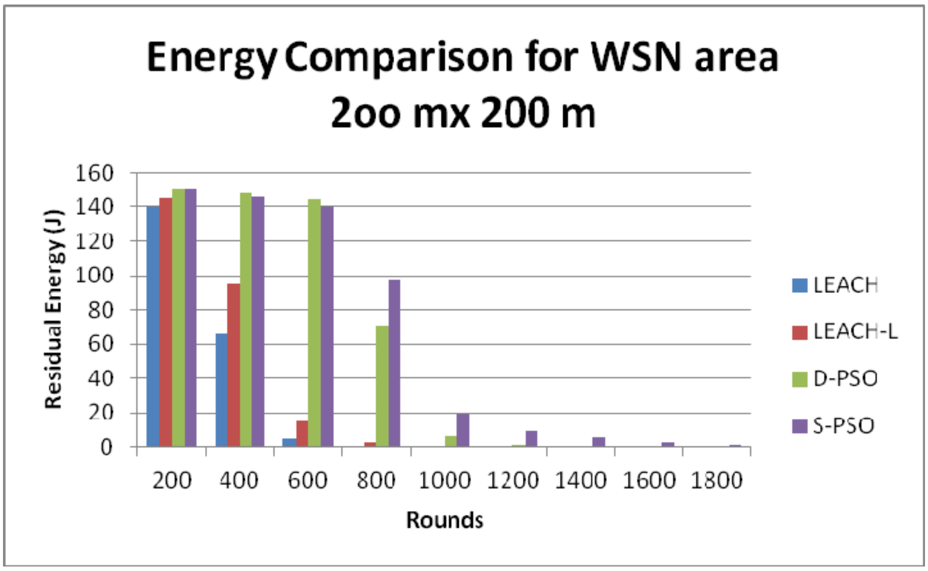

Fig. 7. Rounds vs Residual Energy (J) for Sensor network area (200mx200m)

Fig. 7 represents the Residual Energy for all the protocols over the smaller network scenario (200mx200m). The residual energy is greater for S-PSO as compared to D-PSO and is able to sustain for larger number of rounds. This shows that energy consumption for S-PSO is significantly less as compared to D-PSO over the smaller network

TABLE II
Lifetime of Protocols in terms of Rounds

Protocols	**Rounds for Scenario1 (Sensor network area-400mx400m)**	**Rounds for Scenario2 (Sensor network area-200mx200m)**
LEACH	434	693
LEACH-L	446	857
S-PSO	608	1956
D-PSO	703	1312

The table is derived from the simulation results. It can be seen that for larger network D-PSO is giving the best results by having the network lifetime of 703 rounds. For the smaller network S-PSO is better than D-PSO by sustaining in the network for longest time comprising of 1956 rounds.

V. Conclusion

In this paper we are able to study the effect of implementing the Single Cluster Head PSO (S-PSO) and the Double Cluster Head PSO (D-PSO) over a small as well as a large sensor network area. From the results we can conclude that these are heuristic algorithms, and the choice of algorithm will depend on the scenario desired. S-PSO is the better choice over D-PSO for extending the network lifetime in case of smaller sensor network area, whereas for the larger area, D-PSO gives better performance than S-PSO by achieving the load balancing.

The main aim in design of any WSN is to achieve energy optimization and result in significant improvement in network lifetime. Thus the choice of algorithm is crucial to achieve the best results for the scenario under consideration.

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