Research Journal of Applied Sciences 8 (8): 418-424, 2013
ISSN: 1815-932X

Load Balancing and Optimization of Network Lifetime by Use of Double Cluster Head Clustering Algorithm and Its Comparison with Various Extended LEACH Versions

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Abstract: The energy efficiency and optimization of network lifetime are the most important design criterion in Wireless Sensor Networks (WSNs). This is because WSNs are equipped with limited non-restorable supply of energy. In this study, a Double Cluster Head Clustering Algorithm is presented whose basis is Particle Swarm Optimization (PSO). In this algorithm, two cluster heads namely the Primary Cluster Head (PCH) and the Secondary Cluster (SCH) are generated. PCH is used to receive and aggregate data from its cluster member nodes and send the aggregated data to SCH. SCH then transmits this aggregated data to base station directly. For larger networks this algorithm certainly improves the basic PSO as there is a division of work load among the cluster heads which results in balanced energy utilization throughout the network. This protocol is then compared with various extended versions of LEACH protocol and the effect of all these protocols is studied collectively to optimize the network lifetime.

Key words: LEACH, Particle Swarm Optimization (PSO), Primary Cluster Head (PCH), Secondary Cluster Head (SCH), Wireless Sensor Network (WSN)

INTRODUCTION

A Wireless Sensor Network (WSN) consists of a large number of sensors and at least one base station. Sensor nodes are supplied with transceivers to gather information from its environment and pass it on up to a certain base station where the measured parameters can be gathered and made accessible for the end user. Recent advancements in micro sensor technology has made the sensors available in large numbers, at less cost, small in size and are capable to be deployed for various applications such as military, environmental monitoring and several such real time applications. The sensors are autonomous small devices with several constraints like the battery power, computational capacity, communication range and memory. While considering the overall network design problem, out of the many important aspects, energy efficiency is considered the prime design issue as the sensor node can be provided with a limited supply of energy. In some scenarios, replacement of energy sources can be impossible and so sensor network lifetime is strongly dependent on the battery lifetime.

One of the design methods to effectively manage overall energy consumption of the network is clustering. It minimizes the number of sensor nodes taking part in the long distance communication and distributes the energy consumption evenly throughout the nodes. In this system, a group of sensor nodes are formed and cluster heads are elected for each cluster. The cluster head transmits the data to the base station thereby reducing the energy expended by each node for direct communication with the sink or the base station. This as well augments the resource allocation and the bandwidth reutilization. Several cluster based protocols have been proposed in the literature till date to extend the network longevity. LEACH a very well known protocol was introduced by Heinzelman *et al*. (2000). LEACH is a periodic protocol which operates in rounds consisting of the cluster setup phase and the steady state phase. LEACH is certainly responsible for considerable energy saving thereby prolonging the network lifetime as compared to conventional multi hop protocols. Subsequently several modifications to LEACH have been proposed which are discussed in the paper ahead.

Particle swarm optimization is a centralized, energy aware cluster based protocol which is simple and computationally efficient in solving several optimization problems. This protocol was proposed earlier by Kennedy and Eberhart (1995). Using the PSO algorithm the Double Cluster Head Clustering algorithm (D-PSO) is implemented on the basis of original LEACH. This protocol considers the node energy equilibrium along with optimization in cluster head selection. D-PSO makes

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use of two cluster heads differing from the original PSO. This results in better balancing the workloads thus enhancing the network lifetime in case of larger sensor networks.

MATERIALS AND METHODS

Protocols description: This study provided a detailed description of the various clustering algorithms whose performance would be compared in order to achieve energy optimization in Wireless Sensor Networks.

LEACH protocol: LEACH protocol is a pioneering work with regards to the clustering techniques employed to solve various energy optimization problems in WSN. It is the first hierarchical cluster-based routing protocol for WSN which partitions the nodes into clusters. In every cluster, a dedicated node called Cluster Head (CH) is responsible for creating a TDMA (Time Division Multiple Access) schedule and sending aggregated data from nodes to the Base Station (BS) using CDMA (Code Division Multiple Access). Residual nodes are cluster member nodes. Clustering in LEACH is shown by Fig. 1. This protocol is divided into rounds consisting of two phases.

Set-up phase: It consists of advertisement phase and the cluster set-up phase.

Steady phase: It consists of schedule creation and the data transmission phase.

Set-up phase: Initially during cluster formation, each node decides if it will become a Cluster Head (CH) or not. The decision is based upon the number of required cluster heads and the number of times the node has become a CH so far. Decision is made by node n by selecting a random number between 0 and 1. If this generated number is less than the threshold T(n), node becomes CH for the current round:

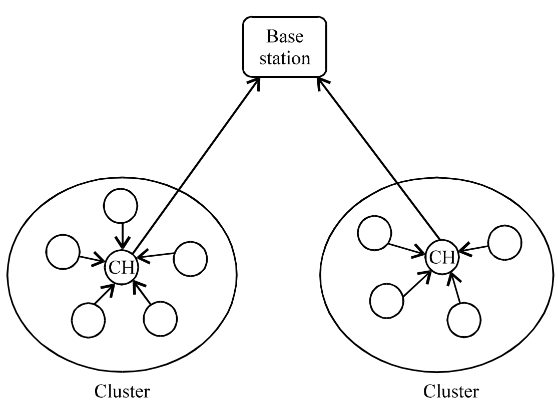

Fig. 1: Clustering in LEACH protocol

$$T(n) = \begin{cases} \dfrac{P}{1-P\times(r\times\text{mod}\frac{1}{p})} & \text{if } n \in G \\ = 0 & \text{Otherwise} \end{cases} \quad (1)$$

Where:

P = The desired percentage of cluster heads
r = The current round
G = The set of nodes which have not been CHs in the last 1/P rounds

Using this equation every node will become CH sometime within 1/P rounds. Here, an assumption is made that all nodes begin with same amount of energy. After the CH election, it broadcasts an advertisement message to rest of the nodes using CSMA-MAC protocol. After the completion of this phase, each node decides to which CH it should belong which depends on the received signal strength of the advertisement.

Steady phase: The first part of this phase is schedule creation in which the CH node creates 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 thus minimizing the energy dissipation. When the entire data is received, CH node performs some signal processing to compress the data and then it can be sent to the base station. This is the steady state operation. After a certain fixed time, the next round of choosing the CH can begin.

LEACH-M protocol: In LEACH, each CH directly communicates with BS no matter the distance linking CH and BS. This will lead to lot of its energy consumption if the distance is far. On the other hand, Multihop-LEACH, i.e., LEACH-M protocol (Shang and Lei, 2010) selects optimal path between the CH and the BS through other CHs and use these CHs as a relay station to transmit data all the way through them. First, multi-hop communication is implemented among CHs. After that as per the selected optimal path, these CHs send out the data to the subsequent CH which is nearest to BS. Finally, this CH sends data to BS. LEACH-M protocol is almost the same as LEACH protocol, only difference is that it makes communication mode from single hop to multi-hop between CHs and BS.

LEACH-L protocol: An advanced energy balanced multiple-hop routing protocol named Energy LEACH or LEACH-L (Xiangning and Yulin, 2007; Shang and Lei, 2010) can be characterized as follows:

- When the cluster-heads are close to they directly correspond with the Base Station (BS)
- When they are faraway, they telecommunicate by multiple-hop way and the shortest transmission distance is limited. The sensors in different areas use different frequencies and gaps to communicate with BS. Radio Energy Dissipation Model is given by Fig. 2

In order to elaborate the idea, some parameters are defined as follows:

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

$$E_{RX}(L) = E_{elect} L \quad (3)$$

$$do = \frac{\sqrt{\in_{fs}}}{\sqrt{\in_{tr}}} \quad (4)$$

Where:

E_{elest} = The consumed energy per bit
$\in_{fs}$ = Energy consumed by free space amplifier
$\in_{tr}$ = Energy consumed by multipath amplifier
d = The distance between transmitter and receiver
L = The length of the message in bits

Both the free space (d^2 power loss) and the multi-path fading (d^4 power loss) channel models are used in the model, depending on the distance between the transmitter and receiver. Now the transmission cost (E_{TX}) and receiving cost (E_{RX}) is calculated as:

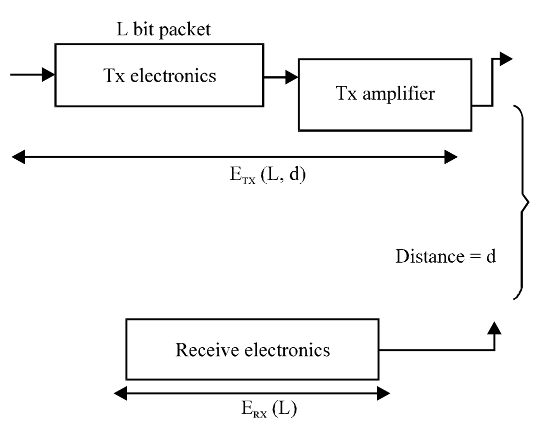

Fig. 2: Radio Energy Dissipation Model

A sensor consumes some amount of energy for data aggregation (E_{DA}) as well. Researchers assumed that the sensed information is greatly correlated thus the cluster-head can always aggregate the data collected from its members into a single length-fixed packet.

LEACH-F protocol: Data clustering is the process of dividing data elements into classes or clusters so that objects in the same class are as alike as possible and objects in different classes are as different as possible. This clustering can be done in two ways-hard clustering and soft clustering. In hard clustering, data is divided into discrete clusters such that each data element belongs to precisely one cluster. In fuzzy clustering (Anno *et al*., 2008) (which is also known as soft clustering), data elements can fit in to more than one cluster and coupled with every element is a set of membership levels. One of the most widely used fuzzy clustering algorithms is the Fuzzy C Means (FCM) Algorithm (Shamroukh *et al*., 2012). The FCM algorithm attempts to partition a finite collection of n elements $X = \{x_1, x_2, ..., x_n\}$ into a collection of c fuzzy clusters in accordance to some given criterion. When a finite set of data is given, the algorithm returns a list of c cluster centres $C = \{c_1, c_2, ..., c_c\}$ and a partition matrix:

$$W = w_{i,j} \in [0, 1], i = 1, 2,..,n, j = 1, 2,..,c \quad (5)$$

where each element wij conveys the degree to which element x_i belongs to cluster c_j. FCM aims to minimize an objective function. The standard function is:

$$w_k(x) = \frac{1}{\sum_j \left(\frac{d(center_k, x)}{d(center_j, x)} \right)^{\frac{2}{(m-1)}}} \quad (6)$$

It differs from the k-means objective function by the addition of the membership values w_{ij} and the fuzzifier m. The fuzzifier determines the level of cluster fuzziness. A large m results in smaller memberships, i.e., w_{ij} and hence the fuzzier clusters. In the limit m = 1, the memberships w_{ij} converge to either 0 or 1 which implies a fine partitioning. In case of lack of experimentation or domain knowledge, m is generally set to 2.

Any point x has a set of coefficients thus giving the degree of being in the kth cluster $w_k(x)$. With fuzzy c-means, the centroid of a cluster is the mean of all points, biased by their measure of belonging to the cluster:

$$C_k = \frac{\sum_x w_k(x)x}{\sum_x w_k(x)} \quad (7)$$

The degree of belonging, i.e., $w_k(x)$ is related inversely to the distance from x to the cluster center as calculated on the previous pass. It also depends on a parameter m that controls how much weight is given to the closest center.

Particle swarm optimization: Particle swarm optimization is a centralized, energy aware cluster based routing protocol. It is an evolutionary computing technique which was developed by observation of social behavior of flock of birds. This methodology was originally proposed by Eberhart and Shi (2001). This protocol makes use of a high energy node as the cluster head and produces clusters that are positioned uniformly in entire sensor field. The main idea is choosing a cluster head which can minimize the intra cluster distance, i.e., the distance between itself and the cluster member node and also result in optimization of energy throughout the network. In PSO, a swarm means number of potential solutions where every potential solution is termed as a particle (Latiff *et al*., 2007). Aim of PSO is to find such a particle position which would result to best evaluation of the given fitness function.

Initialization process: Each particle is given the initial parameters consisting of position and velocity vectors randomly and the particles are made to fly randomly in the search space. All particles have to be optimized as per the fitness function evaluation. Each particle is equipped with a velocity to determine the direction of the flight and the distance. The particles will follow the best particle, i.e., the particle which has resulted to best evaluation of the fitness function to search the next best position in the determined solution space. At every iteration the particles update 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:

$$v_{id}(t+1) = wv_{id}(t)+c_1\alpha\left(p_{id}-x_{id}(t)\right)+c_2\beta\left(p_{gd}-x_{id}(t)\right) \quad (8)$$

The position update equation is as follows:

$$x_{id}(t+1) = x_{id}+v_{id}(t+1) \quad (9)$$

Where:

v	=	The particle's velocity
x	=	The particle's position
t	=	The time
c_1 and c_2	=	Learning factors
α and β	=	Random numbers lying between 0 and 1
p_{id}	=	Particle's best position
p_{gd}	=	Best global position
w	=	The inertia weight coefficient

Cluster setup using PSO algorithm: The working of this protocol is based on a centralized control algorithm that is implemented at the base station. The protocol is operated in rounds where each round begins with a setup phase which consists of cluster formation. This is preceded with a steady state phase. At the start of each setup phase, all nodes send information about their current energy status and locations to the base station. On the basis of this information, the base station works out the average energy level of all the nodes. To guarantee that only nodes with a sufficient energy are selected as cluster heads, the nodes equipped with an energy level more than the average are eligible to become a cluster head candidate for this round. Next, the base station runs the PSO algorithm to determine the best K cluster heads. The algorithm flow chart is as shown in Fig. 3. Where pbest refers to best particle position found and gbest refers to best global position in the flow chart.

The fitness function: The most important factor to be considered in PSO is the fitness function evaluation. The performance of the optimal solution of the algorithm can be directly determined by the function. The fitness function is specified by Ruihua *et al*. (2011) is as follows:

$$f = \varepsilon\times f1+(1-\varepsilon)f2 \quad (10)$$

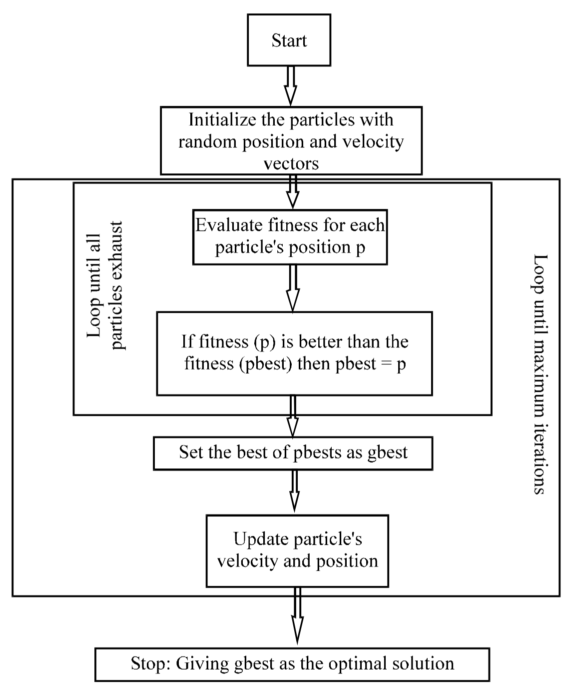

Fig. 3: Flow chart showing operation of basic PSO

$$f1(i) = \frac{E(i)}{\sum_{k=1,\, k\neq i}^{m} E(k)} \quad (11)$$

$$f2(i) = \frac{(m-1)}{\sum_{k=1,\, k\neq i}^{m} d(i,k)} \quad (12)$$

Where:

- f1 (i) = The ratio of node i's energy to the total energy of cluster
- m = The number of nodes within the cluster
- E(k) = The energy of node k
- f2(i) = Total Euclidean distance of cluster nodes to node i
- d(i, k) = The distance between node i and node k
- ϵ = A user defined constant which determines the contribution of each of the functions used

The fitness function as defined fulfils the objective of simultaneously minimizing the intra-cluster distance between the nodes and their cluster head i as computed by f2(i) and also of optimizing the energy efficiency of the network as computed by f1 (i). The node with the maximum value of f(i) is chosen as the cluster head as it is the optimum.

Double Cluster Head Clustering algorithm: The Double Cluster Head Clustering Algorithm (D-PSO) generates two cluster heads using PSO but using LEACH as the basis. The additional feature is that this protocol considers the node energy equilibrium in addition to optimized selection of the cluster head. After the cluster formation the intra cluster data transmission is established. The cluster formation in D-PSO is shown by Fig. 4.

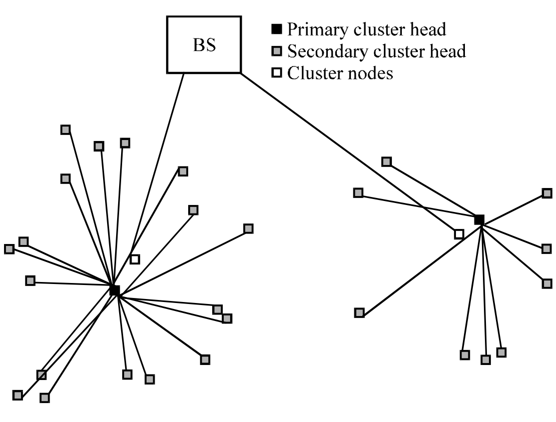

Fig. 4: Cluster formation in D-PSO

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 transmits aggregation data to the base station directly. PCH is not directly in link with the base station which in turn can save energy. This methodology better balances the network workloads and certainly extends the sensor network lifetime.

Selection of primary and secondary cluster head: In iterative process as carried 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 referred to as the suboptimal solution. As per the fitness function, The SCH also has more energy and the nearest distance with the PCH. So, researchers select the suboptimal solution as the SCH. The fitness function used for this cause is same as that given by Eq. 10.

The D-PSO algorithm steps: D-PSO algorithm has periodic execution pattern. Process of the specific steps is as follows:

- The initial clustering is done using LEACH algorithm. All member nodes transmit information about their current energy and locations to the cluster head in every cluster. This cluster head is the preliminary cluster head
- Based on this information, the initial cluster head runs this algorithm to select the master cluster head and vice 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 equation

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 initial cluster head transmits the information that contains the PCH ID and SCH ID to all nodes in the cluster

- PCH then sets up a TDMA schedule for its member nodes to avoid collisions among data messages, so that 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

RESULTS AND DISCUSSION

In this study, researchers assess the performance of all the protocols discussed in the study with the help of simulations. Simulations are carried out with the help of MATLAB. The simulations are run for a network of 400×400 m for 300 nodes. The nodes are equipped with same amount of initial energy and the network lifetime is taken till 30% of the total nodes die out. Simulation parameters are listed in Table 1.

Figure 5 clearly indicates the network longevity defined in terms of number of nodes alive vs. rounds. It can be seen from the results that fuzzy LEACH is performing significantly better than the other LEACH versions. But D-PSO gives the best performance of all followed by the basic PSO. This because D-PSO and PSO produces better network partitioning with cluster heads distributed uniformly in the sensor field.

This simulation result of Fig. 6 also represents the comparison of number of nodes alive vs. rounds but for sink position to be 80 m outside the sensor network area. The results in this case are also in congruence with the results obtained for the prior scenario. But there is a reduction in overall lifetime of all the protocols. In this case also D-PSO is giving the best performance followed by PSO and LEACH-F for improving the network efficiency by optimizing the energy constraint.

Figure 7 represents the comparison of residual energy over the rounds in the network. It is drawn considering the values of residual energy obtained in MATLAB for each round. This graph shows a clear comparison of all the protocols for the energy remaining in the network at different times (rounds). It can be seen that D-PSO is giving the best performance displaying the most prolonged lifetime as it considerably reduces the energy consumption.

Table 1: Specifications for protocol simulation

Parameters	Scenario 1	Scenario 2
Network scope (m^2)	(400, 400)	(400, 400)
Number of sensors	300	300
Location of BS(m)	(200, 200)	(200, 480)
Initial energy	0.5 J	0.5 J
Packet length	4000 bit	4000 bit
Control packet size	100 bit	100 bit
ϵ_{tr} (pJ /bit/m^4)	0.0013	0.0013
ϵ_{fs} (pJ/bit/m^2)	10	10
E_{DA} (nJ/bit)	5	5
ε	0.5	0.5
c_1 and c_2	2	2
α, β	0.5	0.5
w	0.9	0.9

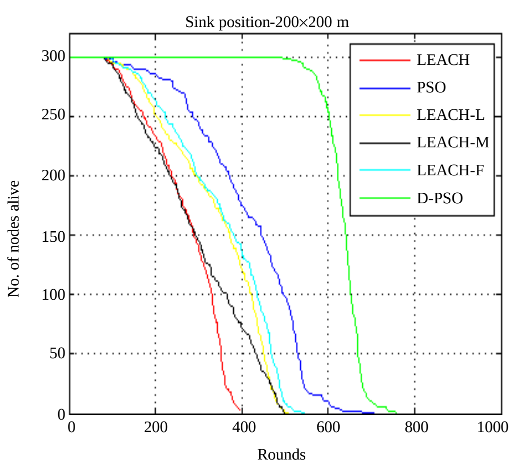

Fig. 5: Number of nodes alive over the rounds for sink position (200, 200)

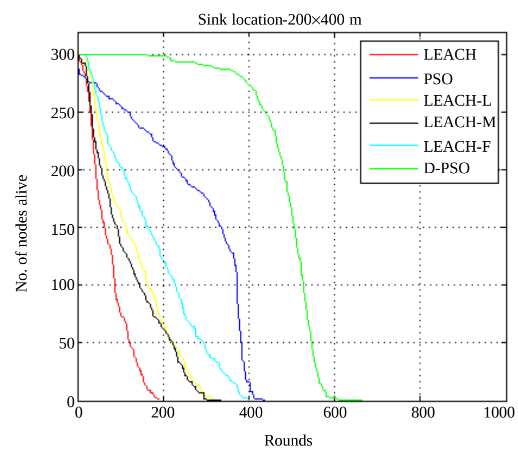

Fig. 6: Number of nodes alive over the rounds for sink position (200, 480)

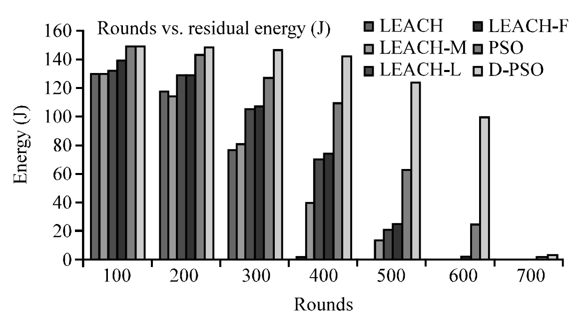

Fig. 7: Residual Energy of the network for sink position (200, 200)

Table 2: Protocols lifetime in terms of rounds

Protocols	Rounds for scenario 1 (Sink position-200×200 m)	Rounds for scenario 2 (Sink position-200×480 m)
LEACH	395	189
LEACH-M	498	333
LEACH-L	505	329
LEACH-F	543	400
PSO	704	436
D-PSO	756	662

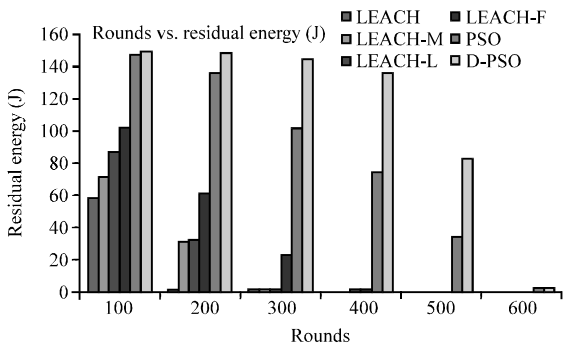

Fig. 8: Residual energy of the network for sink position (200, 480)

Figure 8 also represents the residual energy of all the protocols over a period of time but for scenario 2, i.e., the base station position 80 m outside the sensor network area. As compared to previous scenario, it can be seen that the overall network longevity for all the protocols is reduced. But again in comparison, D-PSO supersedes in network performance by reducing the energy consumption followed by PSO and LEACH-F subsequently.

In Table 2, the comparison of protocols in terms of rounds till which the network is able to sustain for the two mentioned scenarios is given. These values are obtained through MATLAB simulations. It can be seen that for both the scenarios D-PSO is giving the best network lifetime by operating for 756 and 662 rounds, respectively. Accordingly, it can be concluded that D-PSO is notably enhancing the network lifetime compared to other protocols.

CONCLUSION

In this study, researchers are able to study the effect of D-PSO protocol in elongating the network lifetime significantly. Also researchers have successfully compared this algorithm with PSO and several versions of LEACH and their performances are studied. D-PSO is efficiently capable of balancing the work load among the cluster heads. From the results obtained and considering the two scenarios on an average, D-PSO leads to improvement in lifetime as compared to basic LEACH by 40%, Fuzzy LEACH by 25% and PSO by 13%. Thus, the overall energy consumption of the network can be reduced considerably in turn radically extending the network lifetime of the Wireless Sensor Network.

RECOMMENDATIONS

The research includes enhancing the D-PSO algorithm further by implementing multi hop routing among the secondary cluster heads to send data to the base station.

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