Brain Storm Optimization for Energy-Saving Routing Algorithm in Wireless Sensor Networks

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DOI: 10.29322/IJSRP.9.05.2019.p8930
http://dx.doi.org/10.29322/IJSRP.9.05.2019.p8930

Abstract- There are vast application ideas in Wireless sensor networks (WSNs) but their prime disadvantage is that the energy of nodes are limited and energy cannot be supplied. Most traditional routing protocols encounter complications in WSNs. In recent times, thorough study of brain storm optimization (BSO) algorithms has been applied in many fields and now we use it to solve routing problems. Initially, the low energy adaptive clustering hierarchy (LEACH) is considered using fundamental operations and then optimized using BSO to extend the lifetime of the WSN. The proposed routing algorithm relies on a novel fitness which considers energy and distance. The outcome of LEACH is evaluated and compared; obtained result shows that the proposed approach performs more effectively.

Index Terms- Wireless Sensor Networks, Brain Storm Optimization, Routing Algorithm.

1. Introduction

A Wireless Sensor Network (WSN) interconnect wirelessly following an ad hoc configuration through a network of tiny embedded devices called sensors. They are located strategically inside a physical medium and are able to interact with it. As a result, the sensor calculates it needed limits from its surroundings and delivers the detected information [4]. The sensor node sends message to the entire network but however the network topology can be altered continuously and the nodes are likely to fail. However, we should keep in mind that nodes should be independent and repeatedly they will be ignored. This kind of device (sensor node) has limited power, low computational capacities and inadequate memory. Although scalability is the most considered problem in WSNs, their connection strategy for communication and the limited energy to supply the device. Energy efficiency is an important topic in wireless sensor network, which can boost the network for the next months need or even years without liability [2]. Most of the work in energy saving routing only focus on path detection technique based on the largest energy level, the lowest energy consumption, or the minimal hop [3]. These methods can reduce energy consumption in terms of optimization, its dense environment and the high risk group jamming which also should consider the energy-aware routing. Because it will not only affect delay and packet loss of the network performance but then also one of the most significant reasons which leads to extreme energy consumption.

Usually, optimization is about finding the “best available” solution(s) for a known problem. The two basic problems studied in optimization are unimodal and multimodal problems. A unimodal problem has only one optimum solution while a multimodal problem has several or numerous optimum solutions, of which a portion are local optimal solutions. Evolutionary optimization algorithms, or simply the evolutionary algorithms (EA), are mostly hard to find the global optimum solutions for multimodal problems due to the feasible occurrence of the premature convergence [1]. To reach equilibrium, the system adjusts its algorithm parameters. BSO is a new kind of SI algorithm and it is intuitive to think that BSO should be superior to other SI algorithm because BSO emulates the most intelligent animal in the world (human being) instead of simple objects such as ants in ACO, birds in PSO, bees in HBO, and bacteria in BFO. The BSO algorithm proposed by Shi is motivated by the following intelligent behaviors [9]: once human being face a hard problem which every single person may find difficulty in solving, group of persons will get together to brainstorm. These persons are generally with diverse background and they come together for a brainstorming process, which helps them to interactively collaborate to generate great ideas. This manner, the problem can be solved with high chance. Shi has successfully designed a BSO by emulating this brainstorming process in human being to solve problems and conduct simulations on two conventional benchmark functions to confirm its effectiveness and importance in solving optimization problems [9]. The sensor network model illustrated in Fig.1 consist of one base station and a number of sensor nodes deployed over a large topographical area. All the sensors and the base station can either be stationary or moving. Data are transferred from sensor nodes to the sink through a direct or clustered communication pattern.

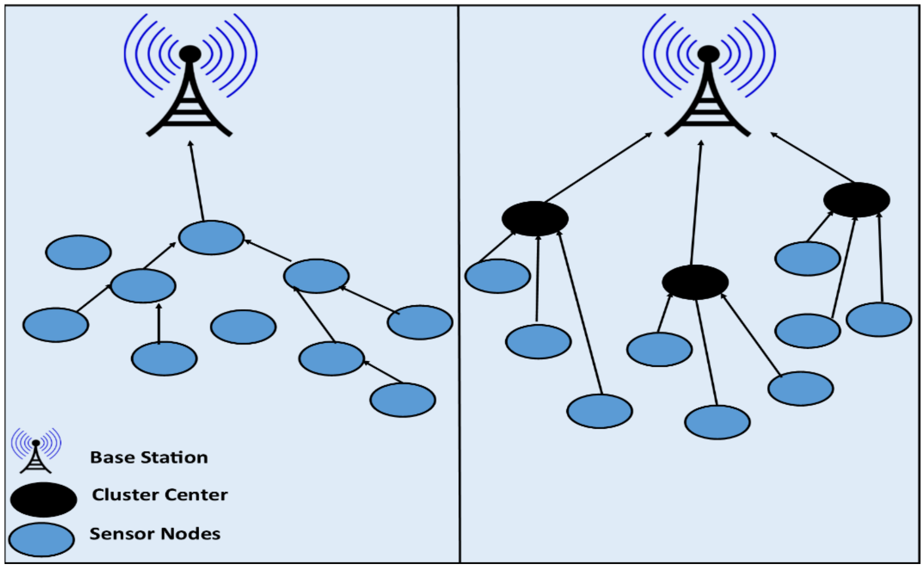

Fig.1 An Example of Direct and Clustered WSN

The essential contributions of this paper are summarized as follows:

i. We applied the modified brain storm optimization algorithm to create the routing structure.
ii. We derive a fitness function for the system considering energy and distance.
iii. We use the BSO-LEACH for the routing structure to compare the LEACH algorithm.

The remaining part of this paper is organized as follows. Summary of related work is described in section 2. In section 3, the Modified Brain Storm Optimization Algorithm is comprehensively explained. Wireless sensor network energy-saving routing using BSO-LEACH is presented in Section 4. Section 5 basically presents the simulation and results considered in the communication structure. Finally, the conclusion is drawn in Section 6.

2. Related Work

Problems such as memory, limited energy, communication link failures, and computational constraints are the few challenges in WSNs [6]. Mostly, formulation in WSN is done through multidimensional optimization problems, and approached through bio-inspired techniques. Low energy adaptive clustering hierarchy (LEACH) is one of the topmost principal approach for clustering [11]. Its purpose is to preserve the energy for an extended time. Other authors have been able to develop LEACH which can be found in [14, 15]. In the communication phase, each sensor transmit data to the cluster head (CH) then from the CH to the BS. In the real scenario, BS located very far from the transmission range of CH. In [13], it addresses WSN issues such as clustering, optimal deployment, node localization, and data-aggregation. Also, ant colony algorithm optimization algorithm has been attempted to solve energy depletion problems for wireless sensor network. In [8], their research permitted every node in the WSN to recover the distance and residual energy of the neighbor nodes. An energy-saving routing architecture with a uniform clustering algorithm is proposed in [16] to reduce the energy consumption in wireless body sensor networks. A centralized and cluster-based method was applied to create a cluster-tree routing structure for the sensor nodes. Z. Ren et al in [17] presented an in-depth study of particle swarm optimization (PSO) algorithm routing problem in WSNs, it then proved that the algorithm can work better to improve the performance of the network. In [18], an Enhanced PSO-Based Clustering Energy Optimization (EPSO-CEO) algorithm for wireless sensor network was proposed which basically considers clustering and cluster head selection for minimizing the power consumption in the WSN.

In [5], the cluster based WSN architecture defined an effective way to optimize the energy consumption by implementing an energy efficient scheme amongst the participating nodes for major events such as design of the hierarchical structure on the consistent interval and the data communication from a node to the base station. In the stated quality of service specification (QSS), the result of the proposed work are connected with the one acquired through the existent low energy adaptive clustering hierarchy (LEACH) and the deterministic stable election protocols (D-SEP). The total progress gain achieved by the proposed work is 31% for LEACH and 10% for D-SEP at specified QSS. In [19], firefly algorithm was applied in solving routing problems. Additionally, a fitness function based on residual energy, node degree and distance was used. In [20], shortest path routing protocol involves an address forwarding in the network. Genetic algorithm through superiority theory is used to achieve energy efficient routing by means of minimizing the path length and thus maximizing the life of the network.

In the field of Computational Intelligence (CI), many algorithms have been inspired from different swarms including insects, animals, and birds. Nature inspired artificial intelligence (AI) methods based software approaches presents a reasonable and quick solution for performance optimization of WSNs [25, 26, 27, 28, 29]. Ant colony optimization algorithm (ACO) have been suggested based on the improvement of LEACH protocol consisting of cluster-heads and sink nodes in a direct communication [21, 22]. The methodology whereby cluster formation and routing is conducted in WSN have been outlined based on genetic algorithm [23]. These algorithms are far and wide utilized in explaining numerous of optimization problems. Increasing the battery life of WSNs is important in enhancing the implementation of WSN. Therefore, in [24] genetic algorithm have been implemented independently on energy models for data communication of WSNs with the objective to find out the optimal energy consumption conditions. BSO concentrates on the cluster centers and allocates them the uppermost priority, it could fall in local optima like any other swarm algorithm. The modified version of BSO proposed is entitled Fuzzy Brain Storming Optimization (FBSO) algorithm [7]. Moreover, the BSO and FBSO have been applied in Wireless Sensor Networks (WSNs) for the Energy Topology Control (ETC) problem. The problem is formed to fit the BSO and FBSO algorithms requirements.

3. Modified BSO Algorithm: A Brief Introduction

In brain storming optimization algorithm [10], the solutions are separated into several clusters. The next iteration always retains the best solution from the previous solution. However, new individuals have the tendency to be created based on one or two individuals in clusters. The usage of a solution becomes superior when the new individual is nearby to the best solution. In Fig. 2, a distinctive brainstorming process is presented. In Osborn's Rules, the four rules tries to better ideas by generating more of them, never criticize any idea produced, unusual ideas are always welcomed and finally stand the tendency to combine and improve ideas. The total population is related to every sensor node and per individual idea in the BSO is the node. In the bounds of the solution space, an individual idea is at random set to a suitable starting condition. A population size of n is considered when a fixed number of n ideas are generated for owners to pick good ideas from.

During each generation, all the ideas are first grouped into *k* clusters using *k*-means clustering approach, and then the paramount one in each cluster is selected as the cluster center. Rarely, a randomly selected center is substituted with a new generated idea with a probability of *p*replace, keeping the swarm from local optimum. Firstly, BSO selects one or two clusters randomly with predetermined likelihood in place of ideas generated by other ideas. The uppermost superiority is known to be the cluster center chosen, if not, select another idea in the cluster. On the other hand, if a new idea is created based on ideas generated by other ideas, it can be written as

$$y_{ij}^{new} = y_{ij}^{old} + \xi N(\mu, \sigma) \quad (1)$$

Else, if a new dependent idea is generated by two existing individuals, the resulting solution is formulated as

$$y_{ij}^{new} = y_{ij}^{old} + \xi N(\mu, \sigma)$$

$$y_{ij}^{new} = \omega_1^* y_{ij}^{old1} + \omega_2^* y_{ij}^{old2} \quad (2)$$

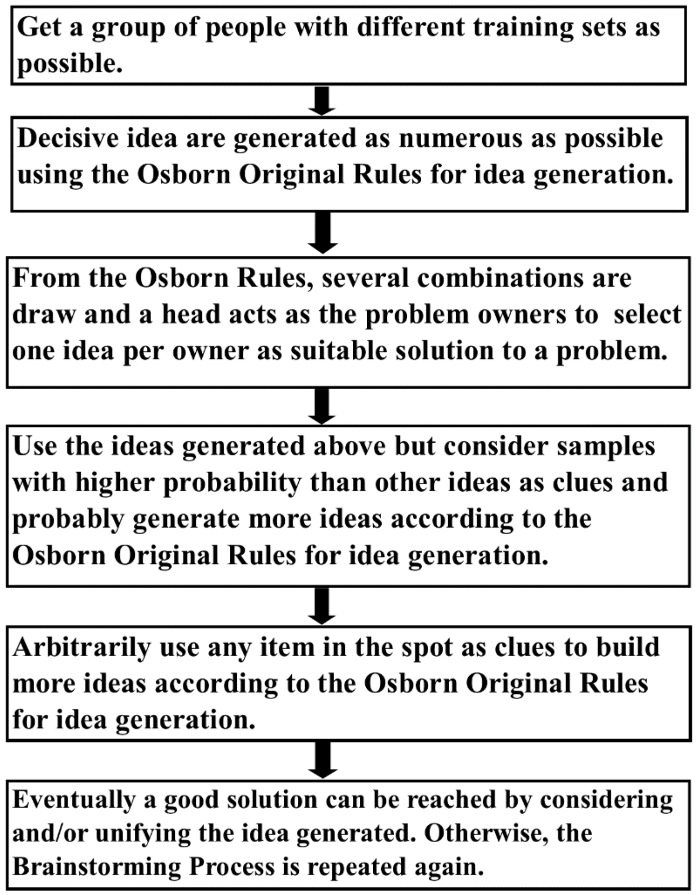

Fig 2. The Brainstorming Process

where y_{ij}^{new} and y_{ij}^{old} are the jth dimension of ith individual of y^{new} and y^{old}, respectively; with mean μ and variance σ the Gaussian random value is given as $N(\mu, \sigma)$; ω_1 and ω_2 are weight values of the two ideas, respectively; and ξ is an regulating factor slows down the convergence speed as the evolution goes, which can be expressed as

$$\xi = rand * logsig\left(\frac{0.5 * I_{max} - I_{cmin}}{k}\right) \quad (3)$$

where $rand$ is a random value between 0 and 1. The I_{max} and I_{cmin} is the maximum number of iteration and current minimum number of iteration respectively. The $logsig$ is a logarithmic sigmoid transfer function, and such form is positive for global search at the start of the evolution and improves local search ability when the process is approaching to the end. Moreover, k is a defined to be a parameter for varying slopes of the $logsig$ function. The newly generated idea is weighed, and if the fitness value is more suitable than the current idea, the old idea will be replaced by new one. Once the newly generated idea is created, it is then considered. Afterwards, the crossover operation is conducted and the best idea among the group is selected to update the old one. Mostly, the described process above is repeated up to n new individuals have been created to finish one generation. The iteration stops if and only if the maximum number of iterations is reached. To end, the outcome of the final solution to the problem is weighed to be the optimal idea.

4. WSN Routing Based on BSO-LEACH

Derivation of fitness function: In general, the suggested fitness of a solution generated should improve the search method to give more computational resources in time and/or space [1]. Therefore, we considering objectives such as residual energy and Euclidean distance.

In data communication, next hop receives and aggregates data then transmitted to the BS. Therefore, higher residual energy next-hop should be optimal as possible, where E_i represents the energy of each sensor and E_{Ci} represents the total residual energy of all the sensor nodes within the cluster and p represents the number of nodes in the cluster. So, our first objective with respect to residual energy is F_1 minimized as:

$$F_1 = \frac{E_i}{\sum_{i=1}^{p} E_{Ci}} \quad (4)$$

The euclidean distance in the middle of the cluster center (CC) and its members and from the CC to the BS should be minimum so that it uses less amount of energy. And so, it's crucial to reduce the distance between CC and BS, where s_i is the source node, CC_i is the cluster center and BS is the base station. However, this has the tendency to improve the network lifetime. So, the second objective with respect to distance is F_2 minimized as:

$$F_2 = \frac{dis(s_i, CC_i)}{\sum_{i=1}^{p}[dis(CC_i, BS) + (s_i, CC_i)]} \quad (5)$$

The fitness function can be calculated using the formula given in equation 8. The Residual energy F_1 and Euclidean distance F_2 is given in equation 6 and 7 respectively.

$$Fitness\ Value: F = F_1 + F_2 \quad (6)$$

The LEACH protocol arranges its sensor nodes hierarchically in clusters, together with a cluster head (CH) for each [30]. The CH of the LEACH is elected starting with a probability which is defined by a random number chosen between 0 and1. The task of CH alternates all the sensors to avoid a single sensor node draining all its battery. The threshold T_n is given in equation 7 which is matched up to the preferred random number.

$$T_n = \begin{cases} \frac{\rho}{1-\rho*(r*mod\frac{1}{\rho})}, & if\ n\epsilon G \\ 0, & Otherwise \end{cases} \quad (7)$$

where ρ is the desired percentage of CCs, r is the current round, and G is the set of nodes that have not been cluster-heads in the last $1/\rho$ rounds.

The operation of LEACH protocol consists of several rounds with two phases in each [31]: Set-up Phase and Steady Phase. The algorithm for LEACH protocol is analyzed by the following procedures.

Step 1: Setup Phase- In the early phases, each potential node stand the probability to be picked spontaneously to become a cluster head (CH). The CH picking stage for the nodes is taken into accounts. The CH is chosen depending on the threshold value T_n. The advertisement phase is when the CHs alert their neighboring node with an advertisement packet that they are now CHs. The non-CH nodes with the strongest signal strength is taken by the advertisement packet. Then in the cluster setup phase, the ordinary member nodes alert the CH that they are now a member to that cluster with "join packet" having their own IDs making use of CSMA. Later in the cluster-setup sub phase, the CH have an objective knowledge of the number of member nodes and their IDs. Conditionally, intra-cluster members receive messages, the CH produces a TDMA schedule, proceeds by taking a random CSMA code, and then forwards the TDMA table to cluster members. The steady-state phase follows next.

Step 2: Steady-state Phase- In the second and final phase of the LEACH, the cluster nodes send their data to the cluster head. The cluster members in each cluster communicate only with the cluster head by way of a single hop communication. The cluster head performs aggregation properties by collecting data and forwarding it to the base station either directly or through other cluster head together with with the static route well-defined in the source code as shown in the clustered WSN of Fig. 1 [31]. As soon as the specified interval is over, the whole network starts from the Set-up phase again.

Algorithm for routing: Steps to find out proximate optimum route;

Step 1. Initialize the node $N_i = \{\forall_i, 1 \le i \le S_m, S_m$ is m potential number of solutions (nodes), maximum iterations I_{max}, Pro1, Pro2, Pro3, and number of cluster.

Step 2. Cluster m solutions into l clusters.

Step 3. Compute the fitness value of each node in the cluster using equation 6.

Step 4. Rank outcomes in each cluster and set the best one as cluster center.

Step 5. New Node Generation:

i. With probability Pro1, replace the selected clusters with randomly generated nodes.

ii. With probability Pro2, randomly pick a cluster; otherwise pick two clusters.

iii. With probability Pro3, pick the cluster center(s) and go to (iv); otherwise chose other nodes from the previously selected clusters; those node(s) represent the old nodes

iv. Generate new node using equation 1; then go to Step v.

v. Evaluate the newly initiated nodes and the old ones; then elect the best node to replace the old one, if any.

vi. If p nodes are updated, go to step 6; otherwise, go to (i).

Step 6. If the current number of iterations $< I_{max}$, go to Step 3.

Step 7. Evaluate the current solutions and then terminate.

The energy model considered in [11, 12] has the function of calculating energy loss of all other sensor nodes in the network. The two channel propagation models used are the free space (d^2 power loss) for direct transmission and the multipath fading channel (d^4 power loss) for packet transmission via multihop. Therefore, the energy drained for this transmission with l-bit packet over distanced d is calculated as:

$$E_{Tx}(L,d) = \begin{cases} L \cdot E_{elec} + L \cdot \varepsilon_{fs} d^2, & d < d_0 \\ L \cdot E_{elec} + L \cdot \varepsilon_{mp} d^4, & d \ge d_0 \end{cases} \quad (8)$$

where ε_{fs} is free space energy loss, ε_{mp} is multipath energy loss, d is distance between source node and destination node, and d_0 is the threshold distance:

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (9)$$

The energy spent for the radio to receive this message is found in equation (10) where E_{elec} implies the energy dissipated per bit to run the transmitter or the receiver circuit. It is influenced by factors like filtering, modulation, digital coding and spreading of the signal.

$$E_{RX}(L,d) = L \cdot E_{elec} \quad (10)$$

5. Simulation and Results

For performance evaluation, the simulations were carried out using Matlab and specific intervals were given for individual plots. In this paper, the residual energy of the network, data packets received at BS, and the number of alive nodes are taken into consideration. It is compared with the BSO-LEACH algorithm and the traditional LEACH algorithm.

BSO Parameters	Value	LEACH Parameters	Value
Deployment Size	$100m * 100m$	Node deployment	Random
Total Nodes	100	BS Location	$50 * 50$
Number of iterations	200	Initial Energy	1J
Number of ideas	50	Packet size	500bytes
Number of clusters	5	d_o	30m
Prob. of renewing the cluster center,Pro1	0.4	E_{elec}	50nJ/bit
Prob. of choosing one center,Pro2	0.4	ε_{fs}	$10pJ/bit/m^2$
Prob. of picking the cluster center,Pro3	0.2	ε_{mp}	$0.0013pJ/bit/m^4$

Table 1. Node distribution Parameters

Figure 4 displays the residual energy versus number of iterations for the LEACH and BSO-LEACH protocols. The two protocols showed a steady fall of energy, but LEACH has a consistent decrease with the number of iterations until iteration 180 because it maintains the same members in each cluster and a new CC is selected only if the current one

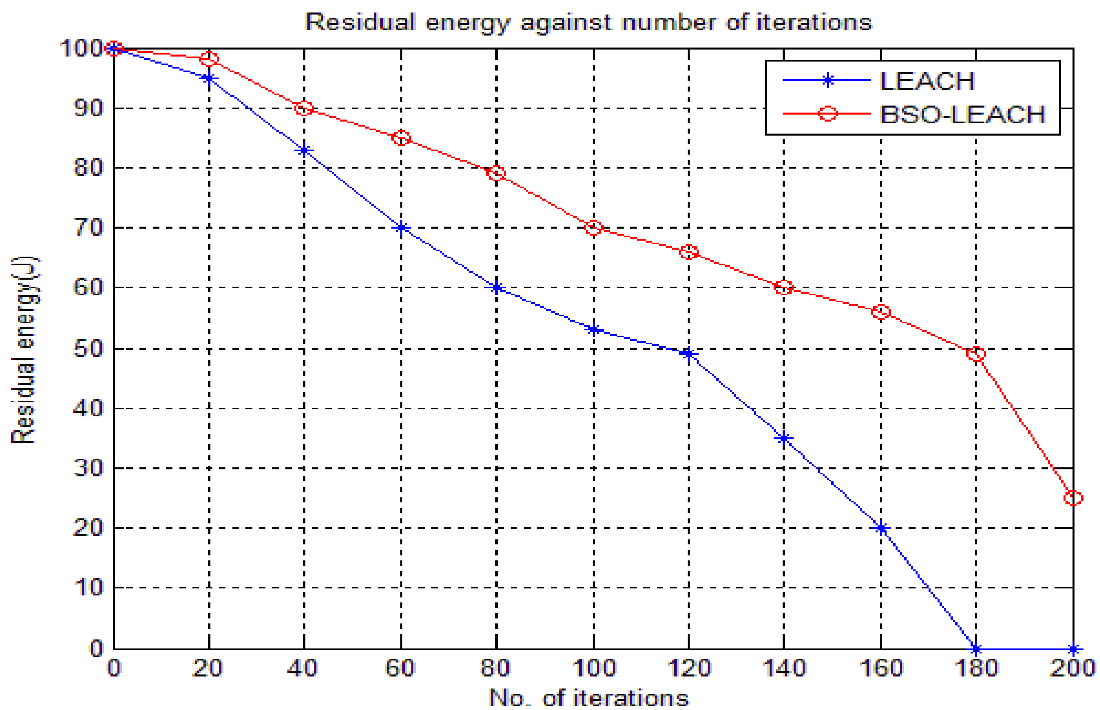

Fig 4: Residual energy against number of iterations

ran out of energy, unlike the BSO-LEACH which usually change the clusters. This difference leads to more control packets, therefore it can be concluded that more energy is consumed on the part of LEACH. When comparing LEACH and BSO-LEACH, we show that LEACH consumes more energy than BSO-LEACH because more data is sent to the BS and massive amount of control packets especially to discover the CCs.

In figure 5, the graph shows amount of data received at the base station against the number of iterations. The simulations show that LEACH and BSO-LEACH have more data delivery to BS, especially BSO-LEACH due to good cluster formation in the network, which ends up delivering more data to the base station. On the other hand, LEACH and BSO-LEACH protocols deliver almost the same amount of data during the initial steps up to iteration 40 because both usually reutilizes the clusters with the same members, so the same data delivery was set in each iteration. On the contrary, it is generally known that network lifetime can be extended to the paramount value by minimizing the energy consumption as much as possible. Therefore, the BSO-LEACH is measured to be better than the LEACH protocol.

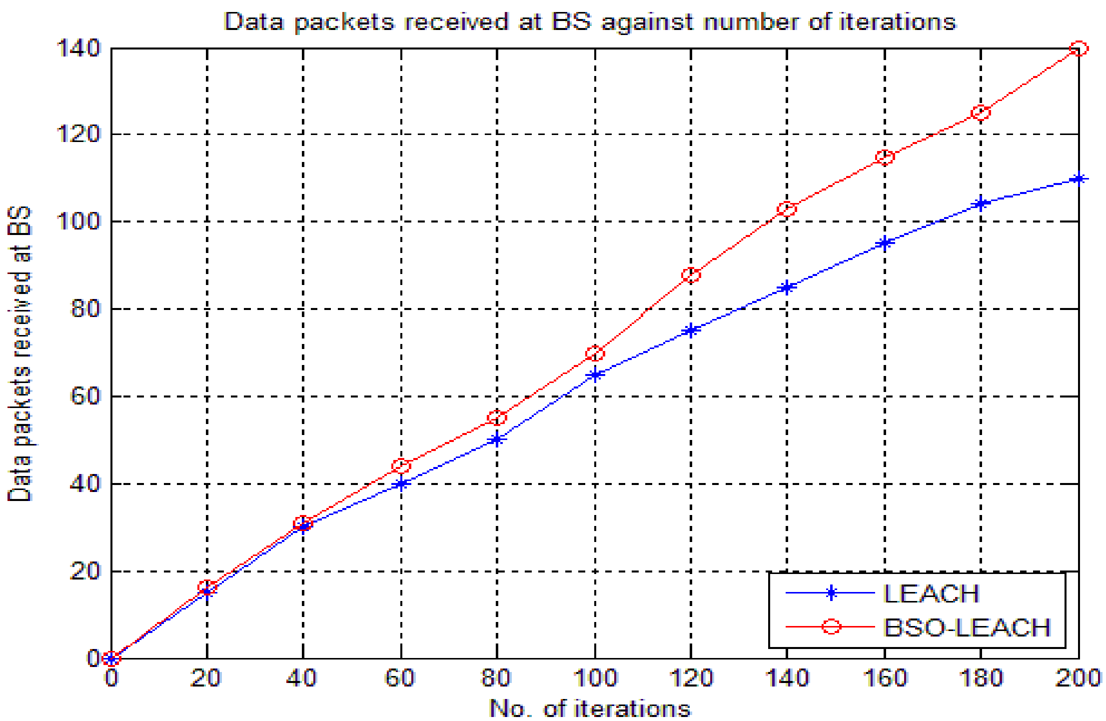

Fig 5: Data packets received at BS against number of iterations

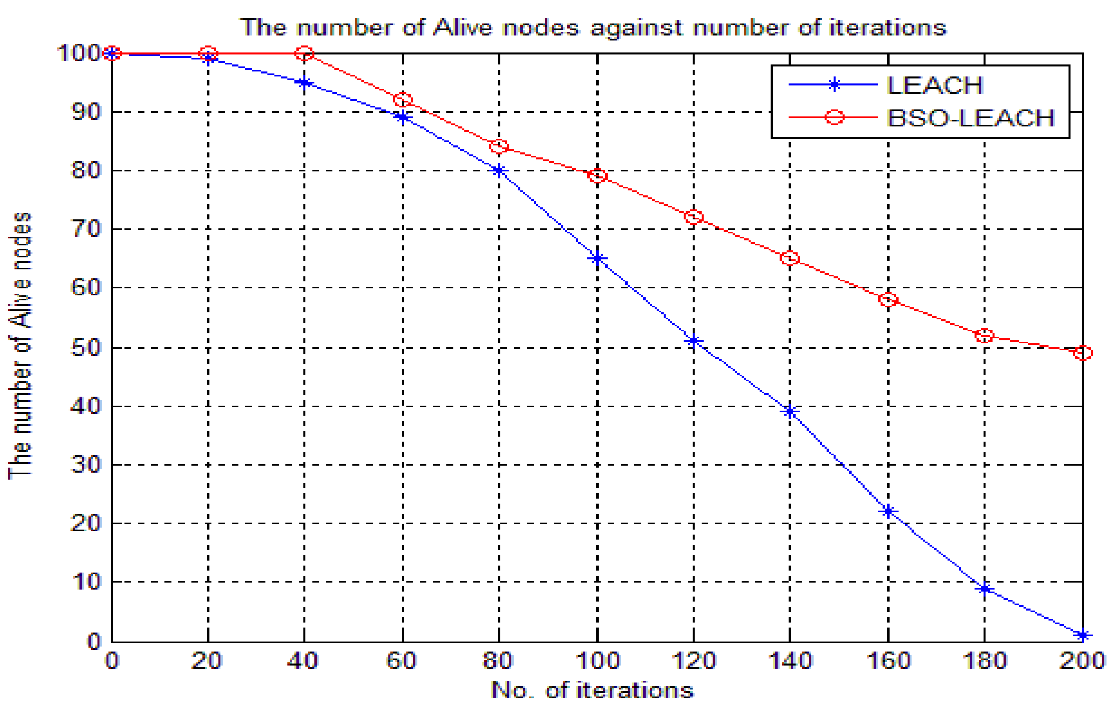

Fig 6: The number of alive nodes against number of iterations

Figure 6 presents the number of nodes that remain alive over the number of iterations. We observed that after the first 20 iterations the number of live nodes for LEACH protocols decrease because it has not changed the CC only after it runs out of energy. Due to the way of CCs selection and the aggregation of data delivered, BSO-LEACH protocol shows decrease suddenly after 40 iterations as compared to the LEACH protocol. Apart from the BSO-LEACH, we can realize that there is immediate loss of nodes when half of the nodes are already not alive.

6. Conclusion

This paper compares LEACH protocol and BSO-LEACH protocol considering their cluster formation and cluster center formation. Here, the BSO algorithm and the normal LEACH algorithm were used to solve energy saving problems in WSNs. After continues cluster center replacement, the energy of the node falls to minimum limit. The BSO-LEACH algorithm efficiently helped in saving the nodes energy in each iteration for a longer lifetime. Therefore, the cluster center with higher energy connects better to the base station. During the very last cluster center replacement, the energy of the entire network drops to a certain point. At the end, it was seen that the BSO-LEACH algorithm performed a little actively than the traditional LEACH algorithm.

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