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Performance Analysis of Wireless Sensor Network by Variation in Cluster Head Selection through mLEACH-CS Algorithm

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Abstract: The energy depletion at the nodes due to large volume of data transmission and data reception for large scale Wireless Sensor Networks (WSN) is one of the important areas of concern. Unbalanced energy consumption due to data traffic overhead at the nodes near the base station (BS) results in early node death and reduction in network lifetime. To balance the load at the wireless nodes during clustering, a novel hybrid clustering and routing protocol has been proposed based on mLEACH (modified Low-Energy Adaptive Clustering Hierarchy) and Cuckoo Search (CS) algorithm. Initially, mLEACH protocol is utilized to solve a novel equation designed to select the cluster heads by rotation at every round of data transmission based on the maximum permissible cluster heads in the network. In the second phase, CS algorithm is implemented for uniform distribution of the cluster heads in the network for efficient multi-hop data routing in the network based on several weighted factors. The performance of the proposed algorithm is compared with other algorithms in literature in terms of energy consumption and network lifetime for different positions of the base station and varied number of cluster heads in the model application area. The proposed mLEACH-CS algorithm shows a significant improvement by 60% considering 300 nodes in the WSN architecture while it decreased to 40% for denser network architecture. Optimal choice of the number and position of the cluster heads in certain network architecture has proved beneficial for designing an energy efficient wireless network with improved network lifetime.

Keywords: Cluster Head Selection; Cuckoo Search Algorithm; Energy Consumption; modified Low-Energy Adaptive Clustering Hierarchy protocol; Network Lifetime; Wireless Sensor Network.

I. INTRODUCTION

The wireless network frequently finds its application in some remote and hostile environments where replacement of the battery sources becomes impossible and the sensor node energy becomes a constraint. Therefore, limited energy usage by the sensor nodes during data transmission and data reception needs to be looked into for development of large scale WSNs. One of the most effective techniques which have been employed in recent wireless applications has been clustering of sensor nodes which help to conserve the energy of the sensor nodes [1]. The entire set of wireless nodes deployed in the application area is divided into several groups known as clusters. Out of the all the nodes in a cluster, one of the nodes is chosen as a cluster head (CH) which collects the data from all the nearby cluster members (CM), aggregate the data and transmit it to be processed in the remote base station. The transmission can take place directly from the cluster head to the base station or through other intermediate cluster heads if the base station is located at some distance. The final data for the monitored event is displayed after processing at the base station where a model prototype of the entire process is recreated. This document is a template. For questions on paper guidelines, please contact us via e-mail. In the view of this, it was found that one of the most popular and energy efficient method for clustering of sensor nodes was proposed by Heinzelman et al. known as Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [2]. In this approach, several nodes were grouped into a single cluster and the cluster head for each round of data transmission was chosen by rotation. This attempt helped to conserve the energy of the nodes and the load was shared between all the cluster members. Each CH was assigned the responsibility for collection of data from each of its cluster member (CM) and transmitted the data to the sink node either directly or through multi-hop communication via other CHs. But selection of optimal number of sensor nodes as CHs and their positioning in the network is a very challenging process. The optimal node placement is important since it helps to address important issues such as minimal energy consumption, coverage of the entire application area and least number of signal overlaps.

Younis et.al on the other hand proposed HEED (Hybrid Energy Efficient Distributed clustering) protocol which periodically selected cluster heads based on residual energy of the nodes [3].

This algorithm considered multiple power level of the sensor nodes and accordingly divided the CHs and the CMs into some hierarchical levels for data transmission. However, this approach could design only two-level hierarchy for the entire network and multi-level hierarchies were not supported. An Energy-Efficient and Power Aware (EEPA) routing algorithm was proposed by researchers in a later work which presented a new energy-efficient dynamic clustering technique. In this approach, each node estimated the probability of itself becoming a cluster head by calculating the strength of the received signal power from the active neighbour nodes [4]. The limitation to these approaches was that no assumptions were made related to the node capabilities, power support or presence of other infrastructures in the periphery of the network leading to interference. The selection of 'm' cluster heads from 'n' sensor nodes was found out to be a non-deterministic polynomial-time hard (NP-hard) problem where the position and number of cluster heads changed for every successive rounds of data transmission [5]. In order to reduce the complexity of this type of non-polynomial problems, various nature inspired meta-heuristic algorithms was utilised for providing efficient solutions regarding placement of cluster heads.

A detailed study on the various classical and swarm intelligence-based clustering approaches proved that a significant improvement in energy savings of the sensor nodes can be obtained [6]. This has prompted the use of several nature inspired meta-heuristic algorithm in the last decade or two in the domain of clustering and routing for wireless sensor networks. Several novel soft computation algorithms have been designed recently such as fish electrolocation optimization which can be later utilised in the domain of optimization of routing path in wireless networks [7]. Centralized LEACH (LEACH-C) was one of the earliest applications of meta-heuristic algorithm-based clustering approach [8]. In this approach, all the sensor nodes initially sent the information about its location and energy to the sink node where simulated annealing based meta-heuristic algorithm is applied to determine the optimal clusters. The node having greater energy than average energy of all the other sensor nodes was elected as the cluster head. But, in this approach there was a greater probability that the elected CH may be far away from the BS as this approach had considered only the energy level of the sensor nodes while selecting CH. More the distance between the CH and the BS resulted in consumption of more energy during data communication between CH and BS. However, LEACH-C performed better than LEACH algorithm in terms of energy consumption and packet delivery ratio [8]. In a later work, Abbas et.al proposed a fuzzy logic and chaotic based genetic algorithm (FLCGA) for cluster head selection process [9]. However, this approach did not consider balanced energy consumption during formation of clusters. A differential evolution-based clustering protocol for wireless networks was proposed in a later work where the objective function was designed based on energy consumption and network lifetime [10]. However, this approach did not focus on uniform distribution of CHs over the entire network, thereby causing unbalanced energy consumption in WSN. In a later work, a clustering approach based on Particle Swarm Optimization (PSO) called enhanced optimized energy efficient routing protocol (E-OEERP) was designed which focused on the left out nodes as one of the members of the cluster [11]. The selection of the CHs through this approach was done considering the distances between the CHS and the base station. This protocol suffered the problem of non-uniform CH distribution resulting in unbalanced energy consumption since all the nodes chosen as CHs were placed near the base station. The routing of data between the CH and the BS was designed through gravitational search algorithm. An unequal clustering protocol based on fuzzy algorithm was proposed in a recent work which considered residual energy of the nodes and the distance between the sensor nodes and the base station as the two input parameters [12]. In a recent work, Rao et.al proposed a clustering protocol based on novel chemical reaction optimization (nCRO) algorithm [13]. Distance between CH and sink, residual energy, and intra-cluster distance were the various parameters that primarily designed the fitness function for application of nCRO. However, non-uniform distribution of the CHs resulted in the energy hole problem. To conserve the energy during transmission of data, a cluste- based energy-efficient data forwarding scheme was designed initially which ensured that even if multiple nodes in a cluster received a data packet, only one node amongst them was elected to send back an acknowledgment signal [14]. This node was elected based on binary exponential back-off algorithm. Another work based on Cascaded Cuckoo Search Algorithm was employed to find the best intermediate positions of the routers to enhance the reliability of the network [15]. Signal attenuation, energy consumption and packet error ratio were the parameters given utmost importance to establish the efficiency of the algorithm. However, recent attempts have focused on simultaneous utilization of clustering and routing algorithm to eliminate the problems related to non-uniform energy consumption and limited network lifetime.

In this work, a modified version of the conventional LEACH protocol, named as modified Low Energy Adaptive Clustering Hierarchy (mLEACH) protocol has been used in unison with a meta-heuristic algorithm known as Cuckoo Search (CS) Algorithm. This hybrid integration of the two algorithms aims at joint optimization of clustering and routing mechanism in the network. Maximum number of nodes eligible to become cluster heads are pre fixed for various number of sensor node deployment scenario in a wireless sensor network.

The position of the cluster heads are selected at every round of data transmission so that a reliable path is established at every round of data transmission. The uniform distribution of the cluster heads ensure that no sensor node is being left out from monitoring and neither there is overlap of signals in any particular cluster head. The overall estimation of the network energy proves reduced energy consumption in the network thereby increasing the lifetime of the network. The results obtained through the proposed approach prove that the attempt to use the node, with maximum residual energy and superior connectivity with all other nodes, as the cluster head helps to eradicate the energy-hole problem related to uneven distribution of cluster heads. The energy consumption is generally high amongst the cluster heads near the base station which needs to handle data from all the nodes and needs to store in the base station. The distribution of the role of cluster head amongst the nodes is therefore important to manage the energy consumption of the network. Considerable amount of improvement in respect to energy consumption and lifetime of the network can be observed compared to the previous works. Performance of the network for diverse number of cluster head deployment and varied sink positions has also been studied which gives an idea about the best network design. Therefore, the main novel contributions of this work have been summarized as follows:

1) Cuckoo Search and modified LEACH algorithm has been co-utilized in this application to jointly optimize the cluster head position and the routing path.
2) mLEACH algorithm aims to select the cluster heads based on residual energy of the nodes and at every round the cluster heads are chosen by rotation. The maximum permissible cluster heads in each round of data transmission has been fixed. Thereby, a novel equation has been proposed for selection of cluster heads through mLEACH algorithm.
3) A novel linear fitness function has been designed based on sink to source distance, the residual energy of the nodes and the highest degree of coverage with minimum signal overlap for optimal positioning of cluster heads to be solved by Cuckoo Search Algorithm.
4) It has been taken care that a proficient multi-hop routing path is created through a number of cluster heads which is well within the pre-specified limit.
5) The performance of the proposed algorithm has been studied for different number of cluster heads and varied base station positions. A comparison of the obtained results has also been done with some classical clustering techniques and some latest proposed protocols found in literature which yields better results.

The rest of the paper has been organized as follows: A brief description of the energy modeling and the problem formulated for this model has been discussed in Section II. Section III discusses the working for the joint optimization through this proposed mLEACH-CS protocol. All the results for the different scenarios and different base station positions and the comparative results with other works in literature have been presented in Section IV. Section V concludes the entire work and gives the scopes for further enhancement of this work in the future.

II. SYSTEM MODEL

A model two-dimensional area of pre-specified size of 200×200 m^2 is selected where a set of nodes to be randomly deployed has been pre specified. For simulation purpose and to find out the best position of the control station for maximum data capture, the sink node or the base station (BS) has been fixed at three different co-ordinates for three different case studies. The three different case studies undertaken here consider the BS to be placed at the centre of the network, at the corner of the network and outside the network respectively.

The sink node or the base station (BS) stores all the data collected from the different cluster heads in the control station and evaluates the performance of the process whose parameters are being measured. The sink node is considered to be an energy rich node and it can easily remain connected to all the nodes which are in the range of the sink node. Therefore, fixing the position of the sink node is also equally important when considering only one sink node in the entire network. The cluster heads are assigned to perform the duties of data collection, data aggregation and data transmission and the energy of these cluster heads need to be managed. Minimum threshold energy is the energy required for the nodes to perform the operation of data transmission and whenever the initial energy of the nodes comes below the threshold energy, the nodes stop to operate. The nodes having high residual energy are selected as cluster heads by rotation at every round of data transmission. In this approach, an integrated approach has been undertaken to select the best nodes as cluster heads and their position in the network has been optimally decided so that the data is efficiently transmitted from the sensor nodes to the base station by the help of the cluster heads. The choice of the cluster heads is dependent on the average distance of transmission between the sensor node and base station, the residual energy of the nodes, the optimal number of cluster heads that can be placed, number of nodes in each cluster and maximum network coverage.

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In the process, it becomes necessary to study the energy modelling of the nodes which is dependent on the transmission energy, reception energy and energy required for data aggregation.

A. Energy Model

This work has adopted the energy model of the entire system as proposed by Heinzelman et al. [2, 8] which is entirely dependent on the data aggregation energy, the size of the data packets and the distance between the sensor and receiver node. The total energy consumption of a cluster head while transmission of data, E_{TX}, is calculated and given by Eq. (1) [2, 8] as:

$$E_{TX}(i) = \sum_{k=1}^{n} \begin{cases} l \times E_{elec} + l \times \varepsilon_{fs} \times {d_k}^2, & if\ d < d_0 \\ l \times E_{elec} + l \times \varepsilon_{mp} \times {d_k}^4, & if\ d \geq d_0 \end{cases} \qquad (1)$$

Here, E_{elec} represents the energy required during data aggregation at the cluster heads, l represents the number of bits in a data packet being sent, n represents the number of nodes to which the cluster head is connected and d_k is the distance between the cluster head and k^{th} sensor node acting as its receiver. The total energy consumed in the process of transmission is calculated as the summation of energy required for data transmission to individual nodes. The amplification co-efficient of the transmission amplifier in free space is given by ε_{fs} and ε_{mp} is the amplification co-efficient of the transmission amplifier during multi-path transmission. The maximum transmission distance for each sensor node is represented by d_0 and its value is generally equal to $\sqrt{(\varepsilon_{fs}/\varepsilon_{mp})}$ [2]. The amount of energy required for receiving l bits at the cluster head is given by E_{RX} and is represented by Eq. (2) [2]:

$$E_{RX}(i) = l \times E_{elec} \qquad (2)$$

The total energy consumed in the wireless network is the summation of the transmission energy and the receiving energy at every node. The total residual energy of the network is obtained by subtracting the total energy consumption of the nodes from the initial total energy of the network. In this work, all the nodes initially deployed in the network are assumed to have same initial energy. The available residual energy of any particular node is calculated by subtracting the energy required for transmission and reception of data determined by Eq. (1) and Eq. (2) from the initial energy of that particular node. Based on the residual energy, distance of transmission of data and cluster size depending on the number of nodes in a cluster, a weighted multi objective multi-dimensional fitness function is designed to solve the problem of optimal router placement in wireless networks.

B. Multi-Objective Fitness Function For Clustering

The best set of optimal positions of the CHs are determined by designing a multi-objective fitness based on residual node energy, degree of node, average distance between sensor node and the base station and maximum network coverage with minimum overlap. The equations related to some of the defining factors such as energy management, node degree, intra cluster distance and network coverage have been found from literature while the equations related to other factors have been designed for this particular problem. Energy management at the cluster heads is necessary since these nodes take up the extra responsibility of data aggregation. So, residual energy of the node needs to be maximum to make itself available as the cluster head for data routing. Energy Management, represented by $Node_{energy}$ in Eq. (3) is one of the functions that needs to minimized to determine the best position of the cluster head [16].

$$Node_{energy} = \sum_{i=1}^{m} \frac{1}{E_{CH_i}} \qquad (3)$$

Here E_{CH_i} is residual energy of the i^{th} CH determined by subtracting the energy consumed from the initial energy of the nodes. The number of CHs in each round of data transmission is represented by $m$which is the sum of the nodes satisfying Eq. (3) and have been elected as the cluster head for that round. The maximum number of cluster heads for a certain deployment has been pre-fixed is represented by m_{max}. The second factor, Node Degree, N_{degree}, determines the number of sensor nodes that can be a member of the cluster for a certain cluster head selected in a certain round of data transmission. Minimization of this parameter helps to balance the data overhead in each of the cluster heads. The parameter, N_{degree}, is determined by help of Eq. (4) [16]:

$$N_{degree} = \sum_{i=1}^{m} |CM_i| \qquad (4)$$

Here, $|CM_i|$ is the number of cluster members of the $i^{th}CH$ in a certain data transmission round and m is the number of CHs in that round of data transmission. The average distance between each of the members in the cluster and the cluster heads are determined after the number of nodes present in the cluster has been determined. This is termed as the intra-cluster distance and this helps to maximize the link quality between the nodes and the cluster head. The equation for intra-cluster distance ($D_{intra-cluster}$) is given as Eq. (5) [16]:

$$D_{intra-cluster} = \sum_{j=1}^{m} \left[\frac{\sum_{i=1}^{|CM_j|} d(CH_j, CM_i)}{|CM_i|} \right] \quad (5)$$

Here, $d(CH_j, CM_i)$ is the Euclidean distance between j^{th} CH and the $i^{th} CM$ and CM_i is the number of cluster members of the $i^{th} CH$ in a certain data transmission round. The distance between the cluster head and the sink node is determined in the next step by a factor named $(D_{cluster-sink})$ which is also based on simple concepts of co-ordinate geometry and is given by Eq. (6) as follows [17]:

$$D_{cluster-sink} = \sum_{i=1}^{m} [(\sqrt{\{(x_i - x_j)^2 + (y_i - y_j)^2\}})] \quad (6)$$

In the above equation, (x_i, y_i) represents the co-ordinates of the cluster heads, (x_j, y_j) represents the co-ordinate of the sink node which is fixed in this problem and m is the number of cluster heads determined in each round of data transmission. In the scenario, that the BS is placed at a faraway distance from the cluster head and is not within the transmission range of the node, a multi-hop routing path is chosen to transmit the data to the base station by data hopping between the cluster heads. To choose an optimal pathway determination of the distances between the cluster heads become necessary to choose the intermediate cluster heads in the data pathway. The average distance between the cluster heads is termed as inter-cluster distance of the cluster heads $(D_{inter-cluster})$ and the equation for inter-cluster distance $(D_{inter-cluster})$ is given by Eq. (7):

$$D_{inter-cluster} = \frac{\sum_{i=1}^{m} d(CH_{i+1}, CH_i)}{m} \quad (7)$$

Here, $d(CH_{i+1}, CH_i)$ is the Euclidean distance between $(i+1)^{th} CH$ and the ith CH and m is the number of cluster heads determined in each round of data transmission. The average distance between the sensor node and the base station is defined as the sum of the total distances between the node and the base station to the number of nodes in the network. This factor helps to ensure that the energy consumption for data transmission over a certain distance remains almost equal for all the selected cluster heads. Minimization of this parameter is necessary to minimize the number of hops in the network and ensure proper communication links. This factor is represented by D_{avg} and is given by Eq. (8) as [16]:

$$D_{avg} = \sum_{j=1}^{m} \frac{1}{N_j} \times (D_{intra-cluster} + D_{inter-cluster} + D_{cluster-sink}) \quad (8)$$

HereN_i, represents the number of sensor nodes in the *'j'thcluster* and *m* represents the number of cluster heads and number of clusters. All other variables have the same meaning as expressed above. The coverage of the entire area of application is one of the main aims of designing any cluster based wireless sensor network so that no sensor node is left out to become a part of the clusters or no sensor node becomes part of two clusters creating signal overlap in the network. To ensure interference free participation of all the nodes and no left out nodes in the network, a parameter termed as Network Coverage (NC) is evaluated as given in Eq. (9) below [16]:

$$NC = \frac{(N-m) - \sum_{j=1}^{m} |CM_u + CM_o|}{\sum_{j=1}^{m} |CM_j|} \quad (9)$$

Here, N is the total number of sensor nodes, $m$is number of CHs and $|CM_j|$ represents number of nodes in the jth cluster. The number of uncovered or left out nodes is given by $|CM_u|$and the number of nodes suffering overlap being part of two clusters is being represented by$|CM_o|$. Based on the above criterions, the final multi-dimensional objective function (*F*) is designed which a weighted sum of all the above parameters as expressed below in Eq. (10) as:

$$F = w_1 \times Node_{energy} + w_2 \times Node_{degree} + w_3 \times D_{avg} + w_4 \times NC \quad (10)$$

Here, w_1, w_2, w_3, $w_4$are the weight factors associated with each of the factors determining the optimal placement of the cluster heads. The weight factors are chosen based on the importance of the individual functions that make up the objective function. For this problem, energy management is the most important function that determines the position of the cluster head in the network. Proper selection and positioning of cluster heads based on the residual energy of the nodes would ensure that the network is active for the longest duration. Therefore, the weight factor w_1 has the highest value among all the other factors while the other weight factors are comparable. The minimization of this linear multi-objective fitness function is subjected to the constraint equations given by Eq. (11), (12), (13), (14) and (15) as follows:

$$Node_{energy} > E_{th} \quad (11)$$

$$m \leq M_c \quad (12)$$

$$Node_{degree} \leq N \quad (13)$$

$$D_{intra-cluster}, D_{inter-cluster}, D_{cluster-sink}, D_{avg} \leq d_0 \quad (14)$$

$$w_1 + w_2 + w_3 + w_4 = 1; \; w_1, w_2, w_3, w_4 \,\epsilon\, (0,1) \quad (15)$$

Here, E_{th} is the minimum threshold energy required for a node to perform; M_c is the maximum number of permissible cluster heads in the network, N is the maximum number of nodes employed in the network and d_0 represents the maximum transmission distance for each sensor node. All other symbols carry the similar meaning as stated previously. Cluster formation process starts after selection of the optimal position of cluster heads and the routing path is determined by help of the position of the routers. An integrated algorithm based on two well known classical algorithms namely CS and LEACH algorithm has been used for optimal positioning of cluster heads and multi-hop data transmission from the source to the sink nodes. Being simple to use and due to its quick convergence rate, Cuckoo Search Optimization has been currently in use in engineering optimization problems. Low Energy Adaptive Clustering Hierarchy (LEACH) protocol has been one of the primarily designed algorithms for clustering approach in the wireless sensor network. In this work, it ensures cluster head determination by rotation in every round of data transmission depending on the residual energy of the nodes. The hybridization of these two algorithms, named as (mLEACH-CS) algorithm, in this work has helped to provide an integrated solution for clustering and routing path determination in the wireless sensor network.

III. PROPOSED SOLUTION METHODOLOGY

The fitness function designed based on the number of nodes in a cluster, the residual energy of the nodes, the distance between the sensor and base station and the maximum network coverage is solved by the modified Cuckoo Search-LEACH algorithm in two phases. In the first phase, the nodes eligible to become CHs is determined by a designed novel function and solved by the LEACH algorithm. In the second phase, Cuckoo Search minimizes the fitness function and helps in optimizing the position of the cluster heads to create a reliable routing path from the sensor node to the sink node. The proposed solution methodology has been therefore divided into two steps which have been discussed in the following sub sections.

LEACH (Low-Energy Adaptive Clustering Hierarchy) algorithm was a clustering-based protocol proposed by Heinzelman et.al in 2000 [2]. This network helps to elect the cluster heads by random rotation at every round of data transmission to distribute the energy load among all the sensors. The designed LEACH algorithm proved that almost 1/8th of the energy could be saved during data transmission and reception in wireless sensor network through the clustering approach adopted in LEACH algorithm. This concept of rotation of cluster heads in the network for each round of data transmission helps to eliminate the energy dissipation in the network and improve the rounds of data transmission. The steps of LEACH algorithm as utilized in this work has been discussed in details below [2]:

1) In the first phase, known as the Advertisement Phase, each of the nodes decide whether or not it wants to become a cluster head for the current round by choosing a random number between 0 and 1. If this number is less than the threshold number, then the node is allowed to become the cluster head for that round of data transmission. The primary equation involving LEACH algorithm to calculate the threshold number has been taken from literature and has been expressed in Eq. (16).

$$T(n) = \begin{cases} \frac{P}{1-P\times(r mod \frac{1}{P})} & if n \epsilon G \\ 0 & otherwise \end{cases} \quad (16)$$

The number of nodes to be elected as cluster head has been pre-specified through the newly modeled equation. The maximum number of permissible cluster heads to be chosen has been fixed initially which helps to control the energy usage in the network. The previously designed equation found in literature [8] has been therefore remodeled through this equation given in Eq. (17) for this problem to choose the cluster heads of the network.

$$\text{For i=1 to n;} \quad \mathrm{T}(n) = \begin{cases} \frac{p\times m_c \times N}{1-p\times(r \; mod \; \frac{1}{m_c})} & if \; n \; \epsilon \; G \\ 0 & otherwise \end{cases} \quad (17)$$

In the above equation, the decision is made by the nodes whether or not it wants to become a cluster-head for a certain cluster in the current round by the help of the threshold value given by *T (n)*. Every node chooses a random number between 0 and 1 and if the chosen number is less than *T (n)*, then the corresponding node becomes Cluster-Head (CH) for that particular round. Here, n is the number of nodes, m_c is the fraction of the nodes that are maximum permissible cluster head, p is the probability of a node to become cluster head and r is the current data transmission round number. The available energy of the i^{th} node is given by $E(i)$ and G is the set of nodes that have not been cluster-heads in the last $1/p$ rounds. In this work, the value of p is chosen to be 0.1 and m_c is chosen to be 0.05 or 0.1 for different case studies.

2) In the cluster set-up phase, the other nodes available in the network receive signal from the cluster heads so that they can decide to which cluster it wants to belong. The nodes of that particular cluster send their data to their cluster head for transmission of their data to the sink node.
3) In the next phase, known as Schedule Creation Phase, the collection of data is done from all the nearby nodes thereby the chance of data collision is reduced.
4) The cluster members send their data to the cluster head and the active nodes in the network continue the data transmission thereby conserving the residual energy.
5) Multiple clusters are formed in the process which tries to transmit data simultaneously to the sink node resulting in channel interference. Depending on the residual energy of the clusters, different channels are created to transmit the data without getting lost.
6) The clustering takes place in every level of data transmission where the cluster-head nodes form a cluster among them and select a cluster head among that cluster known as "super-cluster head" node following Step 1. In this way, through clustering at every hierarchical level, data is transmitted from the sensor nodes to the base station.

The nodes to be elected as cluster heads and super cluster heads are decided by this newly designed formulation of LEACH algorithm. In the next phase this role of the cluster heads are rotated amongst the other nodes and their position in the network are elected through Cuckoo Search Algorithm. The objective function is resolved by help of Cuckoo Search algorithm to find the best position of the cluster heads by optimizing the designed multi-objective fitness function. The entire flowchart of the solution methodology is enumerated below for proper selection of the cluster heads and forming an energy efficient architecture.

Fig. 1 represents the integrated implementation of the Cuckoo Search and LEACH algorithm for solving the current problem of the wireless sensor network. For this algorithm, initially the number of nodes, *N*, has been taken to be 300 and the number of cluster heads has been taken to be 5% or 10% of the sensor nodes. The number of iterations has been chosen to be 5000 to calculate the energy consumption of the network according to the scenario chosen and the result is compared with the other existing algorithms [18]. The number of host nests has been chosen to be 50 and the nest discard probability is taken as 0.25 for the best-case result. The entire simulation program has been developed by designing a program in MATLAB 13 platform [19]. The simulation results have been obtained for different scenarios which are created by changing the placement of the base station, for varied number of nodes in the network and by variation in the number of cluster heads in the network. A detailed report of the different parameters such as network energy consumption and the network lifetime and comparison of the results with previous works in literature presents the superiority of the proposed algorithm.

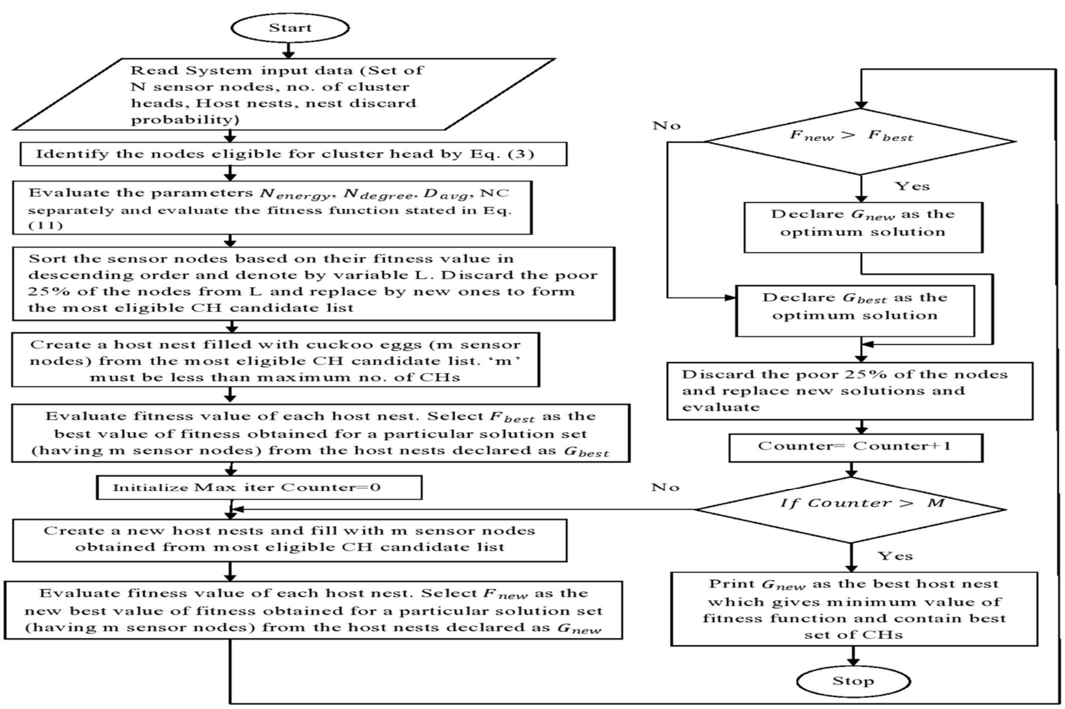

Fig. 1 The integrated MLEACH-CS algorithm

IV. RESULTS AND DISCUSSION

The main determining parameters to evaluate the efficiency of the network designed through mLEACH-CS algorithms have been network lifetime and energy consumption in the network. The round for Last Node Death (LND) or last round of data transmission gives the account of the network lifetime after which the communication in the network comes to a complete stand still. This last node death refers to the point after which no further data communication is possible and the network has become inactive. Therefore, exhaustion of residual energy of the nodes and the last node death of the network provides information about the lifetime of the network. Previous works in literature has also undertaken these two parameters as the standard for estimation of network lifetime. Higher the number of rounds for LND ensures that the entire lifetime of the network is improved. The energy consumption of the network is a joint sum of the energy required during data transmission, data reception and data aggregation in the cluster heads of the network. Lower the energy consumption in the network leads to increase in residual energy of the nodes which can be reutilized as cluster heads in further rounds of data transmission. This approach helps to distribute the load amongst all the nodes equally and thereby the communication links with every other node for longer durations is assured. Uniform deployment of the nodes has been considered in a square sensing area of dimension 200×200 m^2. Table I represents the initial parametric settings used for network analysis [20]. The input values for all the parameters considered for finding the best solution through the mLEACH-CS algorithm has been depicted in details. The number of cluster heads is considered to be 5%-10% of the total number of nodes deployed in the network. This is chosen so that the network does not become overcrowded with cluster heads which may actually hamper the objective of energy efficient clustering and lifetime enhancement. Moreover the nodes working as cluster heads are programmed to handle data from 10 to 20 cluster members to ensure that the memory handling capacity of these cluster heads is not exceeded. The values of the weight factors (w_1,w_2,w_3,w_4) are decided on trial and error method and it has been found that the best case solution for optimal positioning of the cluster heads are found for these values. While determining the values of the weight factors it was kept in mind that the highest weightage was given to w_1. The other values were decided according to the importance of the corresponding factors and in that order.

TABLE I
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Parameter	Value
No. of nodes (N)	300– 700
Size of the Network	200*200 m^2
Base Station Location	Centre (100, 100) Corner (200, 200) Out of field (300,300)
E_{elec} (Data Aggregation Energy)	50nJ/bit/round
ε_{fs} (amplification co-efficient in free space)	10pJ/bit/m^2
ε_{mp} (amplification co-efficient for multi-path transmission)	0.0013pJ/bit/m^4
Initial Energy	2J
Packet Size	4000bits
No. of Cluster Heads (M_c)	5% or 10% of N
Number of Iterations	5000
Number of Host nests	50
Nest Discard Probability	0.25
Weight Factors (w_1,w_2,w_3,w_4)	0.4,0.15,0.2,0.25

The evaluation of the network performance and analysis of the results using mLEACH-CS algorithm for different scenarios of wireless network implementation has been presented here. Comparative results with other algorithms for energy consumption and network lifetime for different positions of base station and varied number of node deployments have been obtained.

A. *Performance Evaluation of Network Energy Consumption for varied number of cluster heads for BS at 100×100 location*

The total energy consumption of a network is calculated based on the energy required for collection of data by the cluster heads, energy required for data aggregation and the transmission and reception energy at every nodes of the network. The total network energy consumed for routing the data from the deployed nodes to the BS increases with increase in number of rounds of data transmission.

The nodes finally stop communicating the data when the residual energy of node becomes less than the threshold energy required for the nodes to operate. To study the performance of the network, four different sensor node deployments in the same application area have been considered. The four different WSN network structures have been named WSN-1, WSN-2, WSN-3 and WSN-4 and the number of sensor nodes have been considered to be 300, 400, 500 and 700 respectively in these four structures. Here, WSN-1 represents dispersed sensor network architecture while WSN-4 represents dense sensor network architecture. The number of cluster heads has been varied from 5% of the nodes to 10% of the nodes in the considered scenarios. The performance of the algorithm was studied for different positions of the base station to validate the superiority of this algorithm. Firstly, the algorithm has been run for comparing the total energy consumption of the network with other existing algorithms namely LEACH [2], LEACH-C [8], PSO-C [11], LDC [20] and PSO-ECHS [18] for varied number of sensor nodes and different number of cluster heads.

Different node deployment strategies were considered to study the energy consumption of the network considering the base station to be fixed at 100×100 location. The initial energy of each sensor node deployed in the area was considered to be 2J and the entire field area has been considered to be 200×200 m^2. The simulations were performed by varying the number of sensor nodes from 300 to 700. For WSN-1, two scenarios with 5% and 10% of sensor nodes as CHs while for WSN-2 and WSN-3, 10% of sensor nodes as CHs have been considered. The simulation has been run for 5000 rounds of data transmission and the energy consumption at the end of these rounds of data transmission has been evaluated and compared. Fig. 2 and Fig. 3 represent the energy consumption considering WSN-1 architecture with 300 nodes and the base station at the centre of the field of application with 15 cluster heads and 30 cluster heads respectively. For both the scenario, it can be observed that the proposed MLEACH-CS algorithm outperforms all the other algorithms in terms of energy consumption. For the initial rounds of data transmission, the performance of MLEACH-CS algorithm is very much comparable with all other algorithms. But with increase in the number of rounds of transmission, a considerable improvement in the performance can be seen. At the end of 5000 rounds, the energy consumption for both the scenarios of 15 CHs and 30 CHs is seen to be 321J and 272J respectively. At the same stage, it can be seen that the entire energy of the energy is consumed for LEACH and LEACH-C protocols. As the sensor nodes are placed near to the CHs, overall lesser network energy is consumed for data transmission and data aggregation at the cluster heads. This is due to the fact that the designed fitness function takes care of the residual energy of the nodes and the distance between the cluster heads and the other sensor nodes. It is also observed that considering for 30 cluster heads in the same network results in decrease of overall network energy compared to 15 cluster heads in the network. This proves that appropriate choice of the number and positioning of the cluster heads in the same network helps to decrease the network energy consumption.

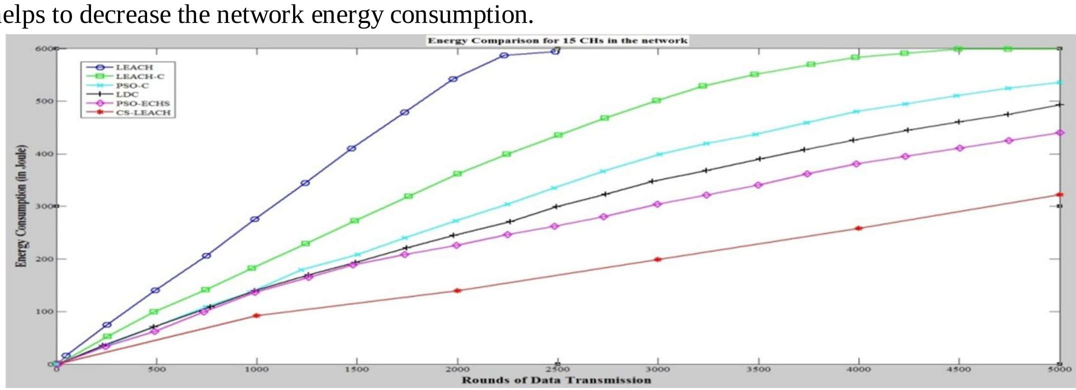

Fig. 2 Energy consumption considering 300 nodes and 15 CHs with BS at centre

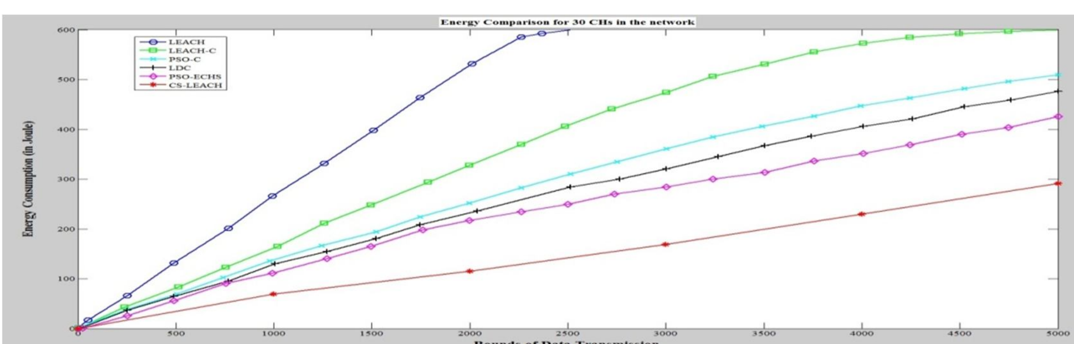

Fig. 3 Energy consumption considering 300 nodes and 30 CHs with BS at centre

As the size of the network increases with increase in number of the deployed nodes, the performance of the designed wireless sensor network can decrease due to signal overlaps and interference in the network. Two dense network architectures have been studied considering 400 and 500 nodes in the network, where 10% of the nodes have been considered to behave as cluster heads. Fig. 4 and Fig. 5 represent the energy consumption for these two network architectures. The energy consumption in the network has relatively increased compared to WSN-1 architecture since more energy for data aggregation is required considering increased number of sensor nodes in the network.

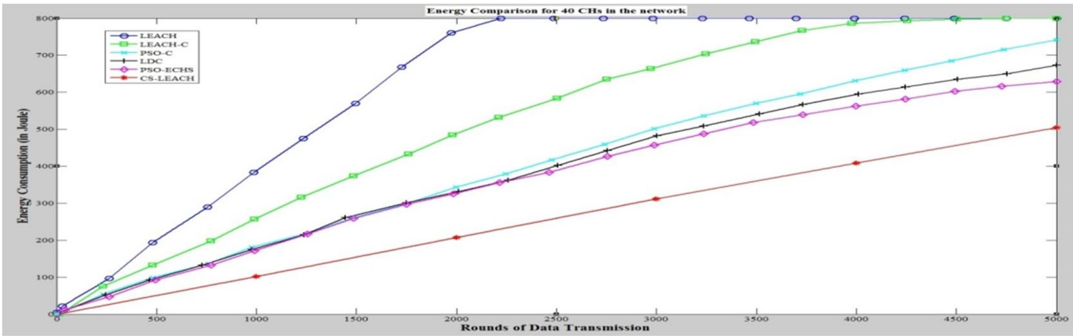

Fig. 4 Energy consumption considering 400 nodes and 40 CHs with BS at centre

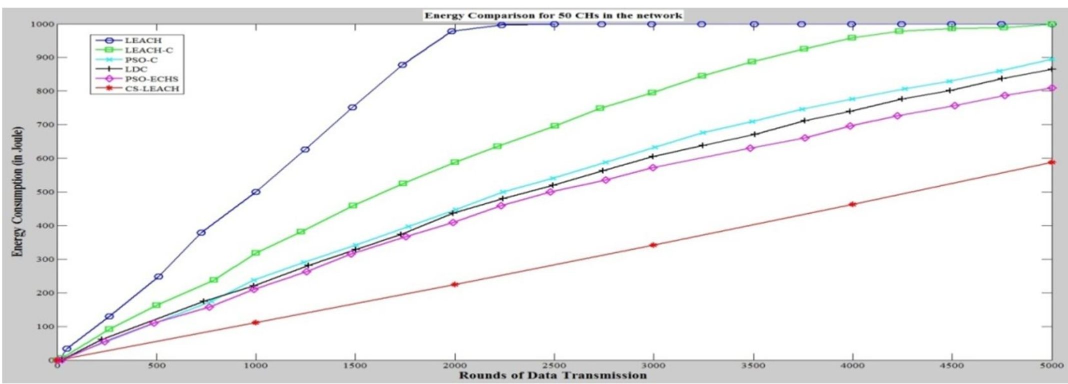

Fig. 5 Energy consumption considering 500 nodes and 50 CHs with BS at centre

The performance of the proposed algorithm has been seen to be improving with every round of data transmission. With increase in the number of rounds of data transmission, the residual energy of the nodes starts decreasing. These results in the selection of CHs in the network play an important role to reduce the energy consumption of the network. The proposed MLEACH-CS algorithm outperforms PSO-ECHS, LDC, PSO-C, LEACH-C and LEACH algorithms in context of proper selection of the CHs using the novel fitness function. To authenticate the fact that the designed approach can efficiently position the cluster heads at any network architecture, the performance of the algorithm for three different positions of the base station with varied number of cluster heads was studied.

B. Energy Consumption due to effect of increase in number of cluster heads at different positions of BS

The simulation has been next performed to compare the total energy consumption of the network for WSN-1, WSN-3 and WSN-4 architecture with 300, 500 and 700 nodes respectively and number of cluster heads equal to 5% of the total nodes. Three positions of the base station have been considered: at the centre of the field, i.e, at (100,100) co-ordinate, at the corner of the field, i.e, at (200,200) co-ordinate and out of the WSN field at (300,300) co-ordinate. The total energy consumption has been calculated at the end of 5000 rounds of data transmission. The results depicted in Figs 6, 7 and 8 represents that the proposed algorithm surpass all the other algorithms in terms of network energy consumption for all the positions of the sink node. The energy consumption has linearly increased when the base station has been shifted from the centre to the base station to out of the field since the data has to travel through a longer distance for base station at corner and out of the field scenario compared to base station at the centre. This leads to larger energy requirement for transmission and reception of the data since the data needs to be reliably transmitted to the base station out of the network.

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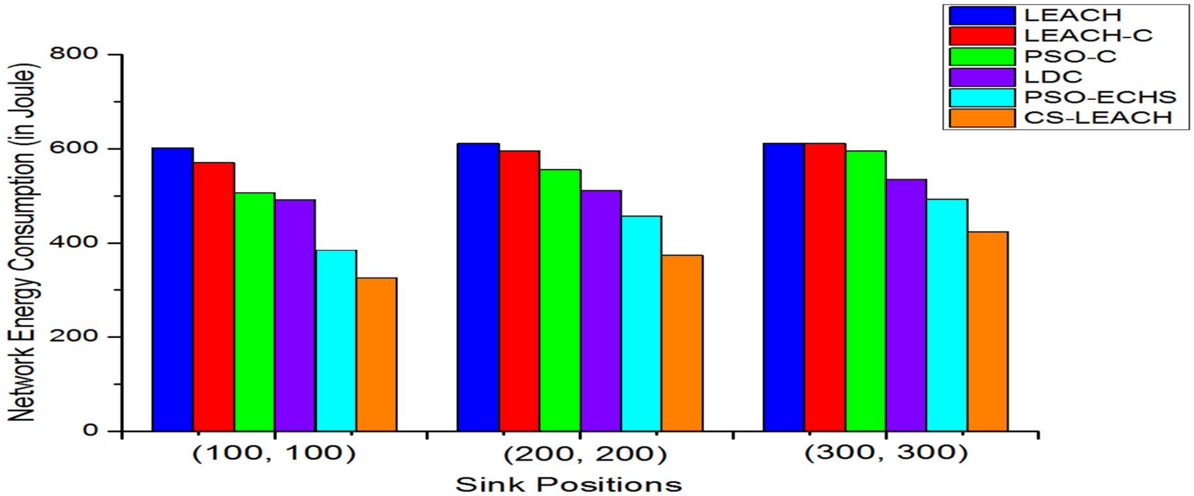

Fig. 6 Network Energy Consumption for 300 nodes at different BS positions

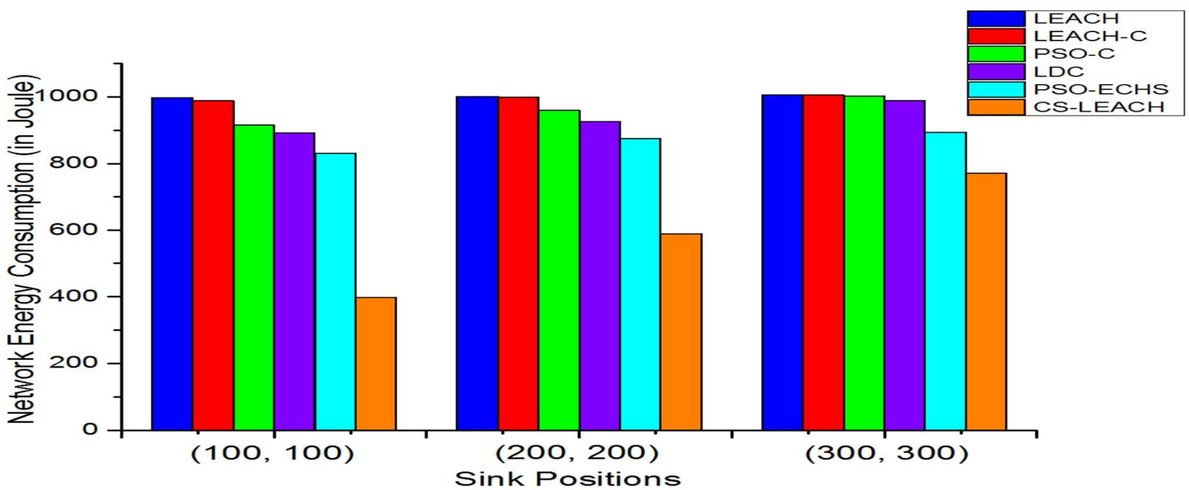

Fig. 7 Network Energy Consumption for 500 nodes at different BS positions

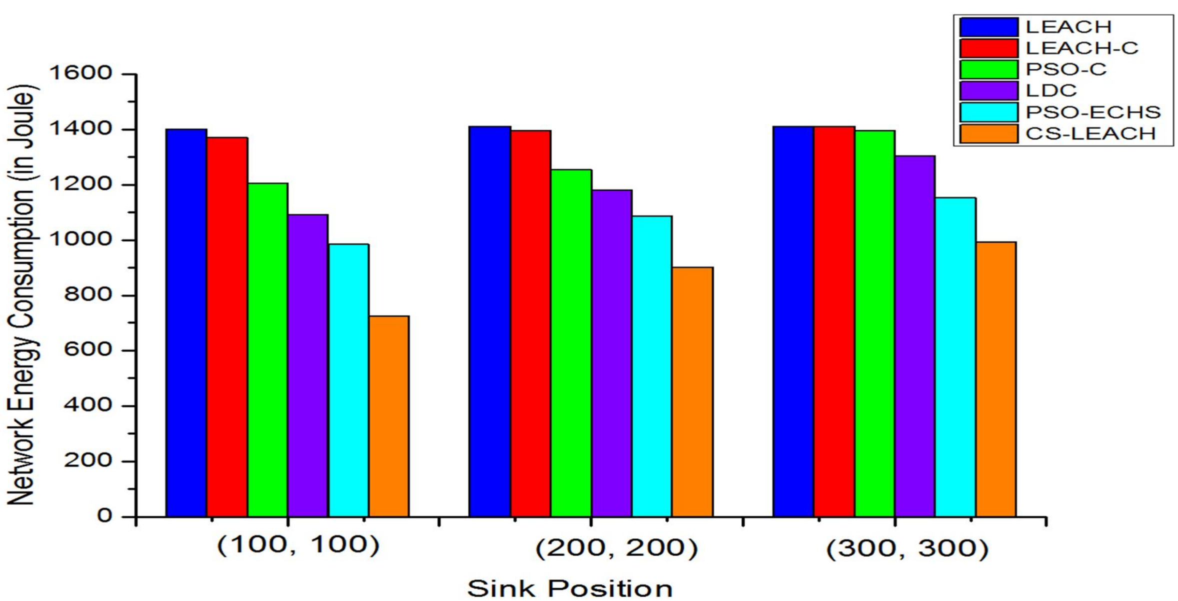

Fig. 8 Network Energy Consumption for 700 nodes at different BS positions

As seen from Fig. 8, the energy consumption has increased in WSN-4 architecture compared to WSN-1 and WSN-3 architecture since the number of nodes deployed in the area has been increased. The dense network architecture considered in WSN-4, results in more signal overlaps compared to WSN-1 architecture. The comparative data presentation shows that network designed through LEACH and LEACH-C algorithm has completely used up the initial energy of the network by the end of 5000 rounds. MLEACH-CS algorithm has shown an improvement by about 16% in comparison to PSO-ECHS algorithm in terms of energy consumption. This can be attributed to the fact that the designed fitness function to be solved using MLEACH-CS algorithm considers the sink distance from the CHs to select the final optimum positions of the CHs. The decrease in energy consumption of the network contributed to the fact that more amount of energy is left over for the network to perform data transmission over longer periods which results in increment of the network lifetime.

C. Enhancement of Network Lifetime for proposed algorithm for varied number of cluster heads and BS at different positions

In view of the improvement in the lifetime of the wireless sensor network, the proposed algorithm has run until the last node in the network dies out. The round for Last Node Death (LND) or the last round after which no data communication takes place has been evaluated using the MLEACH-CS algorithm and compared with the other algorithms available in literature namely LEACH, LEACH-C, PSO-C, LDC and PSO-ECHS. Three different architectures, WSN-1, WSN-2 and WSN-3 as mentioned before has been considered which consist of sensor nodes varying from 300 to 500 and the CHs in the network was varied from 15 to 50. Three different positions of the sink node as before has been considered to be at the centre of the application field, at one corner of the field and outside the field and network lifetime with respect to the base station position has been studied.

Fig. 9 and Fig. 10 represent the network lifetime for WSN-1 architecture considering 15 CHs in the first scenario and 30 CHs in the second scenario. In an overall study, it can be stated that the network lifetime for all the studied techniques has declined as the base station has been moved from the centre of the field to the corner of the field and it was minimal when the base station was placed out of the application area. This can be attributed to the fact that large energy is consumed when the data is needed to be transmitted to farther distances as the transmission energy and the aggregation energy add up. It has also been noted that for the same number of node deployment in the application area, the lifetime of the network increases with the increase in number of cluster heads from 15 to 30 CHs. The increase in number of cluster heads above the optimal level would not again allow any further improvement in the network lifetime since the problems of signal overlap and cross-interference would set in. However, this approach has proved that the optimal choice of the positions of the cluster heads helps to improve the network lifetime. The network lifetime in both the cases is seen to have improved by about 50% when the BS is placed at the centre, by 67% when BS and by about 80% for BS placed out of the field. This validates the superiority of the proposed algorithm in terms of cluster head selection.

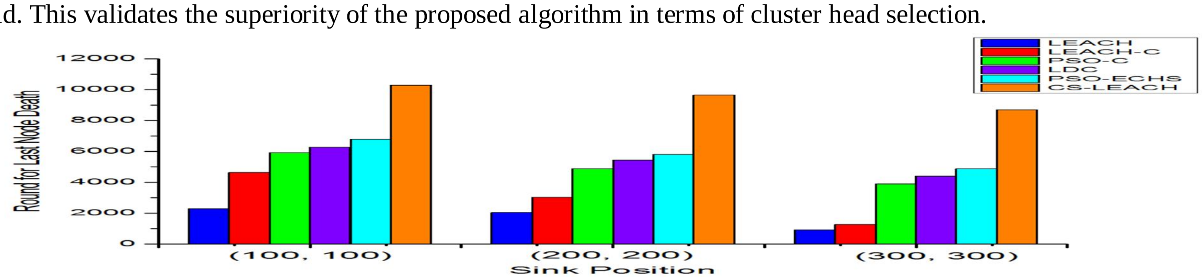

Fig. 9 Network Lifetime for 300 nodes and 15 CHs at different BS positions

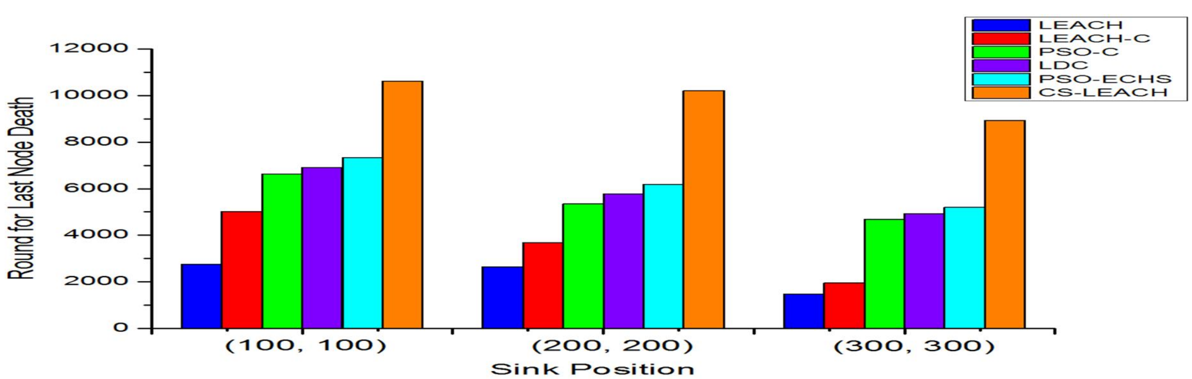

Fig. 10 Network Lifetime for 300 nodes and 30 CHs at different BS positions

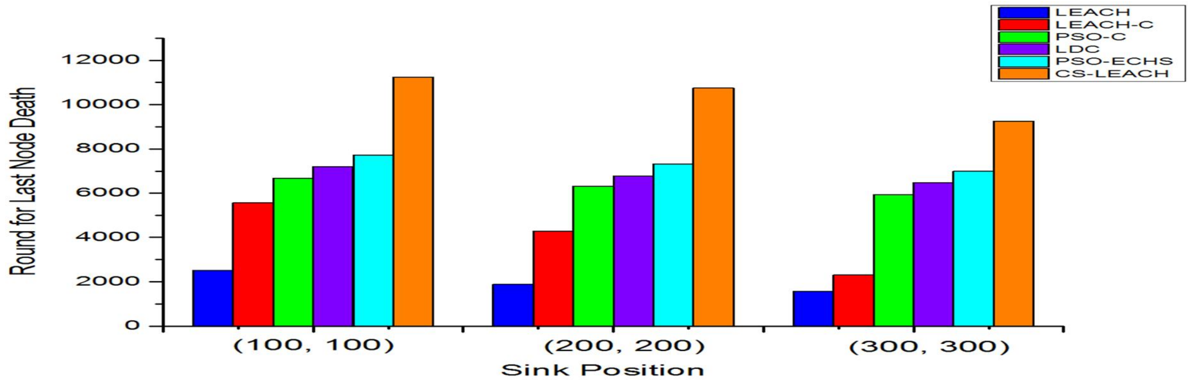

Fig. 11 Network Lifetime for 400 nodes and 40 CHs at different BS positions

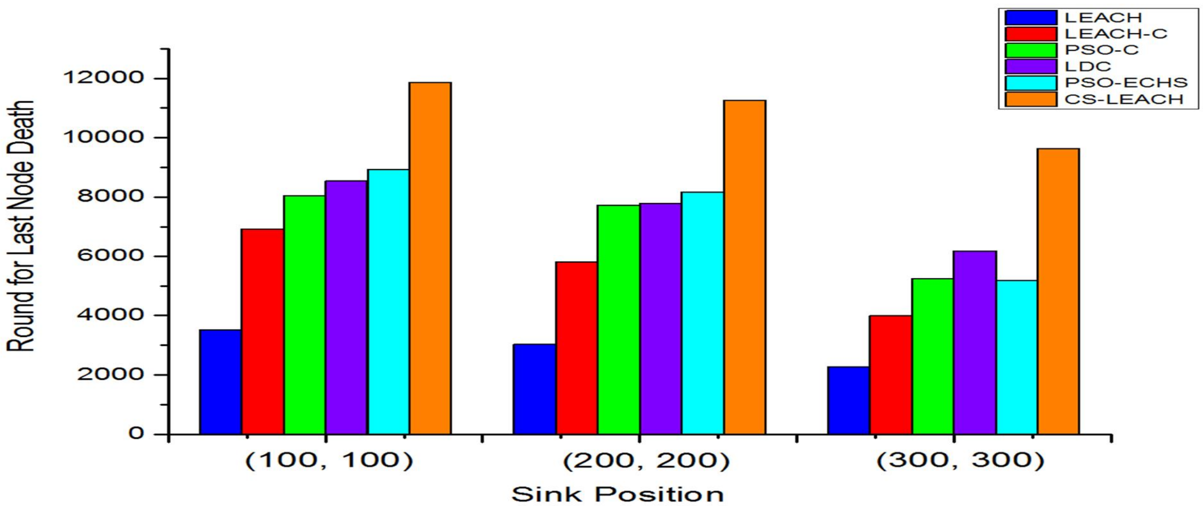

Fig. 12 Network Lifetime for 500 nodes and 50 CHs at different BS positions

From Fig. 11 and Fig. 12, it can be observed that the proposed approach by MLEACH-CS algorithm has proved to provide better solutions compared to LEACH, LEACH-C, PSO-C, LDC and PSO-ECHS algorithm for both WSN-2 and WSN-3 network architecture. For all the three positions of the base station, the network lifetime has shown considerable improvement by about 40% in case of WSN-2 architecture and by around 30% in case of WSN-3 architecture. The network lifetime has obviously improved in comparison to WSN-1 architecture, since the number of nodes considered in WSN-2 and WSN-3 is more than WSN-1 architecture. For all the considered applications, it has been seen that the network lifetime has fallen down when the base station is changed from the centre of the field to the corner or the outfield. However, the decline is less for the proposed algorithm compared to the other algorithms which can be attributed to the fact that the selection of CHs in this method is based on the residual energy of the nodes and distance between the CHs and the sink node.

The cluster head (CH) has more functions that a normal sensor node since it has to execute the duties of data collection, data aggregation and data transmission. This results in consumption of more energy at the CHs than at the normal sensor nodes. Therefore, there is a high chance that a single node fixed as CH in a single cluster may result in dying out of that node quickly due to energy depletion. This would have hampered the network performance and network lifetime since that particular cluster would have become obsolete due to death of the cluster head. This is the reason for selection of CH at every round of transmission by rotation undertaken in this work, where the CHs are selected from the normal sensor nodes with higher residual energy at every round to prolong the network lifetime. The throughput of the network is also highly dependent on the energy consumption and the network lifetime. As the proposed algorithm consumes less energy and the network lifetime is considerably increased compared to the existing ones, higher number of data packets would be received through this approach of network design. It can also be noted that the number of packets received will be more chiefly for the base station positioned at the center compared to the other two positions of the base station.

V. CONCLUSION

This work presented an energy efficient Cluster Head selection and positioning algorithm based on Cuckoo Search Algorithm and LEACH algorithm. To design an energy efficient cluster head election process, the fitness function considers the residual energy of the nodes, maximum number of nodes in a certain cluster, intra-cluster distance, cluster-sink distance and maximum network coverage. The simulation results along with the comparison with other existing algorithms namely PSO-ECHS, LDC, PSO-C, LEACH-C and LEACH algorithm shows the superiority in the performance of the algorithm compared to the other algorithms. This algorithm has been tested extensively for different scenarios considering different positions of the sink node and different number of cluster heads in the network. The proposed algorithm performs better than the existing algorithms in terms of total energy consumption and the network lifetime. It was seen that the energy consumption of the network was minimal when the base station was placed at the centre of the application area compared to the base station at the corner or out of field. The percentage improvement in network lifetime compared to the most recent PSO-ECHS algorithm was seen to be more for WSN-1 architecture compared to WSN-2 and WSN-3 architecture where the network architecture represented dense deployment of the nodes. The number of cluster heads was varied in the WSN-1 architecture in two scenarios and it was seen that choice of optimal number of cluster heads and their efficient positioning helps to reduce the energy consumption in the network considerably. Thus, this approach of cluster head selection has proved to be an efficient one.

This algorithm has considered efficient positioning of the cluster heads to determine the multi-hop routing path but no routing algorithm has been implemented to validate the routing in real life scenario. Future works can focus on hardware implementation of the nodes by the proposed approach and test the data routing through any existing routing algorithm. Various issues such as energy balancing of the nodes and the fault tolerance of WSNs due to transmission delay and channel availability can be given focus while designing a WSN. Other meta-heuristic algorithms can also be implemented to this problem to study the improvement in performance, if any. The proposed algorithm can be put to use to heterogeneous networks consisting of static and dynamic nodes. The authors of this work are trying to implement the idea in real life scenario with help of industries.

VI. ACKNOWLEDGMENT

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