3.1 NEED FOR NATURE INSPIRED META-HEURISTIC OPTIMIZATION ALGORITHMS

The sensor nodes are independent radio devices distributed randomly, which diffuse data in a cooperative manner, which make it easy for deployment in challenging environments. Distance between the communicating nodes is the major factor of energy dissipation (Wang et al 1999) apart from the internal signal processing by electronics. Also, the energy dissipation depends upon the square of the distance between source and sink, which is a non linear dependency.

There are few nature inspired meta-heuristic optimization algorithm used recently for proper cluster head selection in order to provide energy efficient communication (Kang Seok Lee & Zong Woo Geem 2004). These optimization algorithms are used to find the optimal solution for the given nonlinear functions. The energy optimization algorithms available in literature include Particle Swarm Optimization (PSO) (Kennedy & Eberhart 1995) and Artificial Bee Colony (ABC) algorithm (Karaboga & Basturk2007). Although these algorithms are computational complex, they provide better performance than LEACH protocol. Also, the lifetime of a sensor network can be viewed as the time duration from the beginning of data transmission to the first node
death. Hence, the primary objective of these optimization algorithms is to prolong the network lifetime by selecting appropriate cluster head.

Due to the fact that the sensor node has limited electronics and processing ability the energy aware routing is best suitable for data gathering by sensor node. The protocol running on the network should be real time and fast executing. To meet above requirement the proposed protocol is introduced which is based on the flashing behavior of a social insect called firefly. It is also used in many other optimization problems. In this chapter, the optimization of ABC and firefly is used (Senthilnath et al 2011) to increase the network lifetime. The proposed algorithm is compared with LEACH, ABC and firefly algorithm. Simulated result shows that the lifetime is improved using firefly algorithm through optimization. Proposed algorithm is developed as the distributed routing method which dynamically configures the cluster heads for the one round of communication. In each round all the sensor node transmits the collected data to their cluster head which perform the data aggregation and diffuse the aggregated data to the base station. The base station executes the optimization process which is more sophisticated than the sensor nodes and considered to have an unlimited power supply. Further sections of this chapter describe the proposed hybrid method for selecting cluster heads using firefly and ABC algorithms to overcome the drawback of selecting the CH in LEACH.

3.2 FIREFLY ALGORITHM (FA)

The flashing characteristics of fireflies can be idealized so as to develop firefly-inspired algorithms. For simplicity in describing this new Firefly Algorithm (FA) which was developed by Yang (2009) at Cambridge University, the following three idealized rules are utilized:
• All fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex

• Attractiveness is proportional to their brightness, thus for any two flashing fireflies, the less bright one will move towards the brighter one. The attractiveness is proportional to the brightness and they both decrease as their distance increases. If there is no brighter one than a particular firefly, it will move randomly

• The brightness of a firefly is affected or determined by the landscape of the objective function

For a maximization problem, the brightness can simply be proportional to the value of the objective function. Other forms of brightness can be defined in a similar way to the fitness function in genetic algorithms (Xin-She Yang 2010).

### 3.2.1  Clustering using Firefly Algorithm

Clustering is a popular data analysis technique to identify homogeneous groups of objects based on the values of their attributes. For clustering, the energy of the nodes assumes to be similar to that of the light intensity of fireflies in FA algorithm. Also, the movement of the firefly in FA algorithm is similar to the change in location of the cluster head. The movement of less attractive fireflies towards more attractive fireflies is similar to clustering of less energy nodes towards higher energy nodes.

Initially, ‘k’ cluster head are randomly selected with the given clustering probability. Subsequently, clustering will be done and communication takes place. Then, the first round go for energy based switching of cluster head. The nodes that have more energy are eligible for
cluster head than node with less energy. If a node is a cluster head having less energy than other node in that cluster then that node become cluster head and again clustering will be done. After clustering get the fitness value of each optimization round and finally at the end of optimization round get the best set of cluster head which have better fitness value and final clustering done for best fitness value. Fitness value is given in Equation 3.1.

\[
\text{fit}_{CH}(k) = \frac{E_{CH}(k)}{\sum_{i=1}^{n} d_{ik}^2 + d_{CH-BS}^2}
\]  (3.1)

here, k denotes number of the cluster head, ‘n’ signifies number of nodes in the cluster, \(E_{CH}(k)\) is the energy of the cluster head, \(d_{ik}\) is the distance from cluster head to member nodes and \(d_{CH-BS}\) is the distance from cluster head to base station.

3.2.2 Implementation of Firefly Algorithm for WSN

In WSN, as the devices are energy limited, the main objective is to implement an algorithm so that the lifetime of the network increases significantly. This chapter suggests the applicability of firefly algorithm approach for increasing the lifetime of the WSN. Cluster head selection will be done through energy based switching. Here the proposed steps of firefly algorithm are as follows:

Step 1: Initialization

Initialize the constant values of the networks, namely, network area, base station location, number of nodes in the network, initial energy provided to each nodes, data aggregation energy required in each round, transmitter and receiver electronics (\(E_{elec}\)) and transmitter amplifier (\(E_{amp}\)).
number of rounds \( (R_{\text{max}}) \), current round \( (R) \), clustering probability and number of bits transferred \( (K) \).

**Step 2: Distribution of sensor networks**

Now, network will be generated with the given number of nodes. Each node gets their position based on the random location generated by \text{rand} function.

**Step 3: Firefly round begins**

The number of dead nodes is initialized to zero and the energy of each node is computed. If energy of a node is equal to zero then the dead node increment by one. The total number of clusters is randomly generated and the \text{CH} is elected based on the given probability. After formation of cluster, the distance of each node with \text{CH} is computed and linked to the nearest \text{CH}.

**Step 4: Energy based switching**

Here, compare the energy of the current \text{CH} with the other nodes in the cluster group member. If the energy of the node is more than the \text{CH}, then that node will be eligible for the \text{CH}. Such election of \text{CH} is similar to the firefly mechanism where the firefly changes their location, when attracted towards brighter firefly. After the node with higher energy is elected as new \text{CH}, clustering is repeated and the process continues till the maximum round.
Step 5: Fitness value calculation

After energy based switching, the fitness value in the optimization round for suitable clusters is computed using Equation 3.1.

Step 6: Getting best CHs

The fitness value for the clusters of previous optimization round is stored along with the fitness value for the clusters of the current optimization round. After storing the values get the fitness values in descending order and choose top k cluster head for the further process and this step goes on and finally the best possible set of CHs is arrived.

Step 7: Energy consumption

After getting best possible CHs, all the nodes starts sending data to their respective CHs. It collects these data and aggregates and sends it to the Base Station (BS). All nodes update their energy and then algorithm goes back for the next round. Where energy consumption is calculated using first order radio model.

After declaration of cluster heads to the network by base station, each node joins to nearest cluster head by sending a request of membership message. This process, which is the setup phase of the proposed algorithm, forms an initial configuration of the network. Then, CHs gather monitored data from their member nodes one by one using Time Division Multiple Access (TDMA) Medium Access Control (MAC) protocol over a single channel and aggregate them. CHs send these gathered and aggregated data to the base station. This operation constitutes data gathering phase. After setup and data-gathering-phases, a new round starts by selecting new CHs as mentioned before.
Figure 3.1 Flowchart of Firefly Algorithm
3.3  ARTIFICIAL BEE COLONY (ABC) ALGORITHM

Artificial Bee Colony (ABC) algorithm is a nature inspired optimization algorithm based on intelligent foraging behavior of honey bees (Karaboga & Akay 2009). ABC Algorithm is a population based optimization method, which is used in problems where the group or the set of solution is required to find. This algorithm is used in many applications such as electrical power system, parallel and grid computing, data clustering and image analysis, computer science application, signal processing and communication.

The colony of artificial bees consists of three groups: employed, onlookers, and scout bees. The employed bees randomly search for food-source positions (solutions). Then, by dancing, they share information (communicate) about that food source, such as nectar amounts (solutions qualities), with the onlooker bees waiting in the dance area at the hive. The duration of a dance is proportional to the nectar’s content (fitness value) of the food source being exploited by the employed bee. Onlooker bees watch various dances before choosing a food-source position, according to the probability proportional to the quality of that food source. Consequently, a good food-source position attracts more bees than a bad one. Onlookers and scout bees, once they discover a new food source position, may change their status to become employed bees. When the food-source position has been visited (tested) fully, the employed bee associated with it abandons it, and may once more become a scout or onlooker bee. In a robust search process, exploration and exploitation processes must be carried out simultaneously (Kang et al 2009). In the ABC algorithm, onlookers and employed bees perform the exploration process in the search space, while scouts control the exploration process (Karaboga 2009).
The goal of bees in the ABC model is to find the best solution. Therefore, the position of a food source represents a possible solution to the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution.

3.3.1 Clustering using ABC Algorithm

The WSN model consists of a base station and stationary sensor nodes. The nodes are grouped into clusters dynamically as in LEACH. The approach is based on a centralized control mechanism implemented at the base station at two phases. At the first phase, initialization of the network is made when sensor nodes are deployed to the area. Here, the information about the distances between all nodes and energy status are gathered. To obtain the values of distances, nodes send advertisement messages to the network. Each node receives these advertisement messages from other nodes at various signal strengths, and then calculates distance by Equation 3.2,

\[ d_{ij} = s(P_r)^{-1/2} \]  

(3.2)

where \(d_{ij}\) is the distance between node ‘i’ and node ‘j’, ‘f’ is the communication frequency, ‘c’ is the speed of light, \(P_r\) is the received signal strength, and \(P_s\) is the sender signal strength. If the variables \(c\), \(P_s\), and \(f\) are taken as constants then ‘s’ becomes a constant value used for the calculation of the distance meaning the communication range is given in Equation 3.3 which as follows (Karaboga & Akay 2009),

\[ s = \frac{c(P_s)^{1/2}}{4\pi f} \]  

(3.3)

The cluster organization is made by selecting of the CHs for the current tour. Then, sensor nodes are joined to the nearest CHs. After this
selection process, periodical data from the network is gathered via the CHs as the second phase. The selection process of cluster heads is achieved using fitness function obtained analytically in which the communication energy is considered as the significant factor. The distance between the communicating elements is the main concern of energy consumption.

### 3.3.2 Fitness Function for ABC

ABC is used to determine the cluster heads where each solution represents an array having k items in which every item consist a sensor node. The ABC employs a population of bees to find the CHs where the bees fly in the search space. Each employed bee corresponds to cluster heads of sensor nodes.

The fitness of cluster heads selection is stated as a fitness value, which is in inverse proportion to the amount of energy consumption for a tour. If a certain transfer time is required for a data package, the energy consumption is calculated by multiplying transmitting power ($P_s$) and the time ($t$) (Karaboga et al. 2010).

\[
E = \sum_{i=1}^{m} \left( P_i \right) t \geq \alpha \left( \sum_{i=1}^{m} d_i^2 - b^2 \right) t \tag{3.4}
\]

If $w$ is taken as the multiplication of $\alpha$ and $t$, Equation 3.4 is obtained.

\[
E = w \sum_{i=1}^{m} d_i^2 + b^2 \tag{3.5}
\]
Equation 3.4 and Equation 3.5 give the minimum required energy for a cluster. In the equations, \( m \) is the number of nodes, \( i \) is the node index, \( d_i \) is the distance between \( i^{th} \) node and cluster head, \( b \) is the distance between cluster head and the base, and \( E \) is the transfer energy of the cluster.

Considering multiple clusters, the calculation of minimum energy consumption emphasizing the effect of distances will be as in Equation 3.5 expressing sum of the energy consumptions of clusters. In the equation, \( j \) is the cluster index, \( d_{ij} \) is the distance between \( i^{th} \) node and \( j^{th} \) CH, and \( b_j \) is the distance between \( j^{th} \) cluster head and the base.

In order to minimize energy consumption, distances between nodes and CHs, and distances between CHs and the base are considered in the selection process. Since a cluster head should have enough energy to feed the communication in the current tour as a managing element, energy levels of the candidate nodes have also importance on selection. A candidate cluster head should provide enough energy of receiving messages from the nodes in the cluster and transmitting the fused message to the base. According to these considerations, fitness function \( (f_{\text{dist}}) \) is expressed by Equation 3.5 (simply inverse of the energy consumption) and the constraints given in Equation 3.6.

\[
 f_{\text{dist}} = \left[ w \sum_{j=1}^{n} \left( \sum_{i=1}^{k} d_{ij}^2 + b_j^2 \right) \right]^{-1}
\]  

(3.7)

where \( i, j, b_j \) and \( d_{ij} \) are cluster index, node index, distance between \( j^{th} \) cluster head and the base, and distance between \( i^{th} \) node and \( j^{th} \) cluster head, respectively.
The fitness function in Equation 3.7 describes the gateways defined as cluster heads. To provide a simple scheduled data gathering by cluster heads, TDMA protocol is preferred for data aggregation process in intra-cluster communication. CDMA protocol is preferred for the communication through base station which has more complex hardware than sensor nodes in order to achieve simultaneous data receptions from cluster heads.

3.3.3 Steps in ABC Algorithm

The main operational difference between the proposed protocols and LEACH is the selection process of CH and it is performed by ABC algorithm in proposed protocols, while LEACH uses a random selection method. The proposed network clustering protocol is based on a centralized control algorithm that is implemented at the base station (Karaboga et al 2010). The base station is a node with unlimited energy supply. For a sensor network with N nodes and k number of clusters, the sensor network can be clustered as follows:

Step 1: Initialize population, each individual containing k randomly selected cluster heads.

Step 2: Evaluate the fitness function of each individual nodes. For each node n, in the network:

a. Calculate distance \( (n_i, CH_k) \) between \( n_i \) and all cluster heads \( CH_k \).

b. Assign \( n_i \) to \( CH_k \), where distance \( (n_i, CH_k) = \min \{\text{distance} (n_i, CH_k)\} \)

Step 3: Perform the position update by the optimization algorithm.
Step 4: Repeat steps 2 to 4 until the maximum number of cycle is reached.

Step 5: Calculate the energy consumption according to first order radio model. The Flowchart of an ABC algorithm is given in Figure 3.1.

Figure 3.2 Flowchart for the ABC Optimization Algorithm
3.3.4 ABC Implementation

For a sensor network with ‘n’ nodes and ‘k’ number of clusters, the sensor network can be clustered as follows:

**Step 1:** Initially, network is created using the above parameters and the base station is located at the given position.

**Step 2:** The entire sensor network is divided in the form of clusters. Here, ‘k’ nodes are assigned as cluster heads randomly for clustering purpose.

**Step 3:** After selecting the initial cluster heads, all the remaining nodes compute the distance from each cluster head and each member node joins the cluster head which is at minimum distance to it. Proceeding in this manner, the entire network is divided into clusters. Now the distance from base station to other nodes \(d_i\) can be calculated using Euclidean distance formula given in Equation 3.8.

\[
d_i = \sqrt{(x_n - x_i)^2 + (y_n - y_i)^2}
\]  
(3.8)

where \((x_{bs}, y_{bs})\) is the position of base station, \((x_i, y_i)\) is the position of nodes and \(i\) depends on number of nodes in WSN.

**Step 4:** After forming the clusters, compute the fitness function of randomly selected cluster heads using Equation 3.7. For each round a number of optimization iterations take place. The fitness function
of node is computed for each iteration. Then it compares the current fitness function with previous fitness value and memorizes the better fitness value.

**Step 5:** After completion of optimization iteration, select the ‘k’ nodes having best fitness function that will be cluster head nodes for that round.

**Step 6:** Steps 2 to 5 are repeated until the maximum number of round is reached. Each cluster head receives data from its member node, process the data and send it to the base station for each round. Check for dead nodes, alive nodes and residual energy for each round. If the energy of node is less than or equal to zero then it is consider as dead node. Now plot is made for alive nodes, residual energy and throughput of network for each round.

### 3.4 PROPOSED HYBRID ALGORITHM

By taking the advantage of firefly algorithm and ABC algorithm, hybrid firefly-ABC algorithm is proposed. In the case of firefly algorithm, first node death round is much more than ABC algorithm so network life will be more than ABC algorithm without losing any node. In the case of ABC algorithm, last node dies late compare to firefly algorithm, which gives smooth energy consumption throughout the network. Hence, the proposed hybrid algorithm increases the network lifetime by increasing time period of FND and LND. The Flowchart of the proposed hybrid algorithm is shown in Figure 3.3.
Step 1: Initialization

Provide all the initial value required as like in ABC and Firefly algorithm.

Step 2: Sensor network generation

Nodes are deployed in random manner using ‘rand’ command in the given network area.

Step 3: Round begins

In this step, the value of dead node is initialized to zero and then check the energy of each node, if energy of node is equal to zero then the dead node value is incremented by one. Then randomly generate the total number of clusters and CH based on the given probability value and save the result in a structure. After formation of cluster find the distance of each node with each CH and join the cluster in which cluster head is nearest than other CH.

Step 4: Check condition

The firefly algorithm is implemented till first node death and thereafter the network is configured to ABC algorithm.

Step 5: ABC algorithm begins

As soon as the first node dies, ABC algorithm starts and follows all the steps of ABC algorithm along with using one more parameter.
As discussed in previous sections, the cluster head is the node which consumes more energy than other member nodes. In order to protect the cluster head from early death, a criterion is introduced that avoids the early death of cluster head. The cluster head should not die out during the communication which leads to the data loss. The criteria states that the current residual energy \((E_{CH})_{\text{current}}\) means the energy left out in the node must be greater than the required energy \((E_{CH})_{\text{required}}\) to complete the task, which is given in Equation 3.9.

\[
(E_{CH})_{\text{current}} \geq (E_{CH})_{\text{required}}
\]  

(3.9)

In the proposed method, this criterion not only selects cluster head but also the fitness of the cluster head by ABC method, as discussed earlier. Hence, the threshold is defined as the ratio of energy required for a CH in a round to the energy available to that node. If the threshold is more than 1 then clustering is done else the nodes will not be eligible for CH. After completion of optimization iteration, the nodes having best fitness function is selected that will be the cluster head for that round. Repeat steps 2 to 5 until the maximum number of round is reached.
Figure 3.3 Flowchart of the Proposed Hybrid Firefly-ABC Algorithm
3.5 SIMULATION METRICS

The main objective of the simulation is to evaluate the performance of each protocol. Here, a round is defined as one complete cycle of CH selection, data aggregation from member node, and transmission of aggregated data to BS. Evaluation is made based on the following three metrics:

- **Number of nodes dead**

  The performance of a network depends on the lifetime of its node. If the lifetime of the node is high means less number of node dead for longer duration then the network performs well and also transmits more data to the base station.

- **Residual energy of the network**

  Here the residual energy of the network for different algorithm with respect to the number of nodes is analyzed. Any algorithm is better if their residual energy is greater and energy graph is more smooth and flatter then only that algorithm is known as energy optimized algorithm.

- **Throughput of the network**

  Throughput of the network is defined as the number of successfully transmitted bits by the alive nodes during the round process. If the number of alive nodes is more, then throughput of the network will be increased.
3.5.1 Results and Analysis

Figure 3.4 shows the distribution of the 100 nodes in the given sensing area. Nodes are randomly distributed in the given 100*200m² network whereas base station is placed at (50,150) m location. Simulation parameters are shown in Table 3.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor field region</td>
<td>(100*200)m²</td>
</tr>
<tr>
<td>Base station location</td>
<td>(50,150) m</td>
</tr>
<tr>
<td>Number of nodes (n)</td>
<td>100</td>
</tr>
<tr>
<td>Percentage of cluster heads</td>
<td>10%</td>
</tr>
<tr>
<td>Data packet length</td>
<td>4096 bits</td>
</tr>
<tr>
<td>$E_{elec}$</td>
<td>70nJ/bit</td>
</tr>
<tr>
<td>$E_{amp}$</td>
<td>120pJ/bit/m²</td>
</tr>
<tr>
<td>EDA, Initial energy</td>
<td>5nJ, 0.5J</td>
</tr>
</tbody>
</table>

Figure 3.4 Distribution of nodes in WSN
Figure 3.5 shows the dead node comparison of proposed hybrid algorithm along with firefly, ABC, Leach and DT algorithms. For DT the first node death occurs in the early stages after 43rd round. From careful observation of the graph, it clearly states that the first node death is better for firefly algorithm but overall death of nodes is slow in the hybrid algorithm. Hence, hybrid algorithm is better than all other firefly, ABC, LEACH and DT algorithms. For firefly algorithm, the death of the nodes is almost near after 351st round which is clearly observed from the steepness of the slope of the curve in the graph. In the ABC, LEACH and the hybrid algorithms nodes of the network death relatively differ in close manner.
Figure 3.6 Residual Energy Comparisons of Proposed Hybrid and Existing Algorithms

Figure 3.6 shows the residual energy comparison of Hybrid, Firefly, ABC, Leach and DT algorithm. Concluding from the graph, the residual energy of the network is optimized more in the case of hybrid algorithm than other algorithms. In the ABC, LEACH, Firefly and the hybrid algorithms residual energy of the network relatively differ in a close manner. Due to fewer control parameters, and faster convergence it is better than DT and LEACH in terms of residual energy of the network. Choosing the best features from firefly and ABC algorithms, which is elevating the residual energy of the network thus by improving the performance of the network.
Figure 3.7 Throughput Comparisons of Proposed Hybrid and Existing Algorithms

Figure 3.7 shows the Throughput comparison of Hybrid algorithm along with Firefly, ABC, Leach and DT. The graph tells that in the initial rounds more bits of data are sent through Firefly algorithm, but after few rounds more bits of data sent through hybrid algorithm. Moreover, hybrid algorithm will send more bits of data than any other algorithm throughout the process. The hybrid algorithm is better than all other algorithms because it sends more bits of data, and energy is optimized and the overall lifetime of network is also increased in the case of hybrid algorithm. Utilizing the salient features from the firefly and ABC algorithms, the hybrid algorithm performance better than existing algorithms in terms of network parameters.
Table 3.2 Comparison of Network Parameters between Hybrid Firefly-ABC Algorithm and Existing Algorithms

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>First Node Death (rounds)</th>
<th>Last Node Death (rounds)</th>
<th>Residual energy(J) after 350 rounds</th>
<th>Throughput (bits/round) after 350 rounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Transmission</td>
<td>43</td>
<td>320</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Leach</td>
<td>256</td>
<td>490</td>
<td>0.057</td>
<td>217088</td>
</tr>
<tr>
<td>ABC</td>
<td>210</td>
<td>512</td>
<td>0.084</td>
<td>270336</td>
</tr>
<tr>
<td>Firefly</td>
<td>351</td>
<td>440</td>
<td>0.075</td>
<td>409600</td>
</tr>
<tr>
<td>Hybrid</td>
<td>317</td>
<td>542</td>
<td>0.127</td>
<td>397312</td>
</tr>
</tbody>
</table>

From the Table 3.2, the obtained results are compared for DT, LEACH, ABC, FA and Hybrid algorithm. From the table it is clear that Firefly algorithm increases the FND but, more nodes are alive for a longer duration in the proposed hybrid algorithm. The FA not only includes the self-improving process with the current space, but it also includes the improvement among its own space from the previous stages. Therefore, the lifetime of the network is increased in the case of proposed hybrid algorithm because the LND is more in the case of proposed hybrid algorithm. Hence, it can be observed that the hybrid algorithm presents promising solutions in WSN.
3.6 SUMMARY

This chapter discusses the various energy efficient algorithms. In LEACH algorithm, probability based CH selection process occurred, whereas, in ABC, randomly selection of cluster head is done based on the fitness value through given optimization round. In firefly, energy based switching of CH takes place which gives the best possible cluster head which has more energy than any other nodes so first node dead increases in the case of firefly algorithm. The network will work with full efficiency in the case of firefly algorithm for longer duration whereas in the case of ABC algorithm the last node dead increases significantly than LEACH, firefly and DT. In addition, the residual energy curve is more smooth and better for ABC compare to any other algorithms. Now with taking the advantages of ABC and firefly, hybrid algorithm is proposed. This hybridization of firefly-ABC approach increases the lifetime of the network.