Cluster Head Selection in Wireless Sensor Network Using Bio-Inspired Algorithm

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***Abstract*— Routing and Clustering are the two major issues in Wireless Sensor Networks (WSNs) as these measures play a vital role during data transmission. Small battery-powered sensor nodes have an unadorned impact on communication protocols due to severe energy constraints. In clustering, cluster heads are often overloaded with heavy traffic than other members of the cluster. This creates a hotspot problem on a cluster head near to the base station. This is the primary reason to select a proper cluster head in a clustered based routing protocol. In this paper, we have applied the bio-inspired algorithm such as Genetic Algorithm to handle the energy-specific issues in Wireless Sensor Networks. By doing so, we have selected an energy-efficient cluster head that creates an energy-optimized environment leading to a longer Network lifetime. The Proposed Protocol is experimented through a Java-based Custom Simulator, which shows its superiority over traditional computing model in LEACH and K-Means Clustering.**

***Index Terms*— WSN, CH, Genetic Algorithm**

I. Introduction

Rapid growth in Wireless Communication along with VLSI design has led to the development of chip processors like smart sensor motes; those play a vital role in multiple applications. These applications range from military, defense, agriculture, health care and more over towards Internet of Things (IoTs). IoTs is a system of networked devices that depend on those small sensor motes to sense, gather and transfer the data over the Internet without any human intervention. These sensor nodes are self-organized by nature and communicate with each other within a certain radio range. The working principles of these sensor nodes either continuous, or energy driven. The individual node of a WSN is inherently resource constraint; limited processing speed, limited memory and limited with communication bandwidth [1]. WSNs enable new applications and deserve the design of new non-conventional protocols and algorithms owing to the low device complexity along with low power consumption that can resume network for longer time. This motivates massive effort in research activities, standardization process, and industrial investments since last decade [3]. At present most of the researchers have concentrated on developing computationally feasible, energy efficient algorithms/protocols and the application domain is getting restricted to simple data monitoring and reporting applications [4]. Energy consumption is the most important factor in determining the lifetime of the network. Sometimes energy optimization is vital part in WSNs. It is not only emphasizing in reduction of energy consumption but also prolonging network lifetime as much as possible. This ensures that energy awareness is incorporated in each sensor node, communication network, and complete network. This optimization can be done in every aspect and design operations of the network. The design of routing protocols must consider the power, resource constraints of each node, the time varying nature of wireless link, end to end delay and packet loss.

The first category of routing protocols adopts a flat network infrastructure, where all the nodes are treated as peers. Flat routing protocols have several advantages such as minimum overhead maintaining architecture, maintaining multiple routes and fault tolerant. The second category of routing protocols focus on network to achieve energy efficiency, and scalability. In this network, sensor nodes are organized into clusters/groups and one node with higher potential is elected as cluster head. The cluster head manages all the nodes inside the cluster and communicate with other cluster heads till the data reaches at the destination. Enormous studies [1-16] discuss that clustering has enough potential to reduce energy consumption and extends the network lifetime. The third category of the protocols are data centric starts with an intension of data dissemination. But the objective of any protocol should start with the minimization of energy consumption. For example, energy consumption can be reduced through data compression during radio transmission but uses more energy while computation. Further, this energy business purely depends upon the applications. So, the designer of the sensor network protocol must consider the software and hardware needs for efficient usage of energy.

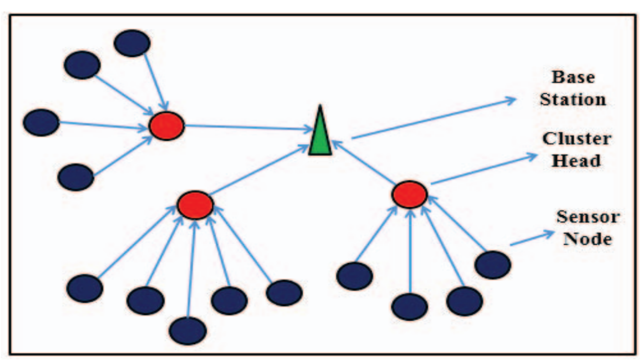

Figure 1: General System Model of Clustered WSN

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The rest of the paper is organized as follows. Section II discusses the background of clustering algorithms used in WSN. Section III presents the general GA Model. Section IV presents the basic structure of GA Model. The proposed algorithm is discussed in Section V. Results and analysis are discussed in Section VI followed by conclusion.

II. Related Work

In this section, we discuss few clustered based routing algorithms for WSN, few Genetic Algorithms and K-Means Algorithm as these algorithms are focused in our proposed work.

A) Traditional Clustering

LEACH [1] is a first clustered based routing protocol that follows a probabilistic model to elect the CH claiming that each sensor node gets equal chance to become a CH. It works on the principle of two phases; steady state phase followed by the set-up phase. The steady state phase looks after forming a cluster and the set-up phase is responsible for transmitting the data to the base station. Each node follows a procedure, opts a random number between 0 to 1, and If the number lies within the threshold value $T(n)$, the node becomes the CH for the current round. The threshold value $T(n)$ is stated in equation (1).

$$T(n) = \begin{cases} \frac{p}{1-p*\left(r \bmod \frac{1}{p}\right)}, if\ n \in G \\ 0, otherwise \end{cases} \quad (1)$$

r is the round already over, p is the probability of the nodes to become CH, G is a set of nodes those have never got a chance to be CH in the last $1/p$ rounds. Although LEACH provides balances the load by rotating the CH, still it has some disadvantages. One may refer [22] [24] for detail information. LEACH-C [2] is the enhancement of LEACH, follows a centralized principle to select the CH. The advantages and drawbacks are discussed in many literatures. Research in [5-10] presents many clustering protocols for WSN. As the proposed work focus on LEACH, K-Means, and GA based clustering protocols, few of them are discussed below.

B) K-Means Clustering

K-Means is an unsupervised learning algorithm, proposed by MacQueen in 1967 [11], initially was meant for data mining. It partitions the data set into certain number of clusters using the Euclidian distance mean, that maximizes the intra-cluster similarities and minimizes inter-cluster similarities. Typically, it generates randomly k points (center of the clusters), k being the expected number of clusters. The distance between each of the data points to each of the centers is calculated and assigned each point to the closest center. The center of the new cluster is calculated by the mean value of all data points in the respective cluster. The distance between the data points is calculated using Euclidean distance defined by equation 2 given below.

$$E = \sum_{i-1}^{k} \sum_{x \in C_i} |X - \overline{X}_i|^2 \quad (2)$$

Few clustering techniques based on K-Means or little deviations are discussed by in [12-14] but we have considered here the basic K-Means clustering.

C) Clustering based on GA

Many different approaches are discussed in [16], [18-22] applying Genetic Algorithm in WSN and prof that it can balance the network load among the sensor nodes to satisfy energy optimization problem. This section presents few genetic algorithm-based routing protocols. A GA based approach for routing in two-tiered sensor networks is proposed in [16] that maintains a longer network lifetime by consuming optimal energy. In [17], a flat routing protocol is discussed that uses MOGA [20] to find paths in wireless sensor networks. In [18], an optimal traffic distribution technique is discussed that improves the lifetime of multi-sensor networks. The work of [19] focuses on an energy efficient scheme based on distributed GA that satisfies the required detection probability. In [21], a GA based protocol is discussed that tries to analyze the QoS parameters. In [22], the author has used a GA based technique for path optimization purpose. Even though several comprehensive studies on clustering are available in the literature, very few have focused the work clarifying step by step procedure of GA incorporating the sensor problems. The lack of clarity inspired us to design a GA based clustering technique which could prove its efficiency through simulation results. The proposed network includes GA principles to form the cluster dynamically and elect an efficient CH based on highest residual energy and lowest distance to BS. The proposed protocol is discussed in detail in Section IV.

III. General structure of GENETIC ALGORITHM

The most common objective to apply genetic algorithm here to optimize energy consumption by selecting suitable cluster head under specific routing conditions. The flow chart of basic GA model is depicted in Fig. 2. When GA is used for problem solving, we need to emphasize three key elements that really influence the system performance; first one is initial population, second one is evaluation of fitness function, and third is GA parameters.

- **Encoding:** It is very crucial to choose the right type of encoding scheme although many encoding schemes are available. These are binary encoding, decimal encoding, octal encoding, tree encoding, and permutation encoding etc. The selection of coding depends on the types of problems we are dealing with.
- **Generation of Initial Population**: Initial population can be created by creating chromosomes. A chromosome contains all the genetic information of an individual. New population is created by using genetic operations such as crossover, mutation, and selection operator.
- **Selection of Fitness function:** The fitness function controls the chromosomes in change over time and brings the variation between finding the optimal solutions or finding no solutions at all.

- **Selection Operator:** There are many methods available for selecting the chromosomes such as roulette wheel selection, tournament selection, elitism selection, steady state selection etc. It depends on the designer how it will be fit for the problems.
- **Crossover and Mutation operation**: The crossover operation is used to generate a new chromosome (offspring) from a set of chromosomes (parents) while the mutation operator randomly flips individual bits (0 to 1 and 1 to 0) into the new chromosome. The probability of flipping the bit is very less i.e less than 5 percentage.

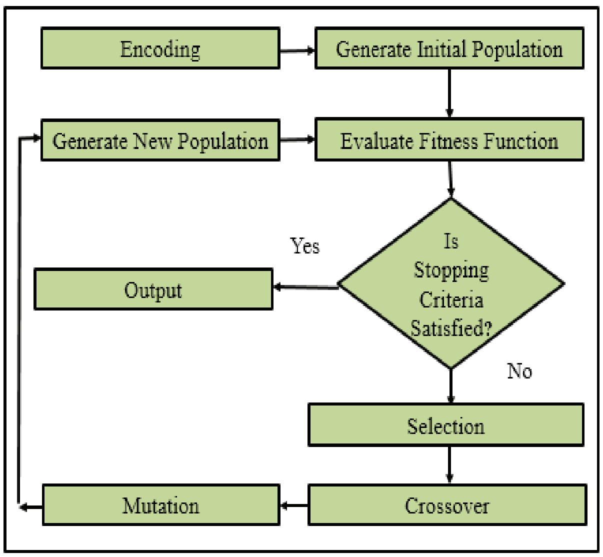

Figure 2: Basic structure of GA

IV. PROPOSED HEURISTIC

A. General Description of Proposed Algorithm

The idea of incorporating GA in WSN is to select an efficient cluster head based on the highest fitness value among all the sensor nodes. We have created the initial population by selecting some random numbers. We have considered the chromosome length 6 based on binary encoding. Each node calculates its fitness value based on the formula given in equation 6 for one generation. The best fit node becomes the CH. The probability of being CH is calculated using the formula as given in equation 7. Then new population is created by following the procedure as discussed in Table 2 and 3. Roulette Wheel selection method is used. Node 5 is having highest fitness value as shown in Table 1 and selected as CH. Perform crossover and mutation and find the best fit value in each generation. Select the CH in each generation based on the best fit value. Stop the algorithm when it arrives at again initial population or till the energy depleted completely in all the sensor nodes.

B. Energy Model Analysis

The first order radio model shown in Fig. 2 is taken from [23]. The total energy consumption to transmit *l* bits over a distance *d* from a transmitter to receiver is given in equation 3.

$$E_{Tx}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d) = \begin{cases} l * E_{elec} + l * \varepsilon_{fs} * d^2 \; if \; d < d_0; \\ l * E_{elec} + l * \varepsilon_{mp} * d^4 \; if \; d \geq d_0; \end{cases} \quad (3)$$

- E_{elec} is the energy dissipated per bit to run the transmitter or the receiver circuit. It mostly depends on the parameters like digital coding, modulation, filtering and spreading of the signal.
- ε_{fs} & ε_{mp} are the transmitter amplifier characteristics, where ε_{fs} is used for free space and ε_{mp} used for multipath.

When the distance between transmitter and receiver is less than the threshold value d_0, the free space model (d^2 power loss) is used. Otherwise, the multipath fading channel model (d^4 power loss) is used. Power amplifier can be adjusted appropriately to invert this loss. The amount of energy consumption to receive *l* bit of data and the threshold value which is the ratio of ε_{fs} & ε_{mp} is given in equation 4 and 5 respectively.

$$E_{Rx}(l) = E_{elec} * l \quad (4)$$
$$d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}} \quad (5)$$

C. The step by step GA operations incorporated in our work

1. **Encoding**: In our proposed work, binary encoding is used. We have generated the chromosome for each node. We can create a class by representing the class in terms of node energy, distance and no. of neighbours as given below. For simplicity, we have taken two bits to represent individual parameter. We can consider any random combination of these two bits to generate the initial population.
   < Energy, Distance and No. of Neighbours >.
   Energy can be represented as: E_r = 00, 01, 10 or 11
   Distance can be represented as: D_i = 00, 01, 10 or 11
   No. of neighbours can be represented by the original binary value. Example, if no. of neighbour nodes is 2 for any sensor node, it can be represented by 10. If the no. of nodes is 3, it can be represented by 11 respectively.
   For instance, for node 1 we have created a chromosome.
   Node 1 = 001011
2. **Creation of Initial Population:** Initial chromosomes can be created by using the binary representation of each node. Table 1 shows the structure of initial population in detail.
3. **Fitness function calculation**: In the proposed approach, we have calculated the fitness function of a chromosome in the population by measuring the total distance of all the sensor nodes to BS, total distance of all the sensor nodes to CH and measuring the only distance from one sensor node to BS as defined in the formula given in 6.

$$f_t\,(x) = D * \frac{d_{s-ch}}{d_{T(s-bs)} - d_{T(s-ch)}} \quad (6)$$

d_{s-ch}= Distance from each sensor node to cluster head
$d_{T(s-bs)}$= Total distance from all the sensor nodes to BS
$d_{T(s-ch)}$= Total distance from all sensor nodes to CH

For instance, the fitness value of Node 1 is as follows.

$$f_{t(Node\ 1)} = 1.1 * \frac{2.5}{75 - 55.75} = 0.04$$

Where, distance from sensor ID 1 is = 2.5 cm
Total distance from all sensor node to BS = 75cm
Total distance from all sensor nodes to CH =55.75
Similarly, each node's fitness value is calculated and presented in Table 1.

4. **Selection Operator**: In our work, Roulette Wheel selection method is used. Probability density function is used to calculate the chance percentage to be the cluster head among all the sensor nodes. The sum of all the calculated fitness value is 0.8. So, probability of one node being the cluster head can be calculated according to the formula given in 7. The results are shown in Table 2 and it is concluded that Node 5 is having a better chance to be the cluster head in first generation.

$$P_{Select} = \frac{f_{t(x)}}{\sum_0^5 f_t(x)} \qquad (7)$$

5. **Crossover Operation**: Table 1 shows the Initial chromosome structure. We have selected randomly 5 chromosomes for 5 nodes in a cluster. The fitness function is calculated using the formula given in equation 6. Table 2 shows the initial population (without crossover operation). Further, we have calculated the fitness function by applying crossover operation. Table 3 shows the new population after performing crossover operation. We have checked through single point crossover as well as multi point crossover operation also. Perform crossover and mutation till best fit value is obtained for a node and that node will be the cluster head. In each generation, the probability of one node becomes the CH with highest fittest score so that it can balance the network load.
6. **Mutation**: We have considered the mutation rate *r* is 0.001 which is very low. In our case, mutation probability is 0.001 x 64= 0.064. It is concluded that one mutation happens in second generation. To demonstration it, we have mutated one bit which is shown in Table 3. Stop the crossover and mutation operation till all the nodes depleted energy completely.

Table 1: Creation of Initial Population

Node ID	**Cr. No.**	**Initial Population**	**Decode Value (D) in 1 decimal point**	***$f_t(x)$***
1	1	0 0 1 0 1 1	1.1	0.04
2	2	0 1 0 0 1 0	1.8	0.09
3	3	0 0 1 1 0 0	1.2	0.08
4	4	0 0 1 1 1 1	1.5	0.12
5	5	1 1 0 1 0 1	5.3	0.47
				Sum= 0.8

Table 2: Procedure for creating New Population

Initial Population	**P_{Select}**	**Actual Count**	**New Population**
001011	0.05= 5%	0	**Discard**
010010	0.11=11%	1	010010
001100	0.1= 10%	0	**Discard**
001111	0.15= 15%	1	001111
110101	0.58=58%	3	110101

Table 3: Creation of New Population

Initial Population	**Crossover point**	**New Population**	**Mutation**
001011	010010	011111	
010010	001111	000010	
001100	110101	110101	
001111	110101	110101	
110101	110101	110111	

V. Experimental Set Up and Results

Simulation Settings

To check the validity of the proposed protocol, a Java based Custom Simulator is used. A sensor field of 40 nodes are created at an area of 100m x 100m. We have divided them into 4 clusters based on the geographical area. We have considered the packet size is 4 bytes and data rate are 64 bytes/sec. Simulation parameters of our interest is given in Table 4. We have considered 20 rounds. One round duration is 33ms. Uniform crossover is considered. Crossover rate is 0.5. Mutation rate is 0.001. Few performance metrices are chosen to evaluate the performance of proposed protocol. These are discussed below.

- Packet delivery ratio
- First Node dies
- Average energy consumption
- Throughput

- Network lifetime

Table 4: Simulation Parameters

Number of Sensor Nodes	40
Size of the Sensor Field	100m x100m
Time for Simulation	700 seconds
Range of Transmission	8cm
Data rate	64 bytes/Sec
Packet size	4 bytes
Sensor Initial energy	1000 Joules
Base-Station Initial energy	10,00,000 Joules
Length of Population	6
Number of generations	20
Number of Rounds	20
Crossover Rate	0.5
Communication Model	Bi-directional

A. Evaluation Metrics

Few important metrics are chosen to evaluate the effectiveness of the proposed protocol. These are:

- **Packet delivery ratio**: The sole aim of any protocol is to maximize the delivery of data signals to the BS. So, the ratio of data packets delivered to BS to the number of data packets generated by the source is a proper measure of packet delivery ratio (PDR). Fig. 3 shows the comparison result of our proposed protocol with LEACH and K-Means clustering. It is evident from the results that PDR is good in LEACH initially, but PDR increases slowly in K-Means clustering and it increases even more in proposed GA based Clustering.
- **First Node Dies**: It tells about the time when the first node exhausts the whole amount of energy. It is evident from Fig. 5 that first node dies first in LEACH followed by K-Means and GA-Clustering. Fig. 4 favours GA clustering.
- **Average Residual Energy**: The network lifetime is directly proportional to the average energy consumption. Initially energy consumption is less in LEACH. As the time progress, average energy consumption is more in LEACH and moderate in GA Clustering and less in K-Means. Fig. 5. shows the average residual energy at each protocol after running the simulator for 20 rounds.
- **Throughput**: Throughput is defined as the successful delivery of data packets at BS. It does not consider the sent packets or lost packets. Sometimes it varies w.r.t PDR and sometimes not. Mostly during heavy traffic, throughput deviates from PDR. In our case, traffic is less. So, throughput is all most all equal to PDR.
- **Network Lifetime**: This is the most desired parameter that can sustain the network for longer period. We have measured it with respect to number alive nodes. After 20 rounds, in LEACH almost 70% nodes die, 68% node die in K-Means and only 55% nodes die in our proposed GA based Clustering. Fig. 6 summarizes the results.

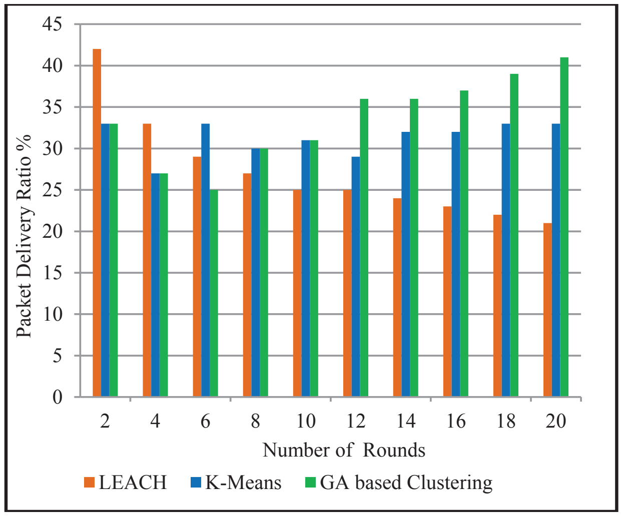

Fig. 3: Packet delivery ratio over No. of Rounds

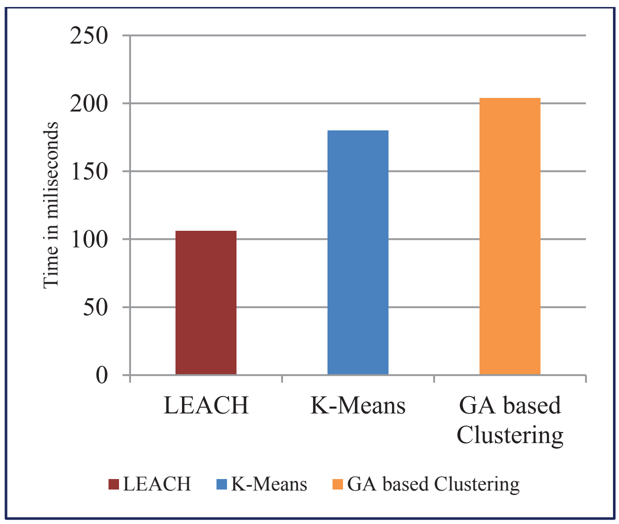

Fig. 4: First Node dies over Time

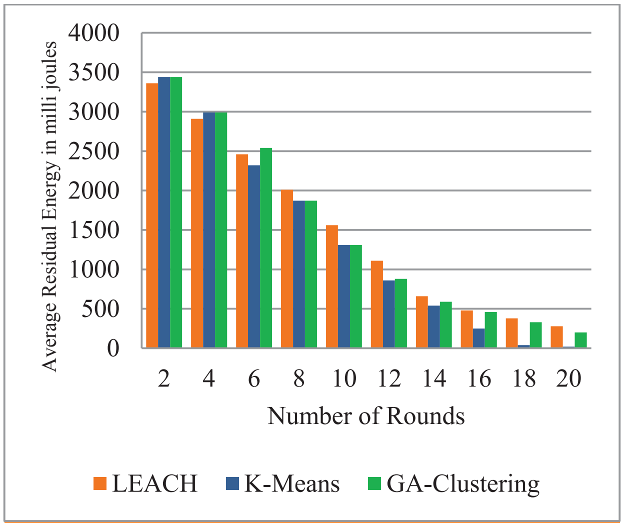

Fig. 5: Average Residual Energy Vs. No. of Rounds

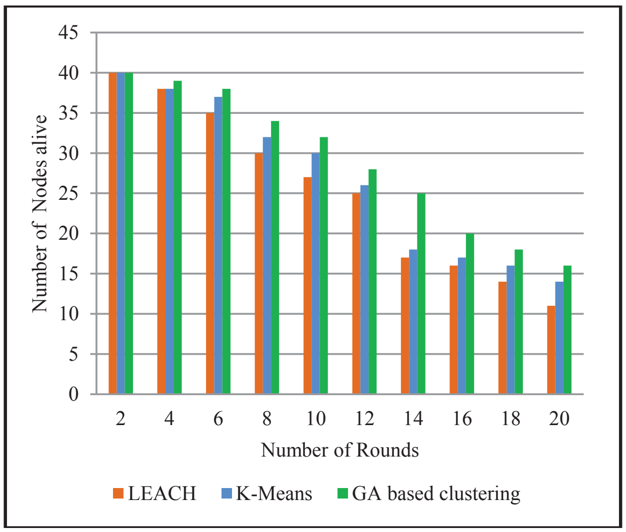

Fig. 6: Network Lifetime w.r.t No. of alive Nodes

VI. CONCLUSION

In this paper, we have put an effort to select an efficient Cluster Head in a cluster-based routing protocol for Wireless Sensor Network. The cluster head is selected based on Genetic Algorithm principle as Genetic algorithm is a natural bio inspired algorithm that provides an optimal or near optimal solutions when the search space is huge. The step by step procedures of GA are incorporated in the Wireless Sensor Network to select an efficient cluster head among the clustered nodes that can balance the network load evenly among the sensor nodes. This could lead an extended network lifetime by optimizing energy consumption. The simulation results proof that GA-Clustering outperforms LEACH and K-Means clustering. It is expected that the proposed algorithm could be more scalable for real time applications

V. ACKNOWLEDGMENT

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