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Cluster Head Election with Hexagonal Node Deployment Technique in Wireless Sensor Networks

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Abstract

Wireless Sensor Networks (WSNs) are a network of large number of wireless sensor nodes deployed over a wide geographical area. The sensor nodes have a limited amount of memory as well as power. Excess extent of energy is dissipated during data transmission to the base station (sink) from normal sensor nodes. The efficient way of prolonging the lifetime of sensor nodes is clustering which optimizes the energy dissipation of WSNs. In this paper, a homogenous clustering algorithm based on fuzzy logic has been proposed in which cluster head election is done with the help of two fuzzy descriptors namely residual energy and proximity distance. The sensor nodes have been hexagonally deployed in the homogenous environment. This covers the sensing area efficiently along with reducing the redundancy in data being transmitted by the sensor nodes. This algorithm has been compared with the low energy adaptive clustering hierarchy (LEACH) protocol. The simulation results show that the proposed approach outperforms the LEACH protocol in terms of number of data packets transmitted to base station, energy consumption and prolonged network lifetime.

***Keywords**: WSN, LEACH, node deployment, clustering*

I. Introduction

Wireless sensor networks are a new generation of recent networks which includes large number of sensor node devices scattered over a large field. Wireless sensor networks are used in army, hygiene, industry, education, agriculture . Sensor nodes in general are powered by small batteries that are hard to replace or recharge. Therefore energy constraint is a major challenge for wide and remote applications. Most of the energy consumption in the network is due to the information transference inside the network. Therefore, it becomes important to optimize the energy consumption and manage the power consumed by the sensor nodes.

Clustering is one of the widely used solutions to decrease the number of network's internal transference. In clustering, sensor nodes are divided into number of clusters and one node is selected as cluster head in each cluster.

In LEACH protocol [1], cluster heads are chosen first and then the members of each cluster head are determined. Cluster members send the received data to cluster head according to TDMA scheduler. Cluster head combines the received data and sends it to base station. As this algorithm just uses local information, the number of cluster heads in each round is not fixed and it may be less or more than the optimized amount in one round. Also, each node should produce and compute a random number and a threshold

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level in every round. LEACH guarantees that every node becomes cluster head evenly but it selects cluster heads randomly without taking into account nodes' energy level and the interrelationship among nodes. Also, it does not consider the location of the base station. This situation causes hot spot problems in multi-hop WSNs.

In this paper, cluster head election based on fuzzy logic along with hexagonal node deployment has been proposed, which aims to prolong the lifetime of WSNs. Fuzzy logic is basically the extension of dual logic (crisp logic) that includes the intermediate value between absolutely true and absolutely false[8,10]. It improves the accuracy in taking a decision about a system that has vague information. It has the efficiency to solve the system uncertainties when mathematical models fail to describe the system. The proposed approach considers the two parameters, residual energy and distance of node to the base station. In different iterations, the cluster head is selected based upon the residual energy and the distance of the sensor node to the base station. This helps to decrease the intra-cluster work of the sensor nodes which are closer to the base station or have lower battery level [9]. Fuzzy logic is utilized for handling the uncertainties in cluster-head radius estimation.

Another drawback of LEACH protocol is that the sensor nodes are randomly deployed throughout the sensing area. This may lead to two sensor nodes being too close to each other so that they are sensing redundant data due to overlapping in the sensing area or the sensors are too far away that they cannot sense the entire area between them.To remove this drawback, the sensor nodes have been homogeneously deployed using the hexagonal approach.

In this paper, the above mentioned limitations of LEACH protocol have been overcome using the fuzzy logic and the hexagonal homogenous deployment.

In section 2, work related to fuzzy logic and sensor deployment in Wireless Sensor Network has been mentioned. Section 3 consists of radio model used for the proposed approach. Section 4 describes the proposed approach that has been simulated in the paper. Further, section 5 consists of simulation parameters and results, and finally in section 6, states the conclusion and the future work that can be carried out.

II. Related Work

A. Unequal Clustering Algorithm for WSN Based On Fuzzy Logic and Improved ACO

In Unequal clustering algorithm for WSN based on fuzzy logic and improved ACO, the tentative cluster heads are selected by considering information held by every sensor node locally such as initial energy of the node, distance between the node and the base station and local density. Fuzzy logic system is used to determine one node's chance of becoming cluster head and estimate the corresponding competence radius [3]. The defuzzification method used is Centre of Area given by the formula:

$$Z_{COA} = \frac{\int_z \mu(z) z dz}{\int_z \mu(z) dz} \quad (1)$$

where μ (z) is the membership function after the outputs of all rules are aggregated. The drawback of the given approach is that the first dead node occurs at round number 861 which is quite low. Also, the nodes are randomly deployed throughout the sensing area and hence redundant data is transmitted by the nodes and the entire area is not sensed properly.

B. Enhancement of Wireless Sensor Network Lifetime by Deploying Heterogeneous Nodes

In Enhancement of wireless sensor network lifetime by deploying heterogeneous nodes, the issue of energy conservation is analyzed leading to subsequent enhancement of network lifetime. On the basis of the analysis done, a pre-determined node deployment scheme using heterogeneous nodes is proposed. Sensor nodes are deployed at the center of each cell ensuring proper coverage of the network [2]. The relay nodes are placed throughout the network area with a target to ensure connectivity. Energy consumption is balanced among the layers so that network lifetime can be prolonged while maintaining connectivity and coverage. The location (X, Y) where the nodes are to be placed is computed as follows:

$$X = \sqrt{3}\, r\, a\, \cos(m(\pi/3)) + \sqrt{3}\, r\, (i-a)\cos\big((m+1)\pi/3\big) + S\, \cos\big((2m \pm 3)\pi/6\big) + Q\cos\big((2p+1)\pi/6\big) \quad (2)$$

$$Y = \sqrt{3}\, r\, a\, \sin\big(m(\pi/3)\big) + \sqrt{3}\, r\, (i-a)\sin\big((m+1)\pi/3\big) + S\, \sin\big((2m \pm 3)\pi/6\big) + Q\, \sin\big((2p+1)\pi/6\big) \quad (3)$$

The value of m identifies each of the six regions into which the network area is divided. The limitation of the given approach is that it does not consider the interrelationship among the sensor nodes and selects the cluster heads randomly.

C. Cluster-Head Election Using Fuzzy Logic for Wireless Sensor Networks

In Cluster-head Election using Fuzzy Logic for Wireless Sensor Networks, the cluster-heads are elected by the base station in each round by calculating the chance each node has to become the cluster-head by considering three fuzzy descriptors - node concentration, energy level in each node and its centrality [4] with respect to the entire cluster. The defuzzification method used was Centre of Gravity given by the formula:

$$COG = \left(\sum \mu_A(x) * x\right) \Big/ \sum \mu_A(x) \quad (4)$$

where $\mu_A(x)$ is the membership function of set A. The limitation of the given approach is that the nodes are deployed randomly hence the data transmitted is redundant and most of the area is not sensed properly.

D. A Fuzzy Approach to Energy Optimized Routing for Wireless Sensor Networks

In Fuzzy Approach to Energy Optimized Routing for Wireless Sensor Networks, fuzzy model for energy aware routing in wireless sensor networks is proposed. The input fuzzy variables are: transmission energy, remaining energy, rate of energy consumption, distance from sink and weight [5]. There is a single output fuzzy variable, cost, the defuzzified value of which determines the cost of link between two sensor nodes. Total 144 rules for fuzzy rule base are used. The limitation of the given approach is that the lifetime of an individual node is lesser in the fuzzy approach due to complexity of rules.

E. Cluster Head Selection Using Fuzzy Logic and Chaotic Based Genetic Algorithm in Wireless Sensor Network

In Cluster Head Selection Using Fuzzy Logic and Chaotic Based Genetic Algorithm in Wireless Sensor Network, fuzzy logic algorithm is proposed based on three variables - energy, density and centrality- to introduce the best nodes to base station as cluster head candidate and to extend the lifetime of sensor nodes[6]. In local level, node’s capability for being cluster head has been evaluated based on two parameters: energy and the number of neighbors. In global level three parameters have been considered: Centrality, closeness to base station and the distance between cluster heads. The network lifetime and first dead node of fuzzy logic is compared is compared with genetic algorithm and LEACH protocol.

III. Energy Model Analysis

The energy dissipation model as used in the proposed approach is shown below in Figure 1. Each sensor node consists of a transmitter and receiver having some transmitter and receiver electronics. Energy is dissipated when nodes transmit and receive data.

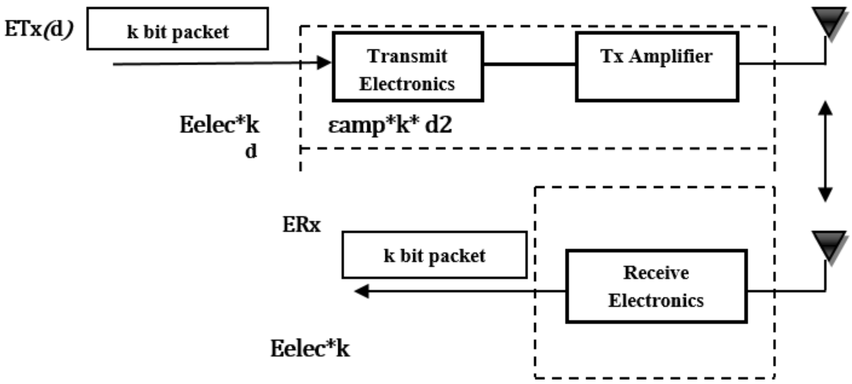

Figure 1. Energy Dissipation Diagram

When the sensor nodes transmit k-bit data by its transmitter, the energy dissipation is:

$$ET\ (k, d) = (Eelec * k) + (E_{fs}*k*d^2) \text{ if } d<= (E_{elec} * k) + (E_{mp}*k*d^4) \text{ if } d>d_0 \qquad (11)$$

- Eelec is the energy dissipated to run the electronics circuits
- k is the packet size
- Efs and Emp are the characteristics of the transmitter amplifier
- d is the distance between the two communicating ends.

When the sensor node receives k-bit data packet, the energy dissipation is

$$ER(k) = Eelec* k \qquad (12)$$

The radio characteristics and energy due to electronics are –
Eelec = 50 nJ/bit
Efs = 10 pJ/bit/m2
Emp = 0.0013pJ/bit/m4
In addition to above energy dissipations, CHs also dissipates energy in data aggregation. The data aggregation energy EDA has the value of 5nJ/bit/signal.

IV. Fuzzy Model

The model of fuzzy logic control consists of a fuzzifier, fuzzy rules, fuzzy inference engine, and a defuzzifier [12]. The crisp data is converted into fuzzy sets by the fuzzifier. Then rules are applied on the fuzzy sets to produce an output in form of a fuzzy set. The defuzzifier then converts the output fuzzy set to crisp output using one of the many defuzzification techniques [13]

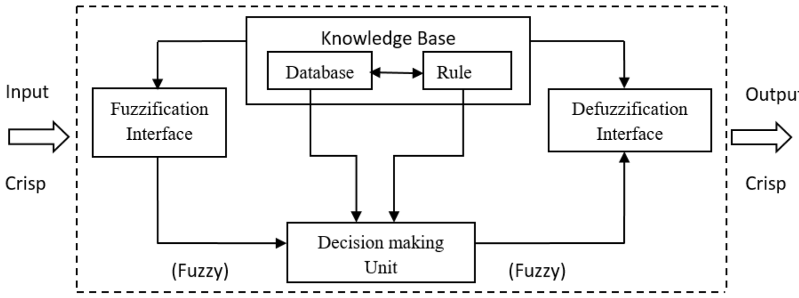

Figure 2. Fuzzy System

A Fuzzy system basically consists of three parts:

(1) Fuzzifier: The fuzzifier maps each crisp input value to the corresponding fuzzy sets and thus assigns it a truth value or degree of membership for each fuzzy set.
(2) The inference engine processes the fuzzified values, which consists of a rule base and various methods for inferring the rules. The rule base is simply a series of IF-THEN rules that relate the input fuzzy variables with the output fuzzy variables described by operators AND, OR etc [14].
(3) Defuzzification: The process of producing a quantifiable result from fuzzy sets and corresponding membership degrees [15].

V. Proposed Approach

Various soft computing algorithms are available to increase the lifetime of a wireless sensor network. In our approach, fuzzy logic helps in cluster head selection whereas the normal nodes are allocated to the cluster heads with the help of LEACH protocol. Fuzzy logic is used to find out the chance for a node to become cluster head which helps in the cluster head selection process [7, 11]. The optimization of the cluster head selection mechanism is used in this approach to increase the lifetime of the network. A sensor deployment technique is also incorporated so as to increase the area covered by the sensors and to reduce the transmission of redundant data to the base station.

In this approach, the cluster-heads are elected by the base station in each round by calculating the chance of each node to become the cluster-head by considering two fuzzy descriptors-energy and distance. In this approach, the most commonly used fuzzy inference technique Mamdani Method is used in this approach. The input parameters for fuzzy logic controller in the proposed approach are:

- Node's Energy: shows the energy remaining of each node after each iteration
- Node's Distance: shows the distance of the node from the base station situated at (50, 50).

In order to calculate the distance, each node calculates its distance from the base station and then this data is passed to the fuzzy logic control as input. Language variables for each of the inputs are:

Energy= (low, medium, high)

Distance= (near, middle, far)

The developed membership functions and their linguistic states are represented in table 1 and figures 3-5.

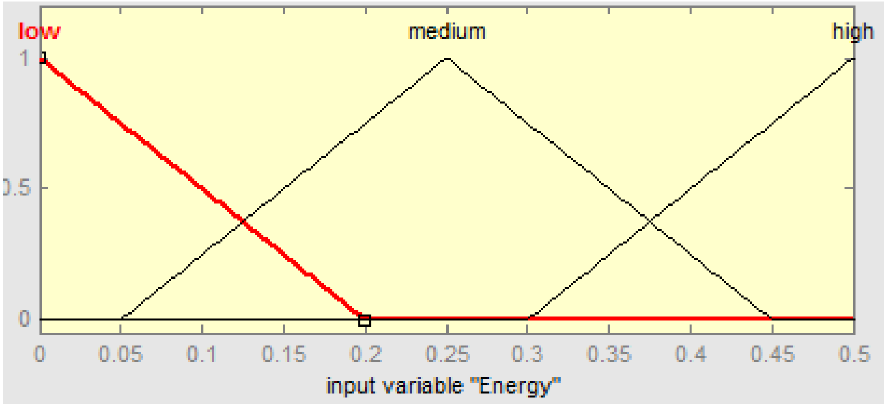

Figure 3. Fuzzy Set for Fuzzy Variable Energy

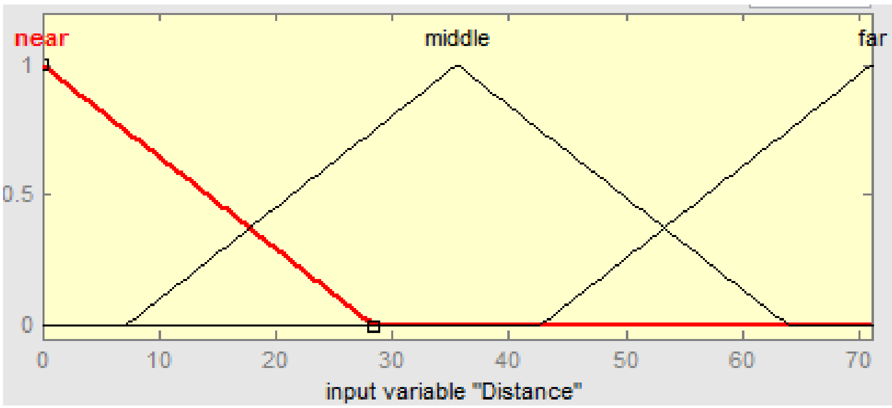

Figure 4. Fuzzy Set for Fuzzy Variable Distance

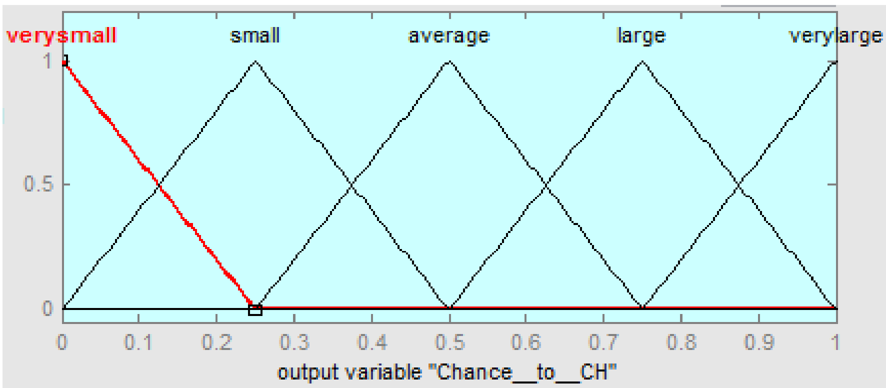

Figure 5. Fuzzy Set for Fuzzy Variable Chance to Ch

Table 1.Fuzzy Sets for Input Fuzzy Variables

Input Variable	Fuzzy Set		
Energy	Low	Medium	High
Distance	Near	Middle	Far

The linguistic variables used to represent the node energy are divided into three levels: *low*, *medium* and *high*, respectively, and there are three levels to represent the node's distance from base station: *near*, *middle* and *far*, respectively.

The outcome to represent the node cluster-head election chance was divided into five levels: *very small*, *small*, *average*, *large*, and *very large*. The fuzzy rule base currently includes rules like the following: if the *energy* is *high* and the *distance* is *middle* then the node's cluster-head election *chance_to_CH* is *very large*.

Thus we use $3^2 = 9$ rules for the fuzzy rule base. The fuzzy rule base is represented in table 2.

Table 2. Fuzzy Rule Base

	Energy	Distance	Chance_to_CH
1.	Low	Far	Very Small
2.	Low	Middle	Small
3.	Low	Near	Small
4.	Medium	Far	Average
5.	Medium	Middle	Average
6.	Medium	Near	Average
7.	High	Far	Large
8.	High	Middle	Very Large
9.	High	Near	Large

The sensor deployment approach mentioned is inspired from the cell structure in mobile communication. The sensors are deployed at the centre of each cell. Although the nodes have a circular sensing area, the deployment virtually represents the nodes in a hexagonal pattern.

The radius of the sensing area of sensor is taken as the distance from the centre of cell to any one of the edge. The distance between any two neighbouring sensors is 10 and the area covered by each sensor is 104.59.

The proposed approach for deployment shows that very few gaps are left between sensors and amount of redundant data sensed by the sensor node becomes very low.

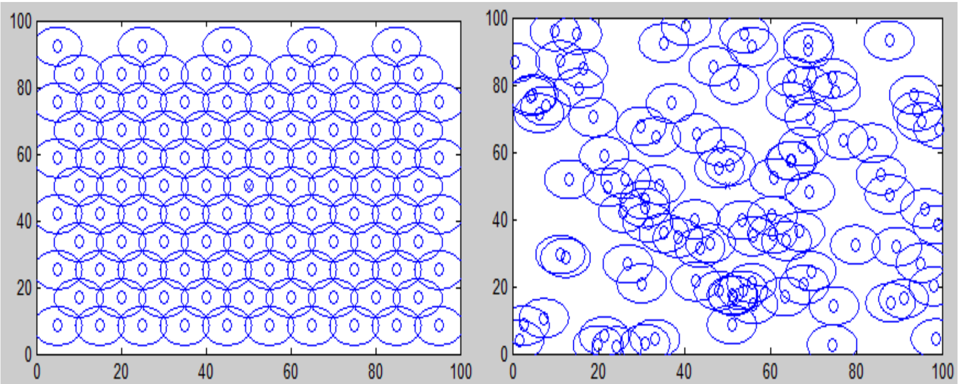

Figure 6. Comparison between Proposed and Random Deployment Strategy

From figure 6 we can see that the proposed approach has very few gaps and very few sensing area has been lost whereas in random node deployment there are a lot of gaps and amount of redundant information is very high.

In our approach as shown in figure 7, we use LEACH protocol as basis for transmitting data from the sensor node to the base station. Algorithm followed in implementing this approach is given below:

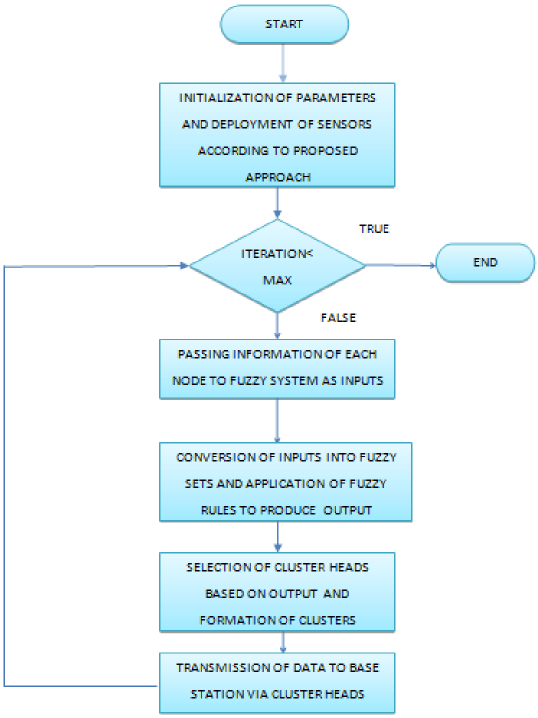

Figure 7.Flow Chart of Proposed Approach

Proposed Algorithm

1. **Sensor Initialization**: All the sensor nodes are initialized with an initial energy Eo.
2. 2**. Sensor Deployment**: The sensors are deployed hexagonally to increase the sensing area and to minimize the redundant data.
3. **Fuzzification**: The crisp input data consisting of energy and distance of node from base station is converted to fuzzy sets.
4. **Application of fuzzy rules**: Fuzzy rules are applied to the fuzzy sets and the fuzzy outputs are formed.
5. **Defuzzification:** The fuzzy sets are converted into classical sets by applying Centroid defuzzification technique.
6. **Cluster Head Selection**: Cluster heads are selected as per the value of the output from the fuzzy inference system.
7. **Cluster Formation**: Clusters are formed surrounding the cluster heads and data is then transferred to the base station via the cluster heads.

VI. Simulation Parameters and Results

In our simulation, we have compared the performance of LEACH protocol with our proposed approach in both random and proposed deployment strategy. These sensor nodes may be distributed in 100*100 square. All the nodes have same transmission range.

The sink node i.e. base station lies at the center of this square area (50, 50). These three algorithms are compared on the basis of:

1. Total number of nodes alive within the system at different rounds of iterations.
2. Total energy of the system at different rounds of iterations.
3. Total number of packets transmitted to the base station at different rounds of iterations.

Simulation results show that the proposed algorithm have higher stability period and better energy utilization as compared to existing LEACH protocol.

For simulation 100 nodes are deployed within a region of 100*100. The parameter values used for simulation are:

Table 3.Simulation Parameters

PARAMETERS	VALUES
Network Size	100x100
Base Station coordinates	50,50
No. of nodes	100
Sensing Radius	5.77
Initial Energy (E_0)	0.5 Joules
ETX=ERX	50*0.000000001 Joules
Transmit Amplifier types Efs Emp	 10*0.000000000001Joules 0.0013*0.000000000001 Joules
Data Aggregation Energy (EDA)	5*0.000000001 Joules
Packet Size	4000 bits
Maximum number of rounds (rmax)	2000

Figure 8 shows the improvement in the stability region of the proposed approach in comparison to the existing LEACH protocol with random deployment and hexagonal deployment.

It is clear from the figure 8 that if we use hexagonal node deployment in LEACH, the stable period of LEACH protocol improves. However, the cluster head selection is random in this case. In our proposed approach the cluster head selection is based on two fuzzy descriptor and node are deployed hexagonally shows that the proposed approach outperforms LEACH in terms of stability period that is the period between the start of network and first node dead.

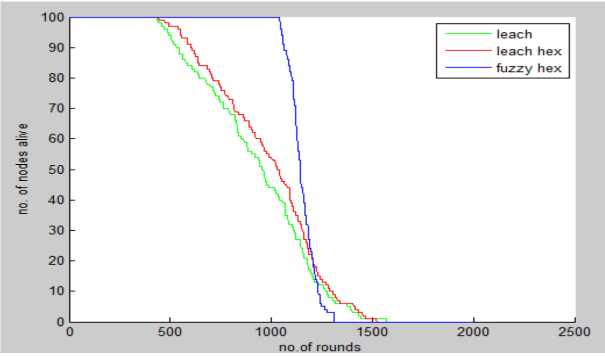

Figure 8. Total No. of Nodes Alive in the System at Different Rounds of Iteration

Figure 9 shows the comparison on the basis of total energy remaining within the system with the total number of rounds. From the figure, it is clear that proposed approach has better energy utilization as compared to the LEACH protocol when the sensors are deployed randomly as well as when the sensors are deployed as per the proposed approach.

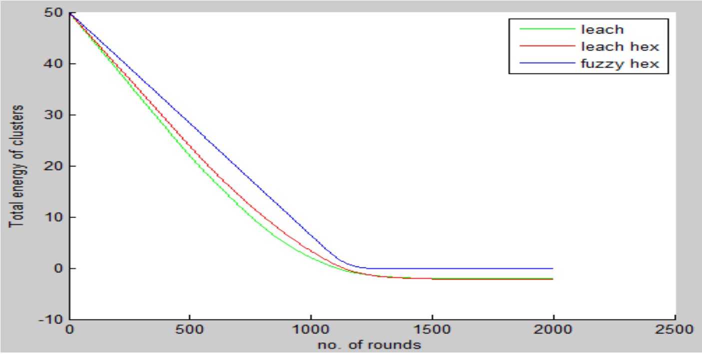

Figure 9. Total Energy of the System at Different Rounds of Iterations

Figure 10shows the information received by the base station and from the figure it is clear that total number of packets received by the base station in case of proposed approach are much greater than the existing LEACH protocol when the sensors are deployed randomly as well as when the nodes are deployed hexagonally.

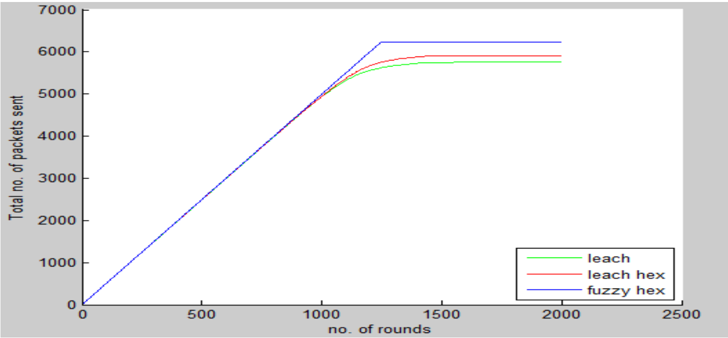

Figure 10. Total Number of Packets Transmitted to the Base Station at Different Rounds of Iterations

VII. Conclusion

Proposed approach is cluster based technique in which respective cluster heads are chosen on the basis of Fuzzy Logic. Proposed approach is able to give best results as proved in simulation results obtained. From the simulation of both the approaches following results are obtained:

1. There is a major improvement in stability period as compared to existing LEACH protocol.
2. Energy utilization is optimized in case of proposed approach as compared to LEACH protocol.
3. Information received by the Base Station has increased considerably.

In future attempts, the process of routing could be optimized using optimization techniques namely ACO and firefly algorithm to improve energy consumption while sending data from nodes to base station.

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