Volume 4, Issue 6, June 2014 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Energy Efficient Heterogeneous Clustering Protocol for Wireless Sensor Networks using Fuzzy Logic with different Base Station Locations

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Abstract - Lifetime enhancement of a wireless sensor network is always an issue for network designers. To obtain this goal number of energy efficient protocols has been developed. Most of these protocols are based on hierarchical approach using clustering. LEACH (Low Energy Adaptive Clustering Hierarchy) was the first hierarchical based clustering algorithm in which cluster heads are determined using probabilistic approach in a dispersed manner. Then many protocols had been proposed but very few of them utilized the concept of energy prediction. In this paper, we introduced Fuzzy based Energy Efficient Heterogeneous Clustering Protocol (FEEHCP), which exhibit the role of fuzzy logic based clustering using two input parameters as Predicted Residual Energy (PRE) and Distance to Base Station (DBS) for appropriate clustering in a heterogeneous sensor network. Heterogeneity considered in this work on the basis of energy, we classify three groups of sensor nodes in the network. The simulation results of FEEHCP shows a significant perfection in terms of FND (First Node Dead), HND (Half Node Dead) compared to LEACH, EEHC and LEACH-ERE algorithms.

Keywords— Clustering, hierarchical, fuzzy logic, probabilistic, wireless sensor network.

I. INTRODUCTION

A wireless sensor network is a technology that emerges as an outcome of the advancement of network technology along with Micro Electro Mechanical Systems (MEMS). MEMS make it possible to design small size, low power sensors having communication and processing capabilities [1]. Wireless sensor networks are mainly valuable in battlefield surveillance; environment monitoring, traffic monitoring [2] and [3], weather and climate monitoring, detection of chemical or biological agent threats, and healthcare monitoring require information gathering in harsh and inhospitable environments. These applications demand the use of various equipment including cameras and acoustic, infrared and seismic sensors for measuring different physical parameters [4]. In a sensor networks nodes sense the information and transmit the collected data to base station through various paths such as direct and multi-hop. Actually, a WSN consist of hundreds to thousands of sensor nodes deployed in a random manner. Every sensor node is accountable for sensing their respective vicinity and transmits sensed information to the Base Station (BS). Sensor nodes utilize non-rechargeable energy sources so the energy optimization in WSNs is a major design issue [5]. The architecture of wireless sensor network mainly consists of target area, sensor nodes, BS and user as shown in Fig. 1.

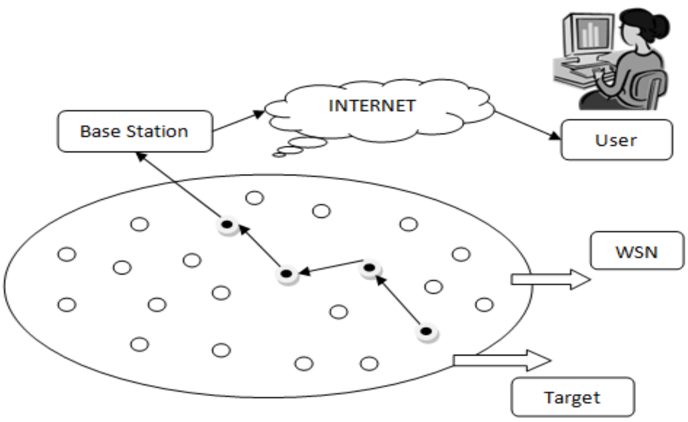

Fig. 1 Wireless sensor network

As, energy optimization is the major issue while designing wireless sensor network. So, a number of communication protocols have been developed in this direction. Most of them were based on Low Energy Adaptive Clustering Hierarchy LEACH [3]. In LEACH protocol it was assumed that all the nodes are equipped with same amount of energy, therefore it is said a homogeneous environment.

II. RELATED WORK

Many researchers have worked for the development of clustering algorithms. An exhaustive research area in sensor networks is to prolong the lifetime of the network. The core objective of clustering in sensor networks is to divide the complete network into small sub sections, so as to extend the lifetime of WSNs by reducing the amount of data transferred. LEACH [3] is the first hierarchical clustering protocol for making sensor networks energy efficient. This protocol selects CHs randomly based on predefined threshold value and then rotates this process to equilibrium the energy consumption. LEACH operation consists of two phases – setup and steady state phase. During setup phase cluster heads are selected and in steady state phase information transmission takes place. The threshold value [3] is given below.

$$T(n) = \begin{cases} \dfrac{p}{1 - p*(r*\mathrm{mod}(1/p)} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

Where p is desired percentage of CHs, r is current round
and G is the set of nodes that have not been cluster head in last 1/p rounds.

After 1/p rounds all nodes become eligible to become cluster heads [3]. After CHs selection each CHs broadcast an advertisement and after receiving these advertisements, rest of the sensor nodes choose their respective cluster head based on the received signal strength. After that CH creates a TDMA frame for scheduling each node's transmission time. LEACH is a distributed approach so results in poor clustering as some CHs are near to the BS and some are very far away. In addition to this as the deployment of the network is random so some CHs have more number of cluster members than others. The CHs far from BS and CHs having more number of cluster members deplete their energy quickly as compared to other CHs. LEACH-C [7], an improvement over LEACH in terms of cluster formation as this is a centralized approach. Base station utilizes universal information about energy and position of nodes in WSN. Every node transmits its current location (possibly using Global Position System Receiver) and energy level to the base station during set up phase. Based upon the location and energy level of nodes, CHs will be selected and rest is same as LEACH. EEHC (Energy Efficient Heterogeneous Clustered) [8], introduced heterogeneity in terms of energy to extend the sensor network's lifetime. In this research work, three categories of sensor nodes are used as normal nodes, advanced nodes and super advanced nodes. Gupta et al. [9] introduced fuzzy logic in wireless sensor networks for CHs selection process using three inputs (residual energy, concentration and centrality). All information regarding these input parameters is provided at BS then CHs are elected in a centralized mode. Kim et al. [10] proposed a distributed protocol for selecting cluster heads using fuzzy logic with inputs as (residual energy and local distance). Lee et al. [11] proposed an outline for energy prediction in wireless sensor networks using fuzzy logic. The proposed protocol named as LEACH-ERE (LEACH Expected Residual Energy) has utilized Energy Prediction methodology in clustering using fuzzy logic with input fuzzy descriptors as residual energy and expected residual energy. Apart from this protocol, the energy of a sensor node after selecting as a CH and run a full round has never been discussed. This approach outperforms LEACH and CHEF (Cluster Head Election using Fuzzy Logic) [15]. LEACH-ERE is more efficient than LEACH about 42.61%. Although this protocol extend the lifetime of the sensor network as compared to LEACH but only limited to homogeneous stationary nodes which can be further modified for better performance using heterogeneous sensor nodes. Din et al. [12] proposed fuzzy logic based clustering approach using two important parameters that are residual energy and centrality. According to this research work, only residual energy is not enough for appropriate clustering that result in prolongation of the network lifetime. A fuzzy rule base of 9 rules has also been used in this research. Heterogeneous environment approach has been considered for this research. The major limitation of this research is that there is no clear idea about exact parameters taken for simulation. Thus, as a future scope of this work heterogeneous sensor node with fuzzy parameters such as distance to base station can be consider for improvement in the lifetime of the sensor network. Also, energy prediction methodology may be added in this for further enhancement of the lifetime.

III. FUZZY BASED ENERGY EFFICIENT HETEROGENEOUS CLUSTERING PROTOCOL (FEEHCP)

A. Mathematical Modeling of Radio Energy Model

In wireless communication, power dissipated depends on distance between transmitter and receiver given by power law function. If distance between transmitter and receiver is less than or equal to crossover distance d_o then free-space environment is considered otherwise two ray ground propagation is considered [30]. For free space environment, Friss Free Space Equation for received power is given as in (2).

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2 L} \quad (2)$$

where, P_t is transmitted power, G_t and G_r are gains of transmitting and receiving antennas respectively, λ is wavelength, d is distance between transmitter and receiver, L is system loss factor (L≥1).

Thus as per equation (2) received power is inversely proportional to the square of the crossover distance. If the distance between transmitter and receiver is greater than $d_{o,}$ then two ray ground propagation models is given as in (3).

$$P_r(d) = \frac{P_t G_t G_r {h_t}^2 {h_r}^2}{d^4} \quad (3)$$

Where h_t and h_r are heights of transmitting and receiving antennas respectively [30]. Equating (3.1) and (3.2) crossover distance can be calculated as given by (4).

$$d_o = \frac{4\pi\sqrt{L}h_t h_r}{\lambda} \tag{4}$$

The power attenuation is dependent on the distance between transmitter and receiver. For short distances (single hop), the propagation loss is inversely proportional to square of the distance (d^2) between transmitter and receiver, whereas for longer distances (multi hop), it is inversely proportional to d^4. In this case, the received signal comes from both the direct path and a ground-refection path. Due to destructive interference when there is more than one path through which the signal arrives, the signal is attenuated as d^4. The radio model used is shown in Fig. 2.

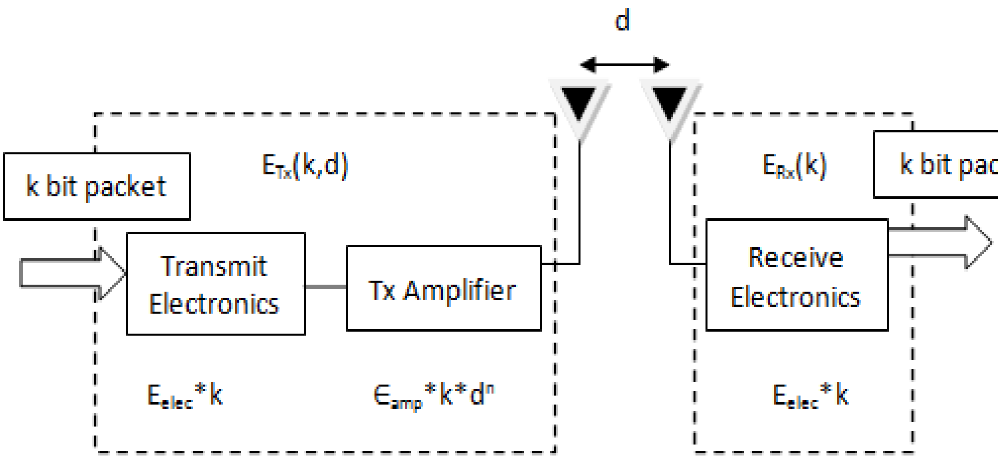

Fig. 2 Radio Model [7]

Thus to transmit a k bit message to distance d, the radios consume energy as per following equations (5) and (6).

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \tag{5}$$

$$E_{Tx}(k,d) = \begin{cases} k*E_{elec} + k*\varepsilon_{fs}*d^2, & d < d_o \\ k*E_{elec} + k*\varepsilon_{mp}*d^4, & d \geq d_o \end{cases} \tag{6}$$

Where E_{elec} is the energy consumption per bit in transmitter and receiver circuits. Also, ε_{fs} and ε_{mp} are the energy consumption factor of amplification for the free space and multipath radio models, respectively. The threshold value do is crossover distance [7] and is given by (7).

$$d_o = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{7}$$

If distance is less than d_o, free space model is used; otherwise two ray ground model is used [3]. To receive this message packet the radio consumes energy as per equation (8).

$$E_{Rx}(k) = k*E_{elec} \tag{8}$$

B. Predicted Residual Energy (PRE)

This is the leftover energy of a sensor node after running a complete round. For calculating this energy one must know the amount of energy consumed in running a complete round as a cluster head. Because most of energy of a sensor node get consumed when it become Cluster Head (CH) because as a CH a sensor node has to receive data from its cluster members, aggregate these data packets into one and then send this packet to Base Station (BS). Thus, if number of cluster heads in previous round known then we can easily calculate the energy consumption by using [5] (9).

$$ECE = CH(r)*[E_{Tx}(k,d_{toBS}) + \{((alive(r+1)/CH(r)) - 1\}*E_{Rx}(k)] \tag{9}$$

where CH(r) is the number of cluster heads in round r, k is the message length in bits, d_{toBS} is distance to the base station can be calculated via received signal strength, alive(r+1) are number of alive nodes in current round. It is believed that all cluster members send their data to CH and then aggregated message will be sent to the BS. So, for calculating expected consumed energy here we assume that the clusters in the next round will be approximately equal as in previous round and the cluster members can be calculate through number of alive nodes in current round divided by the number of CHs. Thus, Predicted Residual Energy can be calculated by [5] (10).

$$PRE = RE - ECE \tag{10}$$

Where RE is residual energy of the sensor node.

C. Proposed Fuzzy Inference System (FIS)

The architecture of FIS (Fuzzy Inference System) consists of three modules as fuzzifier, inference engine and defuzzifier. Proposed work introduced fuzzy logic control for deciding eligible candidates for CHs selection process as shown in Fig. 3 [14]. For each node, FIS (fuzzy inference system) compute the chance using two input parameters as Predicted Residual Energy (PRE) and Distance to Base Station (DBS). The FIS's output contain a set of those nodes which have sufficient energy to run a round successfully.

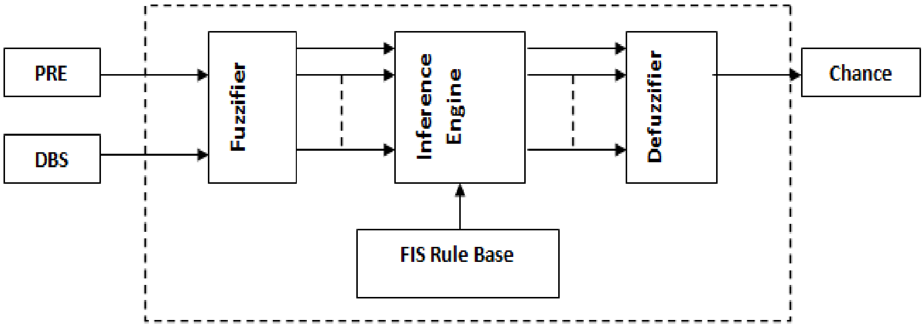

Fig. 3 Proposed Fuzzy Inference System (FIS)

The linguistic variables for PRE (Predicted Residual Energy) are taken as very low, low, medium, high and very high. The membership grades distribution for RE is shown in Fig. 4.

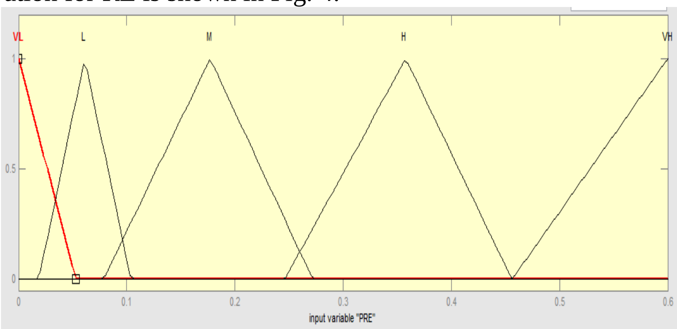

Fig. 4 Lingustic Variables and Membership functions for PRE

The linguistic variables for DBS (Distance to Base Station) are taken as very near, near, medium, far and very far. The membership grades distribution for DBS is shown in Fig. 5.

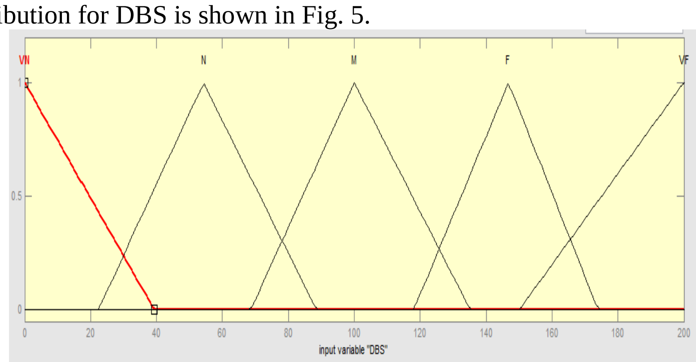

Fig. 5 Lingustic Variables and Membership functions for DBS

The linguistic variables for Chance are taken as very low, low, medium, high and very high. The membership grades distribution for Chance is shown in Fig. 6.

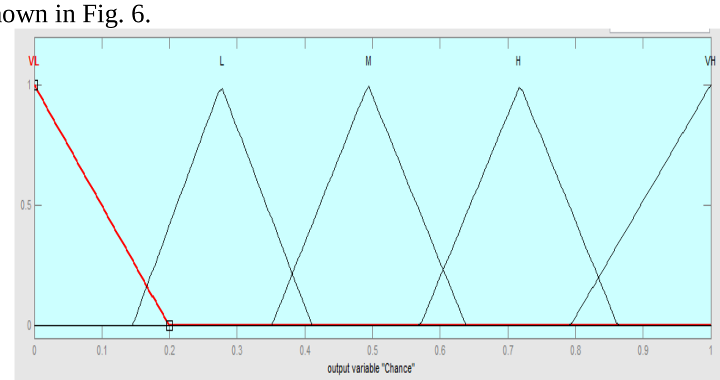

Fig. 6 Lingustic Variables and Membership functions for Chance

In FEEHCP protocol, FIS (Fuzzy Inference System) include 21 rules, mentioned in Table I decide the chance for each node to be a CH by using two input parameters as predicted residual energy and distance to base station. After that a set of eligible candidates is available from which CHs will selected randomly using LEACH threshold value with some modification. The rule-base used in proposed algorithm is given in Table I.

Table I Rule Base for FEEHCP

RULE NO	PRE	DBS	CHANCE
1	very low	very near	very low
2	very low	near	very low
3	very low	medium	very low
4	Low	very near	low
5	Low	near	low
6	Low	medium	very low
7	Medium	very near	high
8	Medium	near	medium
9	Medium	medium	low
10	Medium	far	low
11	Medium	very far	very low
12	high	very near	very high
13	High	near	high
14	high	medium	high
15	high	far	medium
16	high	very far	low
17	very high	very near	very high
18	very high	near	very high
19	very high	medium	very high
20	very high	far	high
21	very high	very far	medium

This parameter indicates the distance of each sensor node from the base station. As in LEACH some cluster heads are very near to the base station and some are very far, thus the CH far away from the BS deplete its energy earlier. So, to overcome this problem this parameter must be consider while deciding cluster heads. The location of every sensor node in deployment area can be find out using Global Positioning System (GPS) installed with each sensor node. Then, using equation (11) the distance can be calculated. The equation used for this purpose is common formula used for finding the distance between two stationary points in space.

$$DBS = \sqrt{(x_d - x(i))^2 + (y_d - y(i))^2} \tag{11}$$

Where, x(i) and y(i) indicate the position of sensor node in x and y co-ordinates and x_d and y_d shows base station location.

D. Heterogeneous Sensor Network

The proposed system model of wireless sensor network is equipped with heterogeneous nodes with respect to their initial amount of energy. There are N nodes distributed uniformly in M*M region. We introduced three classes of nodes in this protocol: group-I, group-II, and group-III nodes. Let A be the fraction of total number of nodes N, and A_0 is the percentage of the total number of nodes A which are equipped with x times more energy than group -III nodes also called as group -I nodes. The rest $N*A*(1-A_0)$ nodes are equipped with y times more energy than the group -III nodes also called as group -II and the remaining N*(1-A) considered as group -III nodes. Let E_0 is the initial energy of every normal node. Then the energy of group -I node is given by $E_0(1+x)$ and energy of each group -II node is given by $E_0(1+y)$. Thus, the total energy of the network will be given by (12).

$$N*E_0*(1-A)+N*E_0*A*(1-A_0)*(1+y)+N*A*A_0*E_0*(1+x) \tag{12}$$

$$= N*E_0*[1+A*(y*(1-A_0)+A_0*x)] \tag{13}$$

In the equation (13), $A_0 << 1$, so $(1-A_0)$ can be considered as 1. Now this equation will be modified as (14).

$$N*E_0*[1+A*(y+A_0*x)] \tag{14}$$

So, the total energy of the system is increased by the factor of $[1+A*(y + A_0*x)]$. Since a heterogeneous network is made up of different types of nodes equipped with different energy resources, it is not advantageous to set same threshold for all the nodes because it would not guarantee formation of (N*p) cluster heads in every round per epoch. To overcome this, a weight is assigned to the optimal probability p. Let p_{g1}, p_{g2} and p_{g3} be the weighted election probabilities of group-I, group-II and group-III nodes respectively and then they are given by (15), (16) and (17) respectively.

$$p_{g1} = p_{g3} * (1 + x) \quad (15)$$

$$p_{g2} = p_{g3} * (1 + y) \quad (16)$$

$$p_{g3} = \frac{p}{1 + A * (y + A_0 * x)} \quad (17)$$

By substituting the value of p_{g3} in equation (15) and (16) the values of p_{g1} and p_{g2} can be calculated. Now substituting weighted probabilities from equations (15), (16) and (17) in equation (1) to obtain threshold values for group-I, group-II and group-III nodes respectively. Let T_{g1}, T_{g2} and T_{g3} be the threshold for group-I, group-II and group-III nodes respectively. Thus for group-III nodes threshold will be:

$$T_{g3} = \begin{cases} \dfrac{p_{g3}}{1 - p_{g3}\left(r \bmod \dfrac{1}{p_{g3}}\right)}, & \text{if } node \in G' \\ 0, & otherwise \end{cases} \quad (18)$$

Similarly the threshold values for group-I and group-II can be calculated.

E. FEEHCP Flow Chart

Fig. 7 shows the flow chart of proposed algorithm.

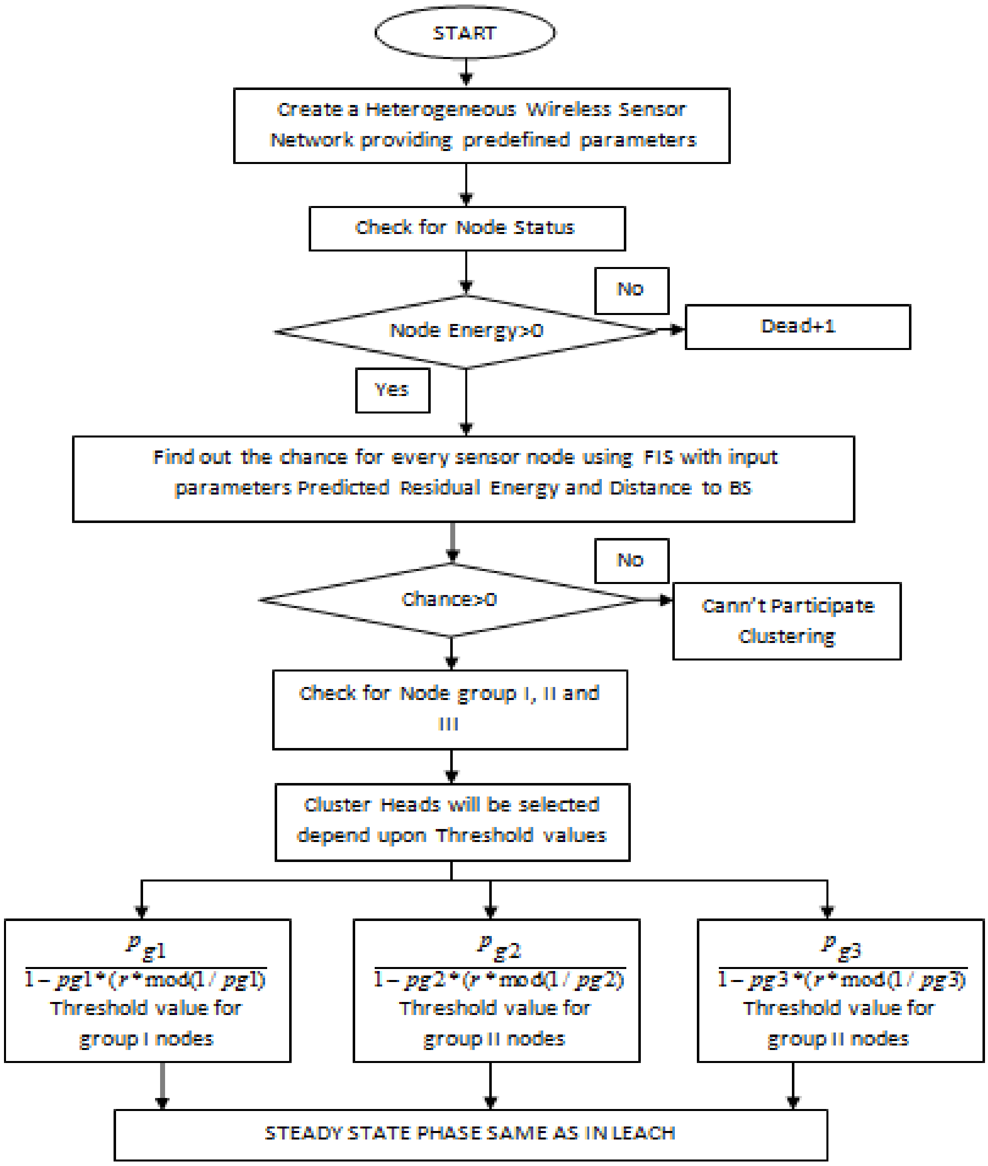

Fig. 7 Flow Chart of FEEHCP

IV. Simulation and Evaluation

In this section simulation outcomes and their evaluation has been discussed. The experimental results of FEEHCP are demonstrated and it has been compared with LEACH, LEACH-ERE and EEHC.

A. Simulation Parameters

In this research work, total of 100 sensor nodes with the dimensions of network as 100m x 100m and the location of base station at (50, 50) which is at the center of the network and (50, 175) which is far away from sensing region is considered. All considered simulation parameters for this research work are mentioned in Table II.

Table II Simulation Parameters

Description	Value
Total nodes in the network, N	100
Desired clusters percentage, p	5%
Base station position	(50, 50) and (50, 175)
Initial energy of normal nodes, E_o	0.2 J
Energy consumed by transmitter or receiver circuit, E_{elec}	50 nJ/bit
Amplification circuit energy in free space, ε_{fs}	10 pJ/bit/m^2
Amplification circuit energy in multipath, ε_{mp}	0.0013 pJ/bit/m^4
Data packet size	4000 Bits

Assumed network configurations are shown in Fig. 8 and Fig. 9.

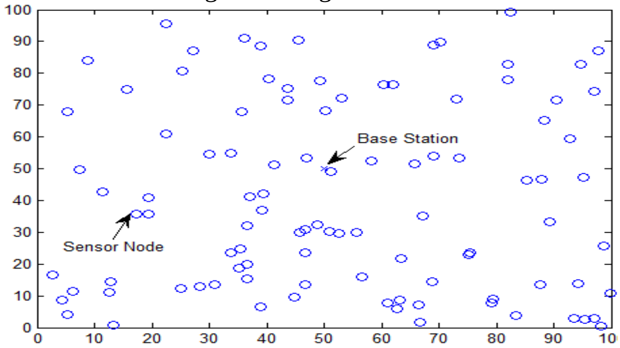

Fig. 8 Test Network with BS at (50, 50)

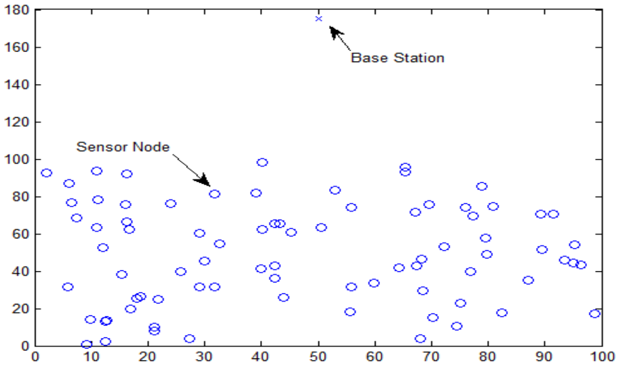

Fig. 9 Test Network with BS at (50, 175)

For introducing fuzzy logic in simulation fuzzy logic toolbox also used. The proposed FIS using fuzzy logic toolbox is shown in Fig. 10.

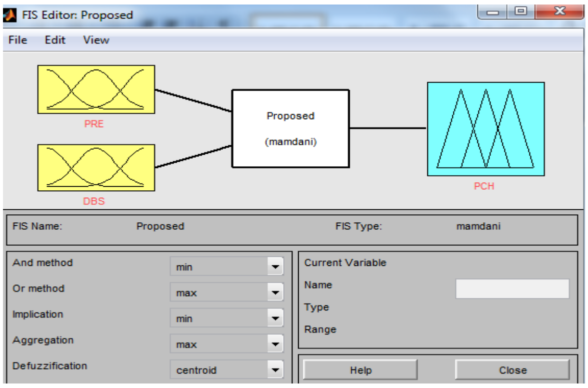

Fig. 10 Proposed FIS using fuzzy logic toolbox

The definitions of validation parameters used to analyze different protocols are:

- Network Lifetime: It is defined as the period from the start of network operation till the last node dead.
- Stability Period or First Node Dead (FND): It is defined as the period from the start of network operation till the death of first node.
- Half Node Dead (HND): It is defined as the period from the start of network operation till the death of half nodes.

A comparison is drawn between the performance of FEEHCP with LEACH, EEHC and LEACH-ERE protocols in terms of network lifetime and in terms of FND and HND performances. Comparison results for network lifetime of FEEHCP with that of LEACH, EECH and LEACH-ERE protocol is shown in Fig. 11 and Fig. 12. From this graph, it is clear that network lifetime of FEEHCP has improved further from other existing protocols. FEEHCP protocol is proposed for heterogeneous WSNs including fuzzy based clustering. Since, nodes are heterogeneous and fuzzy logic based clustering approach had adopted, so the total energy of the network has been increased and properly utilized using energy prediction using fuzzy logic.

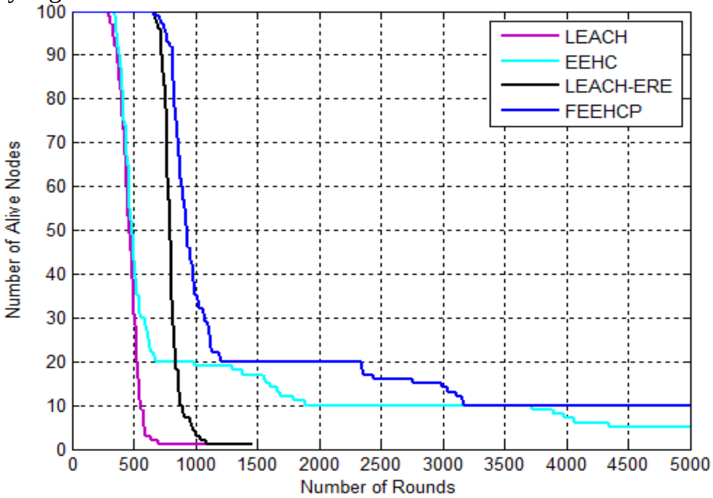

Fig. 11 Comparative Network Lifetime Performance Curve with BS at (50, 50)

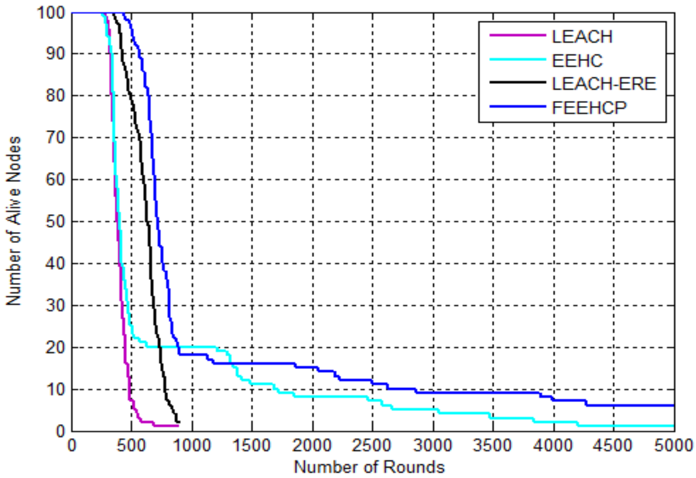

Fig. 12 Comparative Network Lifetime Performance Curve with BS at (50, 175)

In Table III the FND and HND performance parameters are provided for the analysis of network.

Table III Analysis of FEEHCP in comparison to (a) LEACH (b) EEHC (c) LEACH-ERE

Parameter →	**FND**	**HND**	**Improvement %**	
Protocol			**FND**	**HND**
With Base Station at (50, 50)				
LEACH / FEEHCP	316 / 676	467 / 894	113.9	91.4
EEHC / FEEHCP	328 / 676	491 / 894	106.0	82.1
LEACH-ERE / FEEHCP	660 / 676	804 / 894	2.4	11.2
With Base Station at (50, 175)				
LEACH / FEEHCP	279 / 420	373 / 756	50.5	102.6
EEHC / FEEHCP	302 / 420	388 / 756	39.1	94.8
LEACH-ERE / FEEHCP	343 / 420	668 / 756	22.4	13.2

From Table III the improvement achieved by FEEHCP in terms of FND and HND is mentioned. With the inclusion of heterogeneous nodes and fuzzy logic the stable region of FEEHCP becomes larger than other clustering protocols.

In addition to this, results clearly show that the sensor network's lifetime also prolonged. Heterogeneity including fuzzy clustering achieves the lifespan of more than 10000 rounds. Thus, FEEHCP performance is outstanding in comparison to LEACH, EEHC and LEACH-ERE. The FND and HND comparison chart is shown in Fig. 13 and Fig. 14.

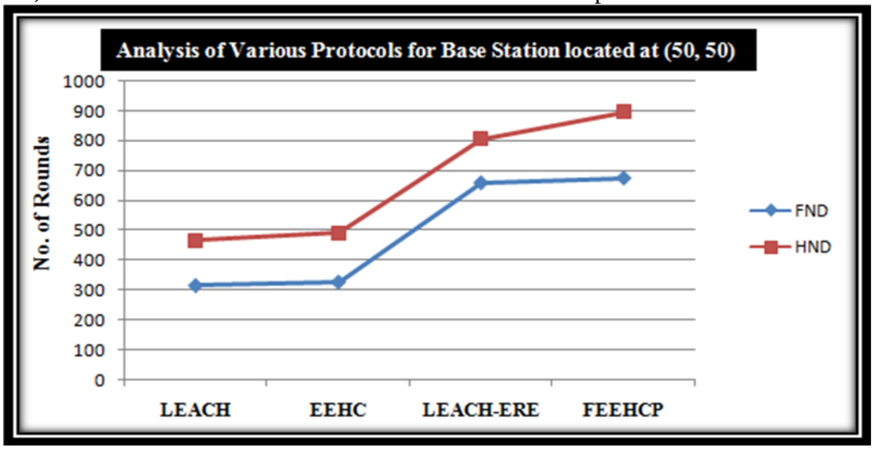

Fig. 13 FND and HND Comparison Chart with BS (50, 50)

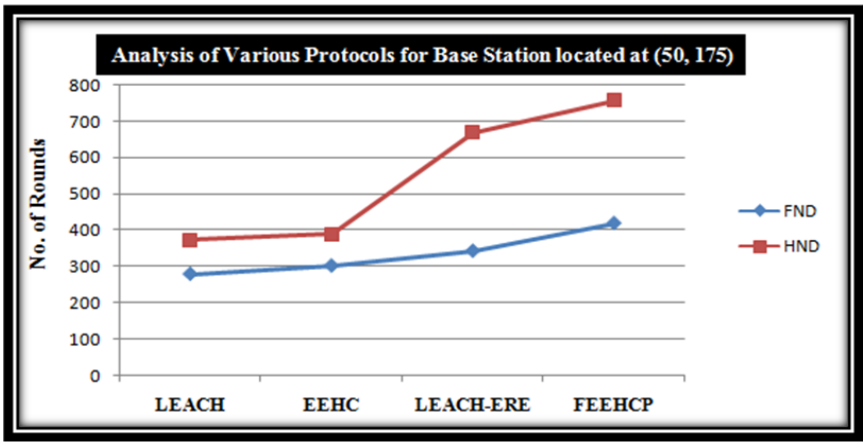

Fig. 14 FND and HND Comparison Chart with BS (50, 175)

V. CONCLUSION AND FUTURE SCOPE

Energy utilization is the major hurdle in sensor networks and to avoid this many clustering schemes are proposed. Most of the fundamental approaches utilize probabilistic approach for cluster head selection. Further advancement has been done with the inclusion of heterogeneity for prolonging the lifespan of sensor network. In this paper, Fuzzy based Energy Efficient Clustering Protocol has been proposed for WSN systems. The following conclusions have been drawn from the simulation results.

- The proposed protocol improved the stability period or FND (First Node Dead) period by a factor of 113.9% and 50.5% for different base station location (50, 50) and (50, 175) respectively compared to LEACH that is improved performance compared to LEACH. This improvement is attributed to the fact that proposed protocol used two input parameters such as Predicted Residual Energy (PRE) and Distance to Base Station (DBS) using fuzzy logic in cluster formation compared to LEACH [10] that uses only one. Relying on one parameter is not suitable to produce good clustering.
- In FEEHCP the energy is consumed in a balanced fashion in the network. As a result, the proposed protocol does not suffer from an early node death problem that could happen in the case where some nodes consume energy at a higher rate than others.
- FEEHCP operates in a distributed and centralized manner where decisions are made based on local information only as well as information available with BS.
- Inspired from Energy Efficient Heterogeneous Clustering (EEHC) [8] for the prolongation of the lifetime of sensor network in FEEHCP three categories of heterogeneous sensor nodes group-I, group-II and group-III are used in terms of energy heterogeneity.

ACKNOWLEDGMENT

The authors would like to thank the management of SRM institute for their most support and encouragement. Also they are thankful to the Electronics department for their invaluable detailed advices on grammar, organization, and the theme of the paper. They are greatly indebted to their families for always encouraging them to attain their goal.

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