EEUCWFL: Energy Efficient Unequal Clustering With Multi-Input Multi-Output Fuzzy Logic

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EEUCWFL: Energy Efficient Unequal Clustering With Multi-Input Multi-Output Fuzzy Logic

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Abstract The Wireless Sensor Network (WSN) consists a group of sensors and a Base Station (BS) or sink. Sensors gather data from the sensing area and send these data to BS, either directly or through multi-hop data transmission. There are several methods of efficient data transmission. Clustering is one of them. WSN uses the many different algorithms for making the cluster to transmit the data from the physical environment to the BS. Clustering makes the WSN Network efficient and improves the network lifetime. Other data transmission methods like direct transmission consumes very much energy so the life span of the sensor nodes becomes low in comparison to the clustering algorithm. The disadvantage of multi-hop data transmission of clustering algorithm is that a cluster head closer to sink has to forward the data of its own cluster as well as the data of near by clusters. So the node near base station dies sooner. This problem is known as hot-spot problem. The solution of hot-spot problem is unequal clustering. Nodes near base station should be smaller in size to balance the remaining energy of the nodes. In this paper, we have proposed a clustering algorithm (EEUCWFL) which uses multi-input multi-output fuzzy logic to select an optimal cluster head with unequal cluster size. We compared our proposed algorithm with three best known algorithms LEACH, EEUC and CHEF. The Results show that our proposed algorithm optimize energy consumption and improves the network lifetime.

Keywords Wireless Sensor Network, Cluster, Energy, Sensor, Cluster Head, Efficiency, Multi-Objective Optimization, Sink, Base Station, Fuzzy Logic, Data, Transmission.

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1 Introduction

Due to advances in technology, we have very effective, efficient, low powered and small size sensors. These sensors are deployed in remote areas to get some information. Sensors transmits the sensed data to the sink node (or Base Station). Sink Nodes are connected to the internet so once the data is reached to the sink, it will easily reach to the end user. Sensors are battery powered devices. It is not feasible to reach the sensor nodes once they are deployed. So once they are out of battery, they might be considered as dead. To increase the network lifetime it is very important to use sensors energy efficiently. Several methods are proposed to improve the energy of sensor node. One of the best method to optimize energy is clustering. In clustering, some clustering methods are used to select cluster heads from the normal nodes. There are several methods for the selection of cluster head, which is discussed in the section II of this paper. Once the cluster head is selected, all the other remaining nodes join the nearest cluster head to form a cluster. All the normal nodes send their sensed data to their cluster head. The cluster head pre-process the received data and sends them to the sink node either in direct communication or in multi-hop data transmission way. In direct data transmission, the cluster heads far from sink have to use more energy to send their data so these cluster heads dies sooner. In multi-hop data transmission, all the cluster heads sends their data to the nearby cluster head which is closer to the sink node. In this method, the cluster heads closer to the sink have to send the data of their cluster as well as the data received from nearby cluster heads. This causes more energy consumption. So in multi-hop data transmission, the cluster heads near the sink node dies sooner. This problem is known as hot spot problem in WSN. The solution of hot-spot problem is to make the clusters of unequal size. Clusters near the base station should be smaller and the clusters far from sink should be larger. In this way the cluster head near the sink consumes less energy due to the smaller size of cluster but it will also consume the additional energy for the data transmission of other cluster heads. Similarly the cluster heads far from base station consumes more energy due to larger cluster size, but they don't have to forward the data of other cluster heads. Thus unequal clustering balances the energy consumption's among the nodes.

In the proposed algorithm EEUCWFL, we have used fuzzy logic with three input variables which is remaining energy (e), distance to the base station (d_{BS}) and density (D_i). We have two fuzzy outputs competition radius (R_{comp}) and chance (Ch). Initially some some tentative cluster heads are selected randomly. Each tentative cluster head competes in its competition radius for becoming cluster head. The Cluster Head (Ch) with highest chance is selected as cluster head. In each round, some randomly selected cluster heads compete for becoming cluster heads and with the help of fuzzy logic final cluster heads are decided in each round. Once the cluster heads are finalized, each non-cluster head nodes or normal nodes finds the nearest cluster head and join them to form cluster. In each round each normal node sends their sensed data to its cluster head by using time division multiple access (TDMA). The cluster head pre-process and compress the received data and forward this data to some other nearby cluster head which is closer to sink. The nearby node pre-process and merge the received data from nearby cluster heads with the data of its own cluster and forward it to sink or some other nearby cluster head which is closer to sink. The round completes when the data of all the sensor nodes reaches to the base station. In next round again the cluster head is decided, the cluster is formed and the data is transmitted in the similar way. EEUCWFL is compared with some best known algorithms LEACH, EEUC and CHEF. The parameter for comparison is taken as First Node Dies (FND), Half Node Dies (HND) and Last Node Dies (LND). Once half of the nodes of a network is dead the the sensed data might not be informative so we do not consider Last Node Dies (LND) in our comparison. We have considered random positions of sensor nodes and sink at out of AOI.

In this paper, in section II, state of art and related work is explained. The algorithm and working of EEUCWFL is explained in section III. In section IV, results are are compared with three existing algorithms LEACH, EEUC and CHEF. Section V includes the conclusion followed by future work. Acknowledgements and References of this paper added in the last.

2 RELATED WORK

There are several algorithms proposed for WSN to improve the energy efficiency and to solve the problem of hot-spot. The simplest one is direct communication. In direct communication, each node sends its sensed data to the sink directly. In this method, if the sink is far from the sensing area, it requires huge amount of energy to transmit the data. To save the energy, several clustering methods of data communication are proposed. The most traditional clustering algorithm is LEACH [1] which is based on random clustering to enhance the efficiency of WSN. LEACH algorithm uses hierarchical clustering to make clusters and thus, this algorithm proves to be a stepping stone for upcoming algorithms. The problem with LEACH is that it uses probabilistic methods to elect the cluster head. In LEACH to be a cluster head in each round, a random number p is generated by each node, if p is less than threshold $T(n)$ then the node is selected as cluster head. The threshold $T(n)$ can be calculated as:

$$T(n) = \begin{cases} \frac{p}{1-p(r \mod \frac{1}{p})}, & \text{if } n \in G \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

Where $T(n)$ id threshold value of round r and p is the predefined percentage of cluster head. G is the group of sensor nodes that were not selected as cluster head in previous $1/p$ rounds. Due to random selection of cluster head in LEACH sometimes a node with very low energy becomes cluster head. Such nodes may die sooner. Also sometimes node at boundaries may become cluster head, which may cause extra energy consumption. LEACH C is an improved version of LEACH which is based on centralized clustering [[2]]. In LEACH

C base station sorts tentative cluster heads based on their remaining energy and selects cluster head with higher energy. Optimized LEACH-C selects a group of cluster head similar to LEACH-C and then taking re_transmission and acknowledge into consideration creates a model of energy consumption of cluster heads [[3]]. It calculates highest energy consumed by a cluster head and in next round nodes with energy higher than highest energy consumed by a cluster head in previous round will be tentative cluster head. By selecting cluster heads in this way Optimized LEACH-C minimizes the chances of dead node in each round. EDCA algorithm is an improvement over LEACH algorithm [[4]]. This algorithm uses remaining energy and the distance from a node to base station for the selection of cluster head. EDCA calculates resultant factor and sort it in decreasing order. The 10% nodes which have highest resultant factor value become Cluster Head.

In HEED [[5]] tentative cluster head selection is based on remaining energy. Final cluster heads are decided by the communication cost. HEED uses multi-hop routing protocol for data communication. HEED uses probabilistic model to cluster heads. It selects cluster head on the basis of remaining energy of a node [[5]]. If a tie occurs, it uses some other parameters like node degree, distance to neighboring node, intra-cluster communication cost to break the tie. In HEED the probability of a node can be calculated as:

$$CH_{prob} = C_{prob} * \frac{E_{residual}}{E_{max}} \tag{2}$$

Where $E_{residual}$ is remaining energy of node. E_{max} is initial energy of node. Initially C_{prob} is same for all the node which is 5%. As the residual energy of a node decreases, its probability to become cluster head also decreases. HEED does not consider unequal clustering so it may suffer from hot-spot problem. There are several algorithms who have considered a hot-spot problem.

In [[6]] an unequal clustering method is proposed for heterogeneous network. In this method cluster heads are deployed at pre-defined locations and multi-hop routing protocol is used for data communication. In EECS [[7]] size of cluster is decided by the distance from sink node. It uses single hop of data communication and nodes further from sink has lower cluster size so that they have less data which will save energy. Due to single hop communication, cluster heads far from sink dies faster if the area is big in EECS.

In EEUC [[8]] the concept of variable competition radius is introduced. In EEUC the competition radius of a node depends on its distance to the sink. Maximum competition radius ($R_c omp^o$) is fixed. All the other tentative cluster head nodes calculates their competition radius by the formula given in equation 1.

$$S_i.R_{comp} = (1 - c\frac{d_{max} - d(s_i, BS)}{d_{max} - d_{min}}) * R^0_{comp} \tag{3}$$

Here $S_i.R_{comp}$ is the competition radius of i^{th} node. d_{max} is maximum distance and and d_{min} is minimum distance between sensor nodes and sink. Here $d(Si, BS)$ denotes the distance of i^{th} node from base station. Thus in EEUC due to variable competition radius unequal clusters are formed. These clusters have smaller size if they are near base station and have larger size if they are away from base station. With the help of unequal clustering, EEUC solves the problem of hot-spot. In [[9]] particle swarm optimization (PSO) is used for efficient cluster head selection. In [[10]] load balancing concept is used to balance the data transmission load among the sensor nodes to improve network lifetime. In [[11]] sleep scheduling model is proposed to achieve higher lifetime of sensor network.

EAUCF [[12]] tries to decrease intra-cluster communication cost of cluster head, which are either closer to the sink or has low energy. It uses fuzzy logic with two input parameters, residual energy and distance to sink or base station for the calculation of radius of cluster head. CHEF [[13]] selects cluster head in distributed manner using fuzzy logic. In CHEF chance to become cluster head is computed using fuzzy logic. CHEF uses two input parameters for fuzzy logic, Energy and Distance. Energy is the residual energy of a sensor node. Distance is the sum of the distance between other sensor nodes within radius r. The value of r is fixed and same for all the nodes in CHEF.In [[14]] authors have proposed six parameters viz. distance,density, remaining energy, vulnerability index, Centrality and distance between CH to select the cluster head by using two step fuzzy logic. In [[15] fuzzy logic is used for cluster head selection with three input parameters Remaining Energy, Distance to BS and Density. In [[16]] fuzzy logic is used for the selection of cluster head with three parameters 'Energy', 'Distance to Base Station' and 'Density' with the concept of area division. In EEUCWFL, we have used three input parameters to calculate competition radius and chance of a tentative cluster head. The system model of EEUCWFL is explained in section III.

3 SYSTEM MODEL

In EEUCWFL we have used fuzzy logic with three input membership function and two output membership function as shown in figure 1. To get crisp output, we have used Center of Area (COA) method of defuzzification. In COA method of defuzzification, for continuous membership function, defuzzified value χ can be calculated as

$$\chi = \frac{\int x\mu_A(x)dx}{\int \mu_A(x)dx} \tag{4}$$

Initially in each round a random number ρ is generated by each node. If ρ is less than C_{opt}, the node becomes tentative cluster head. C_{opt} is a pre-defined threshold. Now these tentative cluster head nods calculate their Competition radius (R_{comp}) and Chance (Ch). Now each tentative node competes in its competition radius (R_{comp}) to become cluster head. If a node i has highest chance (Ch) in its competition radius (R_{comp}) then it becomes cluster head otherwise if there is a node j in the competition radius of i, then i leaves the competition and decimates QUIT_COMPETITION_MSG in radius. R^0_{comp} is maximum competition radius of any node. Once the cluster heads are decided. Each normal node joins the nearest cluster head to form a cluster. After cluster formation, all the normal nodes send their data to their cluster head. The Cluster Head process and aggregates these data and send it to sink node directly if sink

$$d(Si, BS) < TD_{MAX}$$

Where $d(Si, BS)$ is the distance between cluster head i and sink or base station. If for Cluster Head i $d(Si, BS) > TD_MAX$ the Cluster Head i forward its data to a neighbor Cluster Head j such that:

$$d(S_i, BS)^2 > d(S_i, S_j)^2 + d(S_j, BS)^2 \tag{5}$$

Cluster head j aggregates and pre-process the data received from sensor nodes of its own cluster and the data received from nearby cluster heads. These aggregated data is forwarded to base station in similar way as explained above. When the data from all the nodes is received by sink node, the round is complete. In next round again the same process is repeated. We have some assumptions for our proposed. They are described in below.

3.1 Assumptions

Here is some assumption that we have used in our proposed model. These assumptions are:

- All the sensor nodes are identical.
- The deployment of all the sensor nodes is random.
- The position of sink node is fixed.
- Sensor nodes can transmit data at variable energy level, which is based on the distance from sink node.
- The strength of receiving signal can be used to determine the distance.
- In the beginning, the energy of all the nodes is equal.
- It consumes the same amount of energy to forward a packet of L bits from location A to B and from location B to A.
- For our proposed method we have used first order radio model for the calculation of energy consumption, which is explained in equation 1.

In the process of data transmission from sensor nodes to sink node, energy consumption can be categorized into three parts:

- Energy consumption in data transmission (ETX).
- Energy consumption in data receiving (ERX)
- Energy consumption in data aggregation ($EAGGR$).

For EEUCWFL the formula used for the calculation of energy consumption in transmitting (ETX) and receiving (ERX) of 'k' bits data at distance 'd' is given below.

$$E_{TX}(l,d) = \begin{cases} l * E_{elec} + l * \epsilon_{fs} * d^2, & \text{if } d < d_0 \\ l * E_{elec} + l * \epsilon_{mp} * d^4, & \text{otherwise} \end{cases} \tag{6}$$

$$E_{RX}(l,d) = l * E_{elec} \tag{7}$$

If in a cluster, m nodes send their data of l bit to base station Then the length of aggregated message l_{aggr} will be

$$l_{aggr} = m * l + l$$

So energy consumed in data aggregation

$$E_{aggr} = (m * l + l) * E_{DA}$$

or

$$E_{aggr} = (m + l) * l * E_{DA} \tag{8}$$

Where:
E_{TX}=Transmission Energy.
E_{RX}=Received Energy.
l=Size of data packet.
E_{elec}=Energy consumed per bit to run the electronic circuitry
ϵ_{fs}=Per bit energy consumed in the RF amplification if the transmission distance is less than d_o.
ϵ_{mp}=Per bit consumed in the RF amplification if the transmission distance is greater than do. Here do can be calculated as:

$$d_o = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \tag{9}$$

So energy consumed by Cluster Head will be due to data receiving, data aggregation and data transmission. It can be calculated as:

$$E_{CH} = E_{TX}(l,d) + E_{aggr} + E_{RX}(l,d)$$

or If we assume that $d(Si, BS) < do$ and $d(Si, Sj) < do$

$$E_{CH} = m * l * E_{elec} + (m + 1) * l * E_{DA} + S_{aggr} * E_{elec} + S_{aggr} * \epsilon_{mp} * d^2 \tag{10}$$

Where S_AGR is size of aggregated data. It can be calculated as

$$S_{aggr} = l * R_{aggr} * m + l \tag{11}$$

Where l is the size of data bits received from each node, R_{aggr} is aggregation ratio and m is the number of nodes in cluster except Cluster Head.

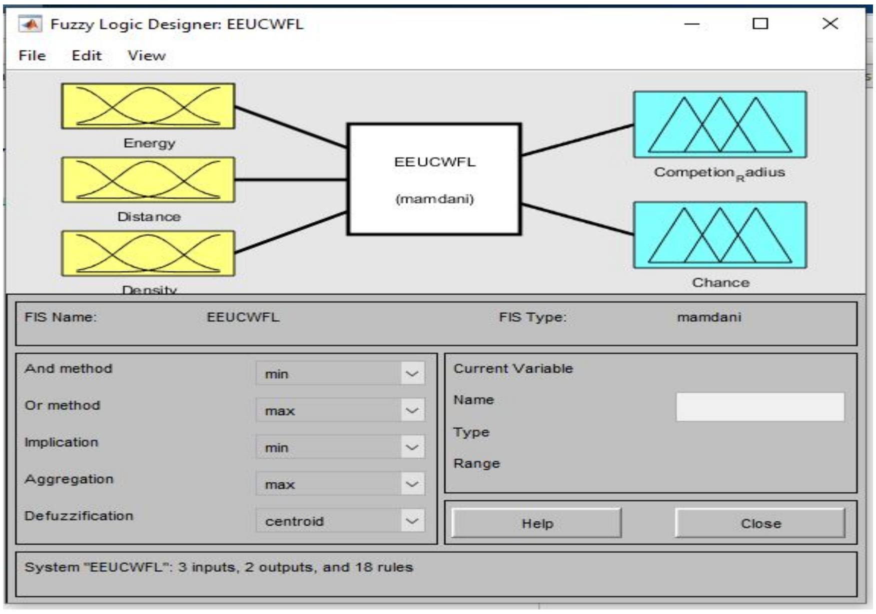

Fig. 1 Input and Output membership function for fuzzy set

Energy consumed by the normal node will be as per equation 6. System model of EEUCWFL is shown in figure 1. We have taken three input variables Energy (e), Distance to base station (d_{BS}) and Density (D_i). Density depends of nodes within radius (R_o).
Density (D_i) of a node can be calculated as:

$$D_i = \frac{\text{Number of alive nodes within radius } R_o}{\text{Total number of alive nodes in network}} \tag{12}$$

The value of R_o is fixed. The formula for R_o that we have used is given below:

$$R_o = \frac{X_m + Y_m}{4} \tag{13}$$

Where X_m and Y_m are the maximum X and Y coordinates of the sensing area.
The fuzzy input variable energy is classified into three groups Low, Medium and High as shown in figure 2. Distance is classified into three classes Low, Medium and Far as shown in figure 3. Similarly Density is also classified into three groups Sparse Normal and Dense.The range of all the variables is tuned for better results. We have taken two fuzzy output variables Competition radius and chance. Each tentative node competes in its competition radius and if the node has highest chance in its competition radius then it will be selected as cluster head. Output variable competition radius is explained in figure 5. Competition radius is classified into nine classes. They are

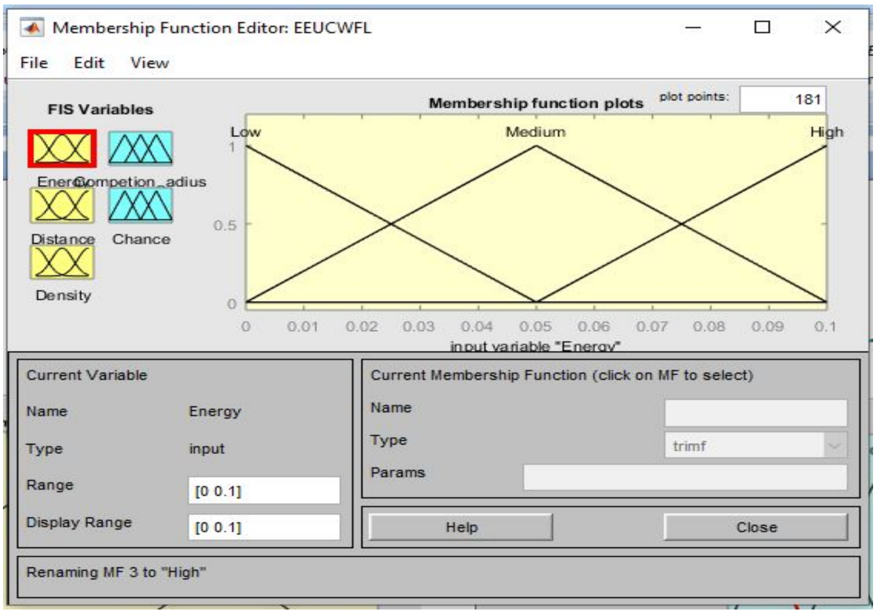

Fig. 2 Input membership function Energy of fuzzy set

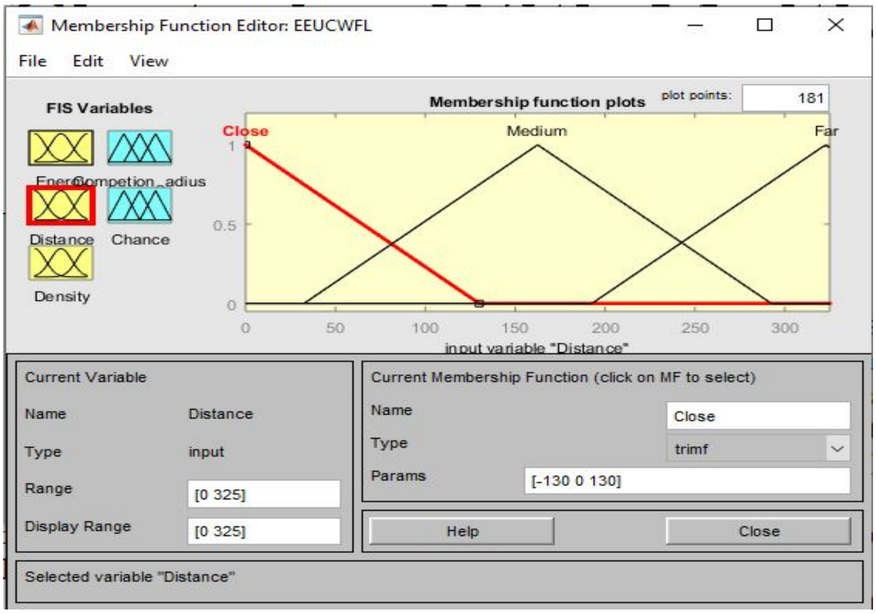

Fig. 3 Input membership function Distance for fuzzy set

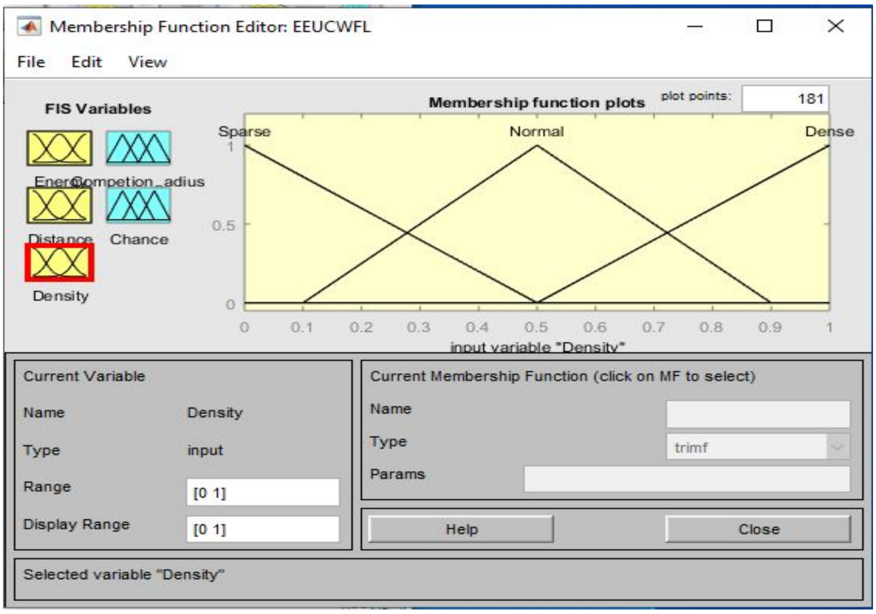

Fig. 4 Input membership function Density for fuzzy set

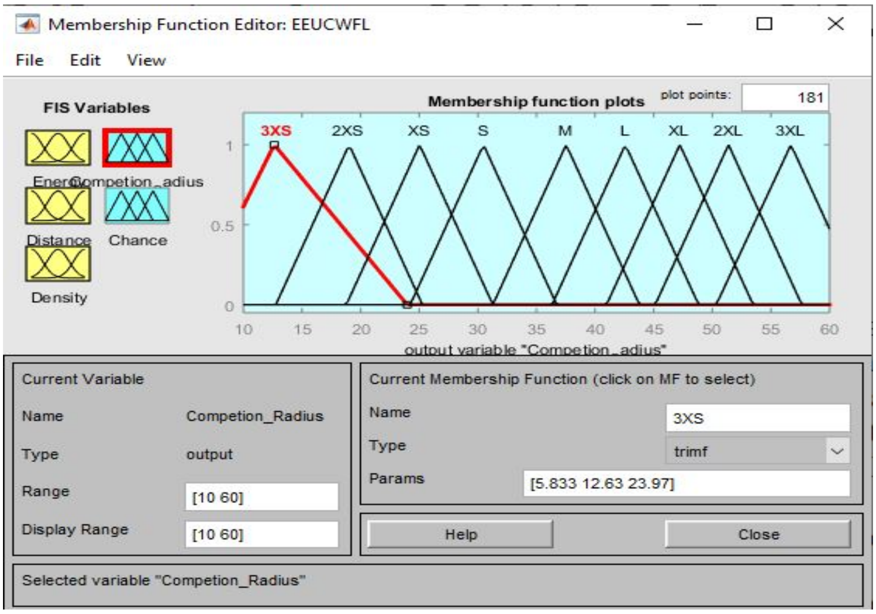

Fig. 5 Output membership function Competition Radius for fuzzy set.

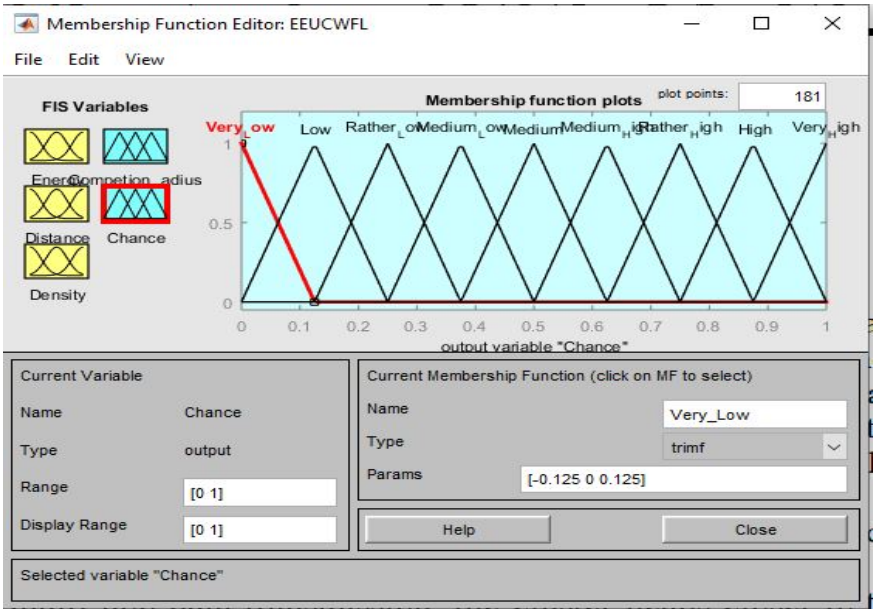

Fig. 6 Output membership function Chance for fuzzy set

$3XS, 2XS, XS, S, M, L, XL, 2XL, 3XL$. $3XS$ represents the smallest competition radius and $3XL$ represents the largest one. The range for competition radius is taken [10, 60]. The second output variable is Chance which is explained in figure 6. The membership function Chance is also classified into nine classes as shown in figure 6. These classes are 'Very Low', 'Low', 'Rather Low', 'Medium Low', 'Medium', 'Medium High', 'Rather High', 'High' and 'Very High', similar to [10]. Range for competition radius for scenario 1 is [10, 60]. The fuzzy rules for Competition Radius and chance are given in figure 7.

R_{comp} mainly depends on input variable Distance and Density. 'Close' distance and 'Dense' density will results in smallest competition radius as shown in figure 5. Similarly 'Far' distance and 'Sparse' density will result in Largest competition radius. The reason for this consideration is that a node closer to Base Station have to forward the data received from nearby cluster heads so competition radius should be small. Smaller competition radius will result in smaller cluster size. Similarly higher density will result in higher number of nodes in cluster which will cause higher energy consumption of cluster head so to balance the energy consumption, cluster size should be reduced. Chance depends on the input variable energy and Density. 'High' energy and 'Dense' density will result in highest Chance. A node with 'Low' energy and 'Sparse' density has least chance of becoming cluster head. In EEUCWFL, Competition Radius and Chance are mutually exclusive. A node with smaller competition radius may have higher chance.

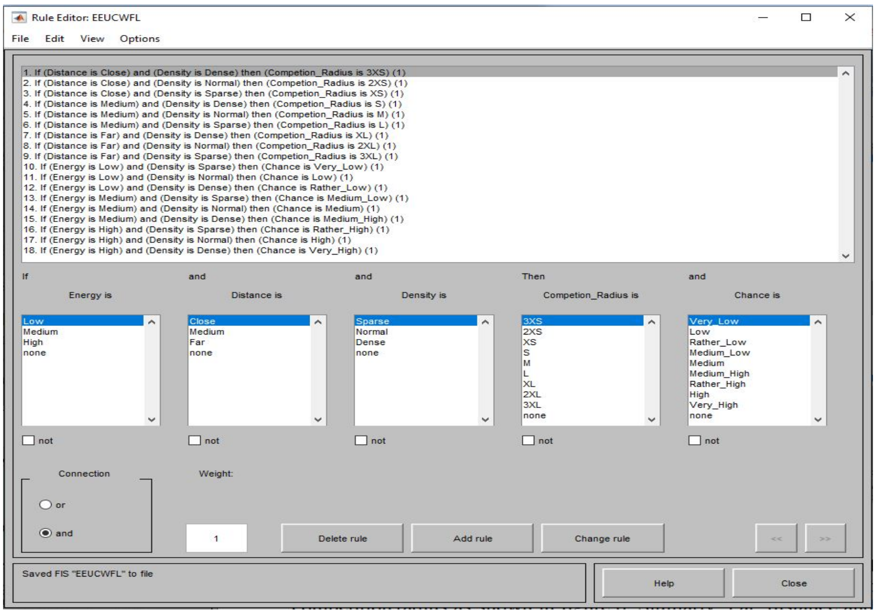

Fig. 7 Fuzzy Rules for Competition Radius and Chance for fuzzy set.

3.2 Proposed Algorithm

In the EEUCWFL, the cluster selection is based on fuzzy output variable Chance (ch). Initially some tentative cluster heads are selected randomly. In EEUCWFL, approximately 40% nodes are selected as tentative cluster head and they participates in final cluster Head selection process. These nodes are called as $tentative\_CH$. The competition radius and chance of these nodes are calculated using fuzzy logic. Each $tentative\_CH$ node competes in its competition radius (R_{comp}). A node with highest Chance (Ch) in its competition radius (R_{comp}) becomes cluster head. Each normal nodes search for nearest cluster Head and join them to form a cluster. If sink is closer than the nearest cluster head then the node join sink node directly. After cluster formation, each normal node forward its data directly to its cluster head. Cluster heads process these received data and aggregate it with their own data. For EEUCWFL, we have considered the aggregation ratio 10%. The aggregated data is now forwarded to to base station in multi-hop data transmission. In the multi-hop data transmission method a node$i$forward its data to node j if:

$$d(i, Sink)^2 > d(i, j)^2 + d(j, Sink)^2 \tag{14}$$

If $d(i, Sink)^2 < d(i, j)^2 + d(j, Sink)^2$ then cluster head sends its data directly to base station. To calculate the energy consumption, we have used the first order of radio model which is same as in LEACH [[1]].
The energy consumption in data transmitting (E_{TX}) and data receiving (E_{RX})

of l bit at distance d is calculated as shown in equation 6 and equation 7. The cluster heads selection algorithm is given below.

Algorithm 1 Algorithm for the selection of Cluster Head

```
for i = 1 : 1 : n do
    Si.Final_Head ← False
    μ ← rand()
    if μ ≤ C_opt then
        Si.Tentative_CH = True
    end if
    Compute Ch and R_comp for tentative Cluster heads using fuzzy logic
    if Si.Tentative_CH=True then
        Compute S_i.Ch
        Compute S_i.R_comp
    end if
end for
for i = 1 : 1 : n do
    if Si.Tentative_CH=True then
        Adv. Candidate_CH_Msg(ID, Ch, R_comp, e)
    end if
end for
After receiving Candidate_CH_Msg from node Sj
if d(Si, Sj) ≤ Si.R_comp ∨ d(Si, Sj) ≤ Sj.R_comp then
    Add Sj to Si.SCCH
end if
for i = 1 : 1 : n do
    for j = 1 : 1 : n do
        if Si.Ch > Sj.Ch ∀ Sj ∈ Si.SCCH then
            Si.Final_Head = True
            AdvFinal_CH_Msg(ID)
        else if Si.Ch ¡ Sj.Ch, where Sj ∈ Si.SCCH then
            Si.Tentative_CH = False
            AdvQuit_Competition_Msg(ID)
        end if
        AfterreceivingFinal_CH_MsgfromnodeSi
        if Si ∈ Sj.SCCH then
            Sj.Tentative_CH = False
            AdvQuit_Competition_Msg(ID)
        end if
        OnreceivingQuit_Competition_Msg(ID)fromSj
        if j ∈ Si.SCCH then
            RemoveSjfromSi.SCCH
        end if
    end for
end for
```

So by algorithm 1, we finally get cluster heads. These cluster heads sends $Final\_CH\_Msg(ID)$ at distance R_{comp}. Each normal node joins the nearest cluster head to form a cluster. Once the cluster is farmed, each normal node sends their data to their cluster head. Cluster heads aggregates all the received data with their own data into one packet of the size S_{aggr} and forward the packet to base station either directly or via multi-hop routing depending upon table caption is above the table

Table 1 Parameter for scenario 1

Sr. No.	Parameter	Value
1	Coverage Area	$(0,0)$ m to $(200,200)$ m
2	No. of Nodes	100
3	Location of Base Station	(100,250) m
3	E_{elec}	50 nj
4	ϵ_{fs}	10 $pj/bit/m^2$
5	ϵ_{mp}	0.0013 $pj/bit/m^4$
6	$DatapacketSize$	4000 $bits$
7	EDA	5 nJ/bit/signal
8	d_o	87.7058 m
9	$InitialEnergy(e)$	0.1 nj
10	C (for EEUC)	0.5
11	T (for EEUC)	0.4
12	TD_{MAX} (for EEUC)	90
13	R^0_{comp}	(for EEUC) 80 m
14	p (for LEACH)	0.1
15	C_{opt} (for EEUCWFL)	0.4
16	R_{comp} (for EEUCWFL)	60 m
17	R_{aggr}	10%
18	R^o (for EEUCWFL)	$(xm + ym)/4$

the distance to base station. We have considered two scenarios for our experiment. In scenario 1 sink is out of Area of Interest (AOI). In scenario 2 the sink is at the center of AOI. The parameters for scenario 1 is shown in table 1.

4 Experiment and Results

In real life, sensors are deployed in remote areas, which are not easily accessible. Base stations are located far from sensing areas. So for our project implementation, we have considered in scenario 1 that base station is located at out of Area of Interest (AoI). The conditions of scenario 1 and scenario 2 are shown below:

- Scenario 1 – Sensor nodes are deployed randomly in area of (0,0) m to (200, 200) m and Base Station is out of AOI i.e. base at (100, 250) m..
- Scenario 2 – Sensor nodes are deployed randomly in area of (0,0) m to (400, 400) m and the Base Station is present at center of AOI i.e. Base Station is at (200,200).

We have compared our proposed work EEUCWFL with LEACH, EEUC and CHEF. The parameters for scenario 1 is given in table 1.

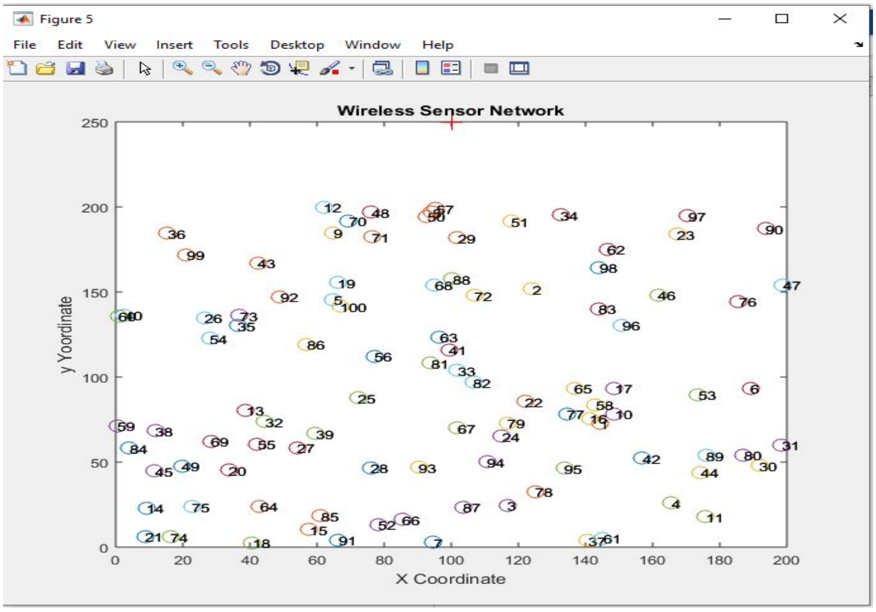

Fig. 8 A random sensor network with Base Station at (100,250).

4.1 Scenario 1

Coverage area is from (0,0) m to (200, 200) m and the base station is at out of AOI.

The random WSN for scenario 1 is given in figure 8. Here 'o' represents sensor nodes and '+' represent base station.

Cluster formation with data transmission for LEACH is shown in figure 9 and the cluster formation with data transmission for EEUCWFL is shown in figure 10. It is clear from the figure 10 that in EEUCWFL, clusters near base station are smaller in size and clusters far from base station are larger in size. The smaller clusters near base station reduces the energy consumption due to intra-cluster communication. This model tries to balance the energy consumption's amongst the cluster heads and thus solves the hot spot problem.

In LEACH Cluster head selection is random, so LEACH suffers from hot-spot problem. Due to random cluster head selection process, sometimes LEACH does not selects optimal Cluster heads. Clustering in EEUCWFL Is shown in figure 10.

It is clear from figure 9 that LEACH does not consider location of node, its distance from sink, its centrality etc. So sometime LEACH selects cluster heads at boundary which leads extra energy consumption. This problem is

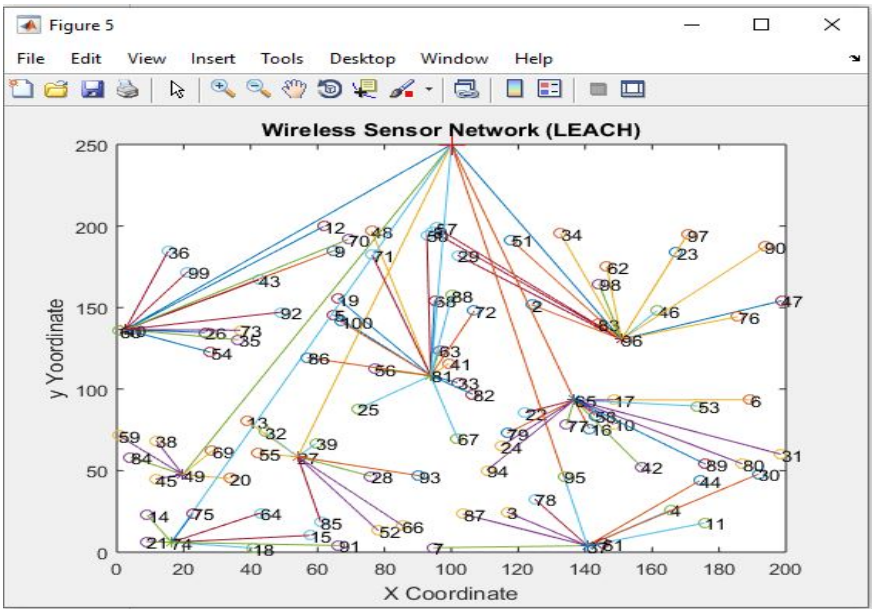

Fig. 9 Cluster formation in LEACH for Scenario 1.

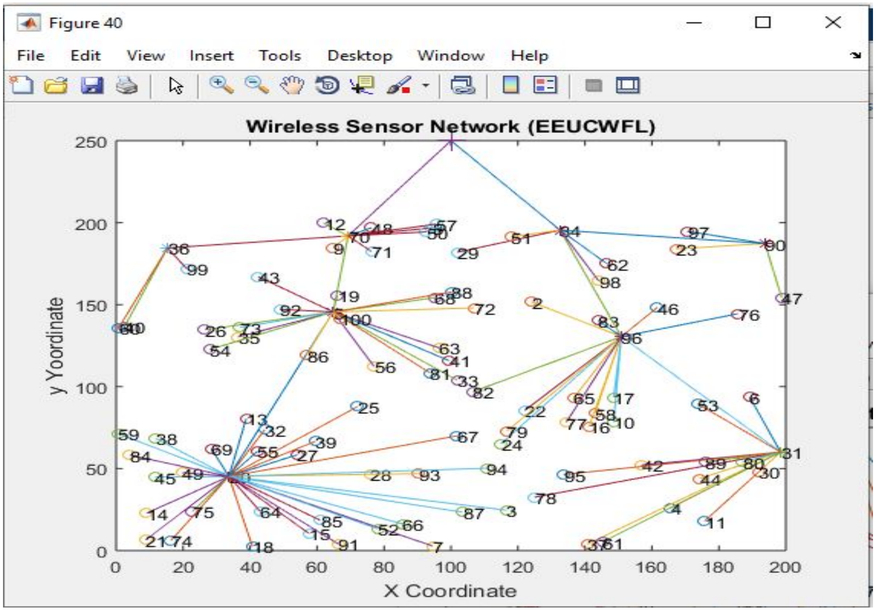

Fig. 10 Cluster formation in EEUCWFL for Scenario 1.

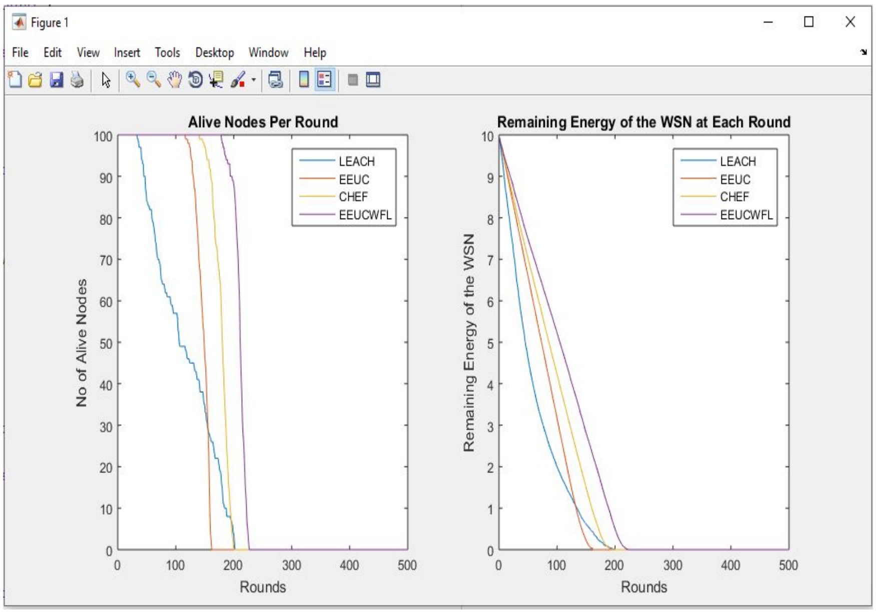

Fig. 11 Comparision of Alive Nodes and Remaining Energy in each round of LEACH, EEUC,CHEF and EEUCWFL for Scenario 1.

eliminated in EEUCWFL as shown in figure 10. The comparison of all the four algorithms was done and the results are shown in figure 11, figure 12 and figure 13. Figure 11 is showing the the comparison of number of alive nodes in each round and at right hand side energy consumption in each round is shown. It is clear from the figure that for FND and HND LEACH performs worst and EEUCWFL performs best. The reason for the worst performance of LEACH is that it does not select optimal cluster and all of its cluster heads forward the data to sink directly. So the nodes away from base station dies sooner. Due to single hop transmission, the cluster heads near to sink need not to forward the data of enter cluster. This saves the energy of nearby cluster heads that's why the LND is better in LEACH as compared to EEUC and CHEF. EEUCWFL performs slightly better than LEACH in case of LND.

In figure 12, the number of cluster head created in each round and the energy consumed in each round is shown for all the four algorithms. Energy consumption in LEACH is very highly variable. In EEUC, CHEF and EEUCWFL energy consumption is very consistent as compared to LEACH. The reason for it is these three algorithms focus on optimal selection of cluster head and all these three algorithms works on multy-hop data transmission. So energy consumption is optimized. In EUCWFL, the competition radius of a node changes with changes in its remaining energy and density. So the number of cluster heads created in each round change significantly in EEUCWFL which is shown in figure 12.

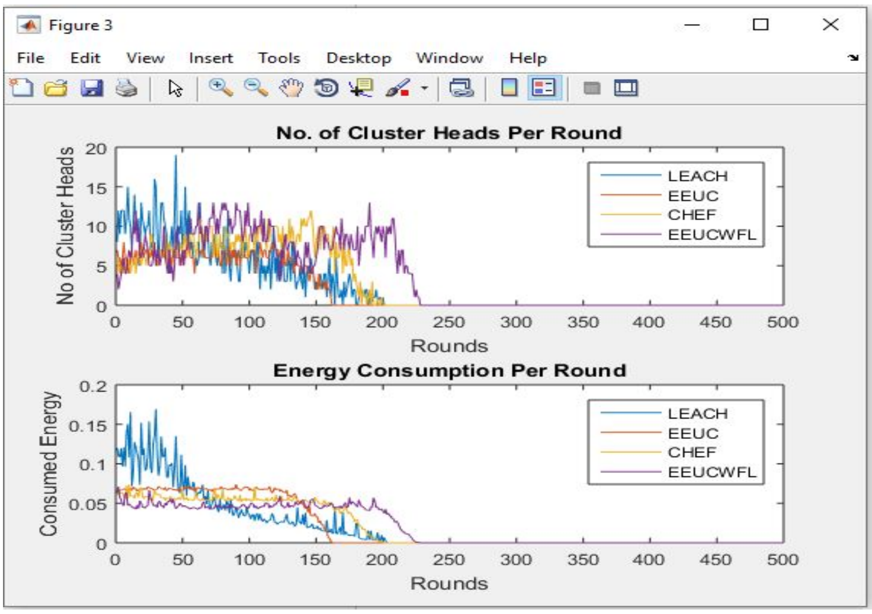

Fig. 12 Comparison of Cluster heads in each round and Energy Consumptions in each round of LEACH, EEUC,CHEF and EEUCWFL.

In figure 13 the comparison of First Node Dies (FND), Half Node Dies (HND) and Last Node Dies (LND) is shown. FND is worst in LEACH and LND is worst in EEUC. EEUCWFL performs better because of its optimal selection of cluster head, its multi-hop data transmission, and its variable competition radius.

4.2 Scenario 2

In scenario 2 we have considered coverage area from $(0, 0)$ m to $(400, 400)$ m. The base station is at the center of AOI i.e (200, 200). Other parameters are same as in scenario 1. A random WSN of scenario 2 is shown below in figure 14.

As shown in figure 14 for scenario 2 we have considered a wireless sensor network of the area 400* 400 m2. Base Station is located at the center of AOI. The reason for considering the bigger area is that the value of do is approximately 87. So if the sensing area is very small, the advantage of multi-hop routing is not considerable. Also in real life scenario, the sensor nodes are very large, so we considered an area of 400*400 m2. Figure 15 shows the cluster formation in EEUCWFL for scenario 2. Here 'o' represents normal nodes, '*' represent Cluster heads and '+' represents Base Station. The line shows the data transmission path. Each normal Nodes Forward their data to the base

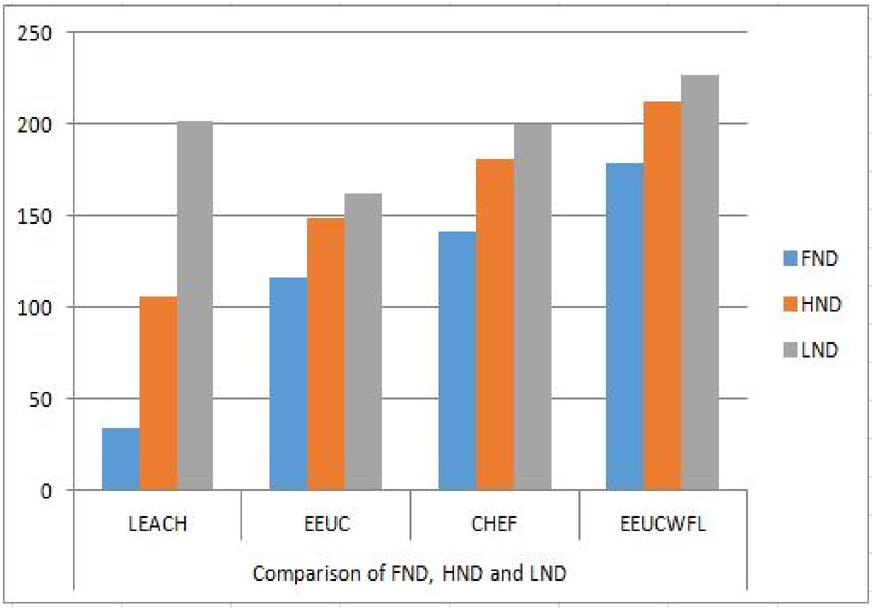

Fig. 13 Comparison of FND, HND and LND of LEACH, EEUC, CHEF and EEUCWFL.

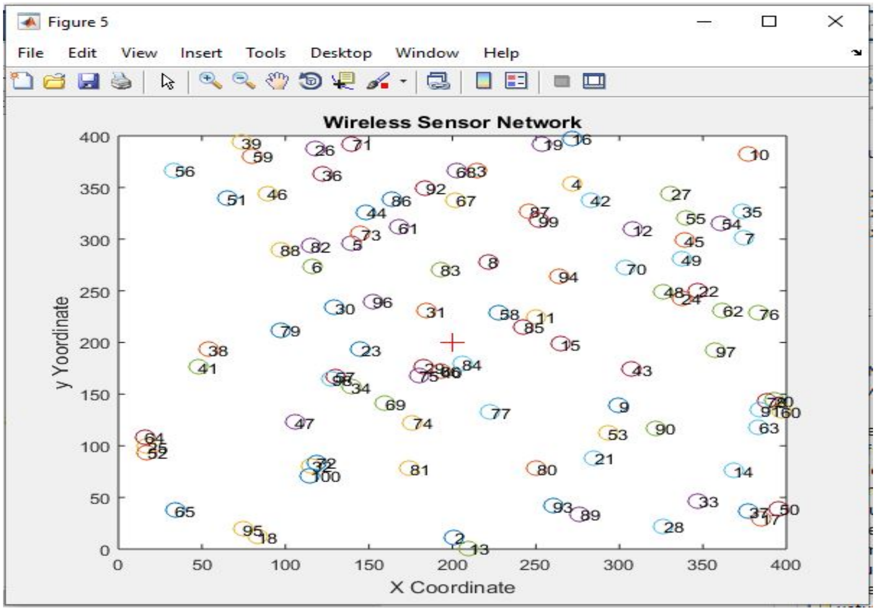

Fig. 14 A randomly generated WSN for scenario 2.

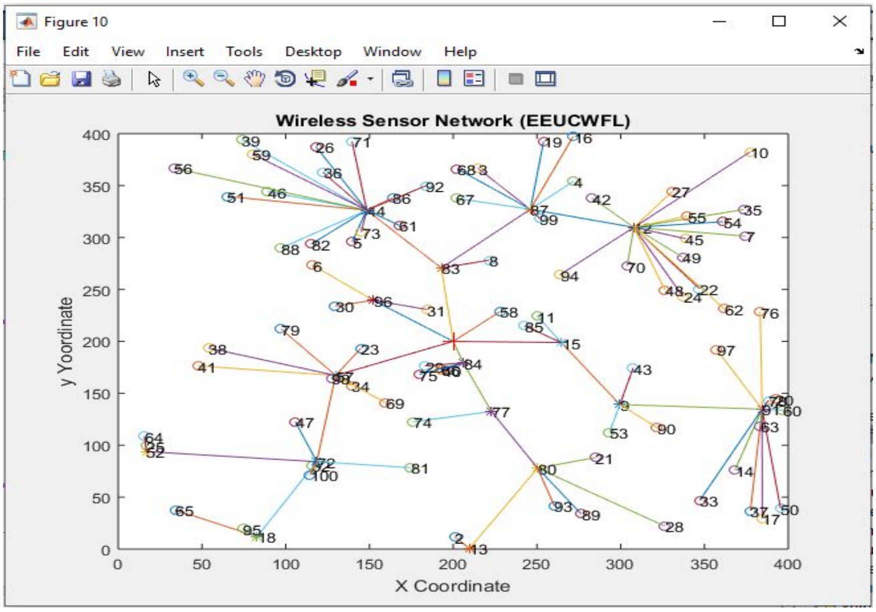

Fig. 15 Cluster formation of EEUCWFL in scenario 2.

station and base station pre-process and aggregate the received data with its own data with an aggregation ratio of 10% and forwards this data to either base station directly or through multi-hop by transferring the data to nearby cluster head closer to sink.

The comparison of the different algorithms is shown in figure 16. LEACH performs worst due to its and random selection of cluster heads and single hop data transmission. EEUCWFL performs best due to its better selection of cluster heads with variable competition radius. In EEUCWFL and CHEF few nodes very close to sink remains alive but they are of no use as most of the nodes in sensor network are dead.

In figure 17, number of cluster heads per round and energy consumption per round is shown. It is clear from graph that energy consumption is very variable in LEACH while in EEUC, CHEF and EEUCWFL it is consistent. Among the letter three algorithms, EEUCWFL consumes lowest energy. In EEUCWFL, competition radius of nodes depends on their remaining energy, so as the remaining energy decreases, the competition radius also decreases, which results in more number of cluster heads which clearly can be seen from energy consumption graph.

The comparison of First Node Die, Half Node Die and Last Node Die are shown in figure 18. FND is lowest in LEACH because of the single hop data transfer. Cluster Heads very far from sink consumes very high energy in data

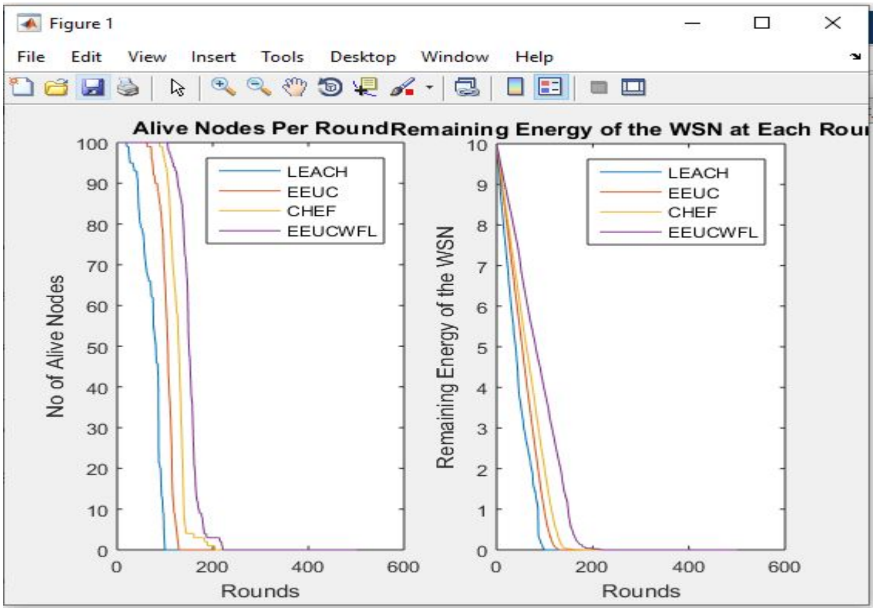

Fig. 16 Comparison of Alive Nodes and Remaining Energy in each round of LEACH, EEUC,CHEF and EEUCWFL for Scenario 2.

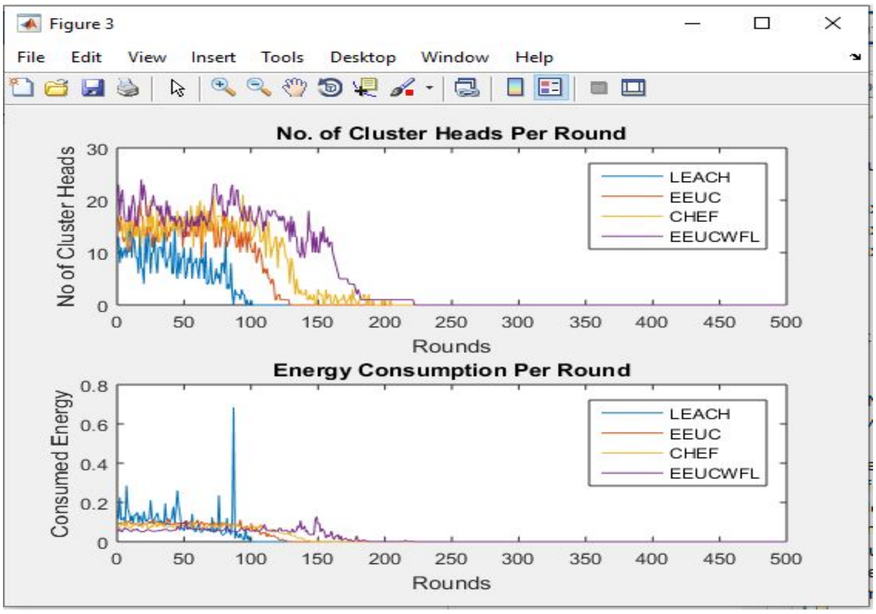

Fig. 17 Comparison of Cluster Heads in each round and Energy Consumption in each round of LEACH, EEUC, CHEF and EEUCWFL for Scenario 2.

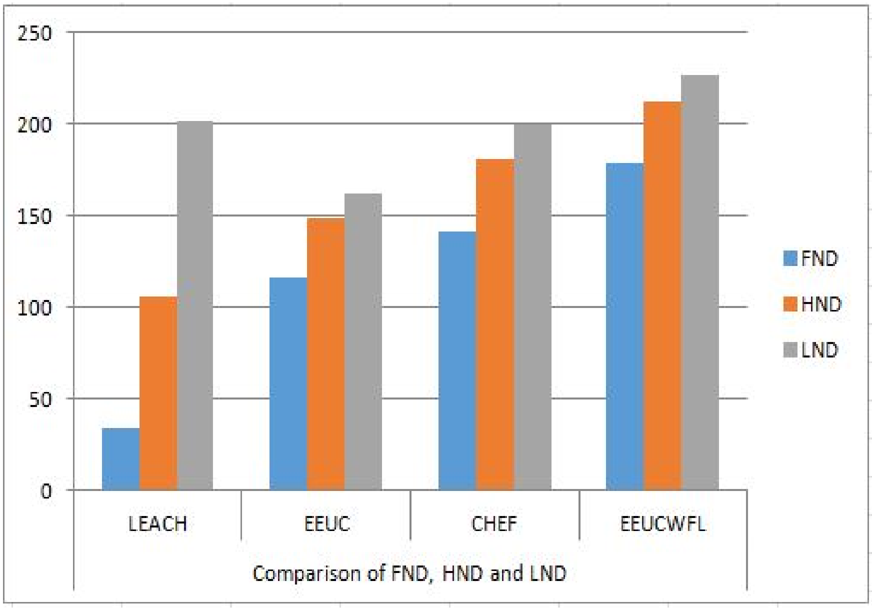

Fig. 18 Comparison of FND, HND and LND of LEACH, EEUC,CHEF and EEUCWFL for scenario 2.

transmission and thus dies sooner. EEUCWFL performs slightly better than CHEF. This is because CHEF considers only remaining energy and distance to sink for the calculation of Chance, but in EEUUCWFL, Chance (Ch) as well as Competition Radius (R_{comp}) both are calculated. Chance (Ch) depends on the remaining energy (e) of the node and Density (D_i) while competition radius (R_{comp}) depends on the remaining energy (e) of the node and distance from the sink node (d_{BS}). So EEUCWFL performs better than CHEF.

5 CONCLUSION & FUTURE WORK

The proposed algorithm EEUCWFL, is an Energy-Efficient based on unequal clustering with the help of multi input multi output fuzzy logic. Results justifies that the proposed algorithm selects better cluster heads. Due to variable competition radius (R_{comp}). The competition radius decreases as the remaining energy of node decreases in EEUCWFL. This leads more cluster heads at nearby places. So nodes have to forward data at smaller distances. This method reduces the energy consumption of nodes. At present, maximum competition radius is decided manually. In future we may introduce some method to decide optimal competition radius as a function of remaining energy and distance.

We have considered two scenarios. The first one with Sink at out of AOI and the second one with the sink at center of AOI. The experiment results show that the proposed algorithm improves the network lifetime in both the scenarios. It maximizes the lifetime of WSN with respect to the parameters FND, HND and LND.

Statements and Declarations

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Conflicts of interests/Competing interests Not applicable.

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