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NEEF: A NOVEL ENERGY EFFICIENT FUZZY LOGIC BASED CLUSTERING PROTOCOL FOR WIRELESS SENSOR NETWORK

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Abstract. The uttermost requirement of the wireless sensor network is prolonged lifetime. Unequal energy degeneration in clustered sensor nodes lead to the premature death of sensor nodes resulting in a lessened lifetime. Most of the proposed protocols primarily choose cluster head on the basis of a random number, which is somewhat discriminating as some nodes which are eligible candidates for cluster head role may be skipped because of this randomness. To rule out this issue, we propose a deterministic novel energy efficient fuzzy logic based clustering protocol (NEEF) which considers primary and secondary factors in fuzzy logic system while selecting cluster heads. After selection of cluster heads, non-cluster head nodes use fuzzy logic for prudent selection of their cluster head for cluster formation. NEEF is simulated and compared with two recent state of the art protocols, namely SCHFTL and DFCR under two scenarios. Simulation results unveil better performance by balancing the load and improvement in terms of stability period, packets forwarded to the base station, improved average energy and extended lifetime.

Key words: Energy Efficiency, Wireless Sensor Network, Clustering, Fuzzy Logic, Cluster Head

AMS subject classifications. 68M11, 94D05

1. Introduction. In recent past decades, wireless sensor network (WSN) has emerged as a vital part of our daily life. With the drastic progression of microelectronics technology which consumes low power in electronic circuitry, WSN is applied in diverse real-time applications like commercial monitoring, healthcare sensing, surrounding monitoring, battlefield surveillance etc. [1]. WSN contains sensor nodes (SN) which can experience, accumulate and compute information from the environment and also maintain it for a protracted time frame. A WSN is a blend of four subsystems altogether with a sensing module, a transceiver module, a processing module, and a power supply module (battery) [2]. These SNs use battery for energy delivery, limited memory for collecting information from the vicinity in which these are deployed and also microprocessor for processing the data and later transferring it to the base station (BS). So, it has been a premier issue for researchers to devise a mechanism to use the energy of SN effectively. WSN can be classified as heterogeneous or homogeneous networks [3]. In a homogeneous network, all nodes possess equal capacities in terms of processing, memory, radio range and energy, whereas in a heterogeneous network, it may be different. Clustering is one of the better solutions for sparing power of SNs and extending network lifetime [4]. Clustering is a method wherein all the SNs are grouped according to some criteria and each group is headed by one of the nodes called a cluster head (CH) [5]. The CH compresses the data supplied by their cluster members (CMs) via statistics fusion to reduce the redundancy and improving the power dissipation rate of the network.

Various clustering algorithms were proposed in the last decades like LEACH [4], PEGASIS [6], HEED [7], SEP [8], LEASE [9], EDFCM [10], SPEZ [11] etc. In WSN, there are two types of information gathering schemes: Hierarchical and Non-Hierarchical. In a hierarchical scheme, SNs communicate the records to the BS via CH in one hop while, in a non-hierarchical scheme, SNs send the records in single and/or multi-hop to the BS via a CH resulting in conserving more energy. Most of the clustering protocols rotate the CH role so that the energy dissipation can be balanced in the network. However, regardless of the dynamic rotation of the CH role, the energy imbalance takes place due to communication distance between SN and the CH. The location of the BS additionally influences the lifetime of the network as a longer distance will use more energy for communication. If the chosen CHs are nearer to the BS then it will dissipate less energy and if the CHs are at distant place then it will drastically deplete energy level. Some researchers have proposed multi-hop

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communication to the BS but it also depletes energy of CH nearer to the BS.

In this paper, we have propound a novel energy efficient fuzzy logic (NEEF) based clustering protocol for WSN that makes use of designed fuzzy system for energy efficacy while selecting the CHs thereby protracting network lifetime. The main contributions are highlighted as follows:

- The influential parameters that affect the battery level of SNs are identified from related work and segregated into primary and secondary factors.
- The primary factors considered are remnant energy level and communication cost to be borne by CH, whereas secondary factors are the density of SN and its aloofnes to the BS.
- To emphasise the election of best suitable node for the CH role, weights are assigned to Fuzzy fitness output value (FF1 and FF2) after experimental evaluation through simulation.
- To balance the load of CH, non-CH nodes choose their CH on the basis of chance obtained from designed fuzzy system which considers the load of CH node and distance from non-CH node to the considered CH.

Subsequent part of this paper is organised as follows: Section 2 discusses literature survey. System model with network and energy dissipation model is discussed in section 3. A description about NEEF protocol is presented in section 4. Simulation experiment and result analysis is done in section 5 and section 6 provides concluding remarks. .

2. Relevant Work. This section discusses some pertinent clustering algorithms in WSN. Maximal clustering algorithms use rounds to describe the lifetime of WSN. Each round consists of CH selection, formation of cluster and the data collection. More the number of rounds, the longer will be the lifetime of WSN. LEACH [4] is a pioneering protocol in clustering algorithms. The goal of LEACH is to choose a node as CH in such a manner that every node gets an opportunity to become a CH. The reason is that a CH node dissipates higher energy than non-CHs nodes, therefore, a node will not dissipate power by turning into the CH repeatedly. It uses randomness in selecting CH, which may converge to no CH in a round. Gupta et al. implemented fuzzy logic for clustering of SN in WSN [12]. This work is an improvement over LEACH. The inputs for fuzzy systems are node degree, centrality and residual energy. However, it uses centralised approach by making use of BS for clustering. Centralised approaches are not easily scalable because of dependency on BS. The CH election mechanism relying on the Fuzzy reasoning (CHEF) was proposed by Kim et al. [13]. This protocol determines probability of node to act as CH. It utilises the transmission range to the BS and the remnant node energy as fuzzy elements for the CH selection, unlike LEACH. The contrast between LEACH and CHEF shows more effective cluster formation in CHEF than on LEACH.

LEACH-FL is an enhanced LEACH variant with Fuzzy Logic [14]. It differs from LEACH in term of the factors used, viz. distance of node from the sink, type of battery used, and the density of a node. Selection of CH is a centralised process, similar to LEACH, handled by the BS, which computes the probability of a SN to become a CH. The authors of LEACH-FL have shown through experiments that the suggested protocol has reduced the energy dissipation rate. The lifetime of network using LEACH-FL protocol exceeds the lifespan of the network while considering LEACH. Lee and Chen have [15] propound a fuzzy logic-based clustering strategy in which a CH node is elected on basis of outstanding energy of a node and the expected outstanding energy. SEP-FL [16] is an enhanced variant of SEP [8], centred on the choice of CH by adjusting the remaining energy probabilities for each node. It offers a larger duration of stabilisation and a reduced duration of disturbance thereby improving node lifetime. The method is based on each node's distance from the BS and remnant energy level. EAUCF [17] is a fuzzy based unequal clustering approach. It proposes to lessen the energy depletion of CHs in pairs as they are either near to the BS or possibly have limited battery power left. EAUCF has a stronger output in terms of first node death (FND), quarter node death (QND) and relatively lower energy depletion in contrast to LEACH, CHEF [13] and EEUC [18].

MOFCA [19] is another technique of clustering in mobile sensor networks. Based on range to node and residual energy, CHs are determined. The radius of the CH is very important in relation to opportunity, which means that if a CH is closer to the BS and has more energy, it can gather and communicate more information. An enhanced variant of EAUCF [20] is FBUC [21] or Fuzzy Based Unequal Clustering. In addition, FBUC utilises a probabilistic limit function instead of a predefined limit number as compared to EAUCF [17] and provides a fuzzy input variable called degree of node which is used to select the CH during cluster radius contest.

In different scenarios, FBUC exhibit lower power dissipation and longer network life than its counterpart in terms of first node death (FND) and last node death (LND). For a WSN to enhance lifetime, a CH selection scheme focused on fuzzy logic and particle swarm optimisation is suggested in [20]. DUCF [22] is another technique that uses fuzzy logic for clustering. Energy, proximity to the BS, and node temperature are regarded to be fuzzy inputs, and all nodes are selected in each round. This technique considers the most suitable node as a CH reducing energy consumption. FBECS [23], on the other hand, considers energy of SN, distance from the BS and density as an input to the FIS for selection of CH. It considers zonal network structure and corresponding probability during the clustering process. FBECS is capable of extending lifetime and stability time. DFLC [24] is another protocol based on the fuzzy logic that is carried out on nodes within the network in a distributed manner. DFLC considers network like a tree where it's nodes can be BS, cluster member and CH. DFLC is compared to ACAWT [25],LEACH, and CHEF [13]. Experimental results demonstrate that DFLC exhibit better performance than other algorithms in terms of chosen performance metrics. ECPF [26] also makes use of the fuzzy logic. Three procedures have been used to extend the life expectancy of the network. For fuzzy logic based calculation, ECPF utilises node degree and node centrality as fuzzy inputs for generating output for CH election.

SCHFTL [27], is based on fuzzy logic system, in which the sensor node uses different parameter at different levels. The first level parameters are remaining energy and centrality, the second level parameters used are communication quality and distance from the BS and the third level are total energy and DOS attack. With the help of this parameter, super cluster head is selected out of the chosen CH. This protocol avoids the data overload, data loss and data retransmission, thereby increases the network life span. DFCR [28] routing protocol is propound that applies unequal clustering mechanism to solve the hotspot problem of WSN by minimising the size of cluster, that are closest to the BS. E-CAFL [29] is another routing protocol proposed to enhance CAFL [30] protocol by allowing node density. It uses three parameters, viz. distance from sink, remaining energy and density of node as input for FIS for estimation of rank for selecting the CH.

In the above mentioned protocols, emphasis is not given to the parameters that majorly affect the energy level of SNs. We have determined the influential parameters and used them in fuzzy logic for best SNs selection in network. In most of the protocols mentioned in related work, they do not consider efficient cluster formation mechanism. We have fuzzy fitness value obtained during CH selection with other influential parameters while forming the clusters in our porposed work.

3. Preliminaries.

This section presents the assumptions made in the network model for the proposed work in line with the energy dissipation model.

3.1. Network Model.

Major presumptions that are made for the network are:

- SNs are randomly arranged in target area.
- After the deployment, all the nodes are stationary.
- BS doesn't have energy constraint.
- Deployed nodes are homogeneous in terms of resources.
- Every node has only one CH.
- The communication link is symmetric.
- The distance between two SN is determined by RSSI (Received Signal Strength Index).
- Initially, SN are unacquainted about their location.

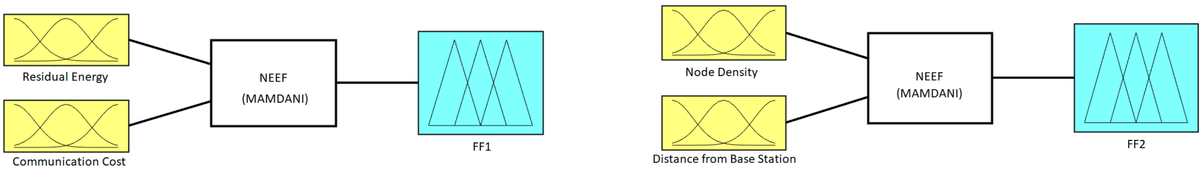
3.2. Energy dissipation model.

For the analysis of proposed work, the energy model adopted in [4] is employed. The energy of the network may be depleted in sensing, aggregation, amplification, transmission and reception. For transmitting and receiving s bits over d distance, energy dissipations are given by

$$E_{Tx}(s,d) = \begin{cases} sE_{elec} + s\epsilon_{fs}d^2, & d < d_o \\ sE_{elec} + s\epsilon_{mp}d^4, & d > d_o \end{cases} \tag{3.1}$$

where do is a threshold which determines either free space or multipath model adopted and it can be calculated by $d_o = \sqrt{\epsilon_{fs}/\epsilon_{mp}}$.

$$E_{Rx}(s) = E_{Rx-elec}(s) = sE_{elec} \tag{3.2}$$



(a) FF1 *(b) FF2*

FIG. 4.1. *Designed FIS*

In amplification of signal, energy dissipated is calculated by

$$E_{amp} = \begin{cases} \epsilon_{fs} d^2, & d < d_o \\ \epsilon_{mp} d^4, & d > d_o \end{cases} \tag{3.3}$$

The communication cost to be borne by a CH in a round is calculated by

$$E_{CH} = ns(E_{elec} + \epsilon_{fs} d_{BS} + E_{DA}) \tag{3.4}$$

The total energy exhausted by a member of a cluster is calculated by

$$E_{CM} = s(E_{elec} + \epsilon_{fs} d_{CH}) \tag{3.5}$$

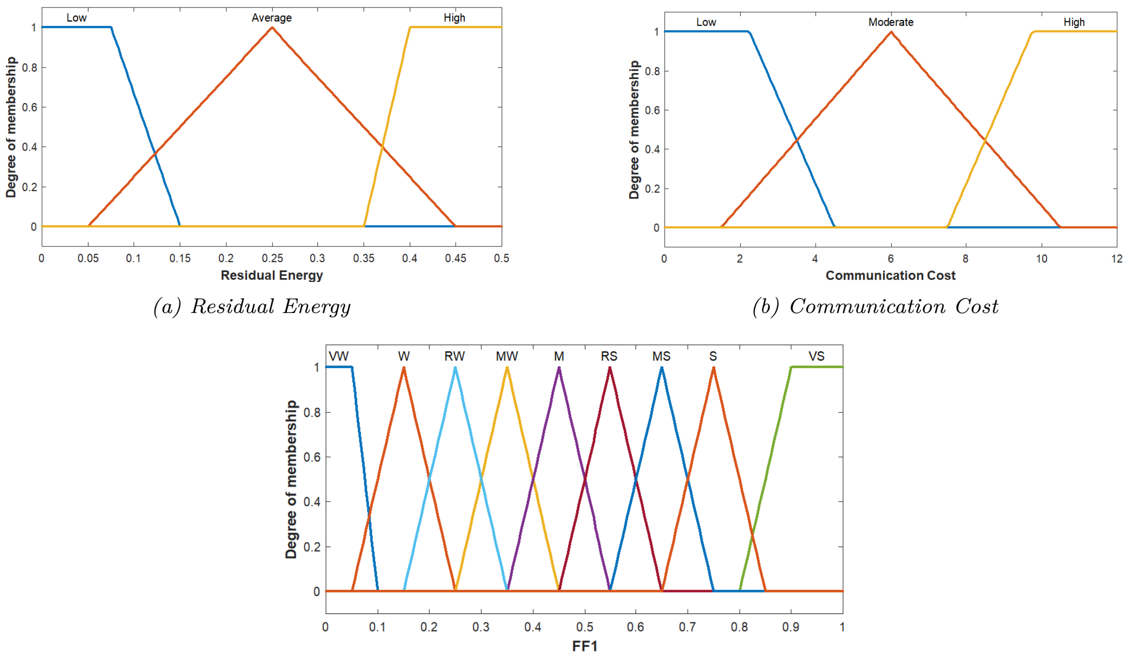
wherein d_{CH} is the distance to its CH.

4. Proposed NEEF protocol. The proposed NEEF protocol consists of four stages in a round i.e. *pre-deployment stage, CH selection stage, cluster formation stage and data dissemination stage.*

4.1. Pre-deployment stage. Before the deployment of SNs in the field, network administrator is required to allocate unique ID to the SNs. The information about the BS is also fed into the SN so that it can determine the BS during the operation of the network. For initial setup of the network and determining the neighbourhood, a TDMA slot is fed into each SN so that collision free broadcast can take place.

4.2. CH selelction stage. Once the deployment of SN is complete, it's time to select the optimal candidates to play the role of CH. Since the role of CH is very crucial, fuzzy logic is applied to determine the optimal candidate. Fuzzy logic is mostly applied to solve the uncertainties in any system. For efficient selection of CH in WSN, there are several overlapping factors like remnant energy, distance between node to the BS, density in neighbourhood, communication cost, etc. Thus, Fuzzy logic is appropriate to solve the optimal CH selection problem as it can blend various factors dealing with uncertainties and provide better results. Since, the nodes are unaware about the location of the BS, a Hello_PKT(BSID) is broadcast by the BS so that every SN can estimate the aloofness from the BS. The SNs will make a broadcast as per the TDMA slot provided in pre-deployment phase. Once all the SNs are aware of the required parameters (distance to the BS, remnant energy, communication cost and density around node), the computation for CH candidature begins at each SN. Two Fuzzy inference system (FIS) have been designed for computing the Fuzzy fitness values (FF1 and FF2) of SNs as shown in Fig. 4.1.

For FF1, residual energy and communication cost are chosen as the input variables. The linguistic variables (LV) chosen are Low(Lw), Average(Ag), High(Hg) and Low(Lw), Moderate(Md), High(Hg) respectively. LV for output variable are Very Weak (VW), Weak (W), Rather Weak (RW), Medium Weak (MW), Medium (Mm), Rather Strong (RStr), Medium Strong (MStr), Strong (VStr) and Very Strong (VStr). The membership function (MF) for different LV which are derived for input and output variables are shown in Fig. 4.2. The FIS processes these input variables on the basis of LV and establishes a functional relationship between input and output LV on the basis of set of IF-THEN mapping rules. These rules which are used for calculating the FF1 is depicted in Table 4.1. These IF-THEN rules are evaluated using Mamdani inference method [31] which we have also depicted in Fig. 4.1 and Fig. 4.5. The reason for using this method is its simplicity and ability to easily interpret and draw conclusion on the basis of given IF-THEN rules. For defuzzification, we have used



(a) Residual Energy

(b) Communication Cost

(c) Fuzzy Fitness Value (FF1)

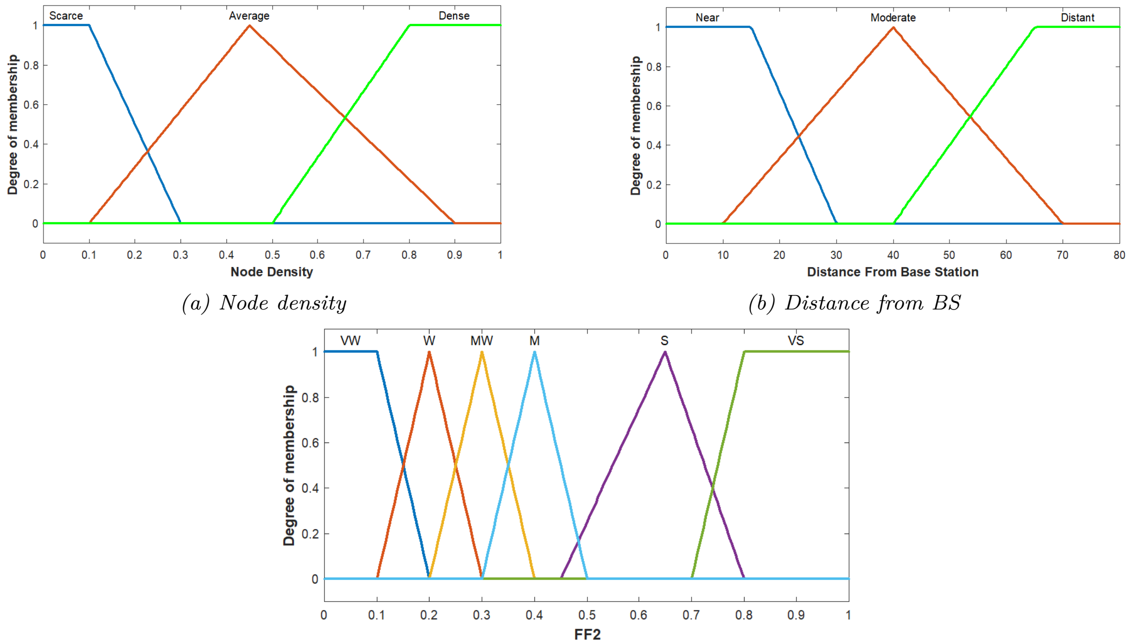
FIG. 4.2. *Membership Functions*

TABLE 4.1
Fuzzy Rules for FF1

Rule No.	Residual Energy	Communication cost	FF1
1	Lw	Hg	VW
2	Lw	Md	W
3	Lw	Lw	RW
4	Ag	Hg	MW
5	Ag	Md	Mm
6	Ag	Lw	RStr
7	Hg	Hg	MStr
8	Hg	Md	Str
9	Hg	Lw	VStr

COA method which is commonly used [30, 32]. For calculating the Fuzzy fitness value FF2, two parameters are considered: node density and distance from BS as shown in Fig. 4.1.

These two parameters have some significance during selection of CH candidate. Node density provides the estimation of neighbouring nodes which can reduce the intra-communication cost as more cluster members will lead to more dissipation of energy as well as coordination overhead. The objective is to distribute the load of CH role at par. Distance from BS determines the communication overhead which the CH has to borne for finally forwarding the data. If the number of neighbouring nodes is more and the BS is at distant place then more number of packets is to be forwarded to the BS which will deplete the energy of CH quickly. The LV for Node density is Scarce (Scr), Average (Ag) and Dense (Ds). Similarly, Near (Nr), Moderate (Md) and Distant (Dt) are the LV opted for Distance from the BS. For output variable FF2, the LV are Very Weak (VW), Weak(W), Medium Weak (MW), Medium(Mm), Strong (Str) and Very Strong(Str). Triangular and trapezoidal membership functions are chosen for interior values and boundary values respectively as shown in Fig. 4.3. The fuzzy IF-Then rules for mapping the input to output variables are depicted in Table 4.2.



(a) *Node density* (b) *Distance from BS*

(c) *Fuzzy Fitness Value (FF2)*

FIG. 4.3. *Membership Functions*

TABLE 4.2
Fuzzy Rules for FF2

Rule No.	Node density	Distance from BS	FF2
1	Scr	Nr	MStr
2	Scr	Md	MW
3	Scr	Dt	MW
4	Ag	Nr	Str
5	Ag	Md	Mm
6	Ag	Dt	W
7	Ds	Nr	VStr
8	Ds	Md	Mtr
9	Ds	Dt	VW

After the computation of FF1 and FF2, every SN calculates its probability of being CH by

$$SN(k).prob = \alpha \times SN(k).FF1 + \beta \times SN(k).FF2 \qquad s.t.(\alpha + \beta) = 1 \tag{4.1}$$

where α and β are arbitrary constants.

We have considered the value of α and β as 0.7 and 0.3 respectively as we got better results with these values as shown in Fig. 4.4. While carrying out experimental analysis of values assigned to α and β , we calculated the average CH to network energy ratio for 500^{th} round with varying values of α and β. The reason for weightage of α more than β is that FF1 considers communication cost as well the remnant energy level of SN which are more influential in choosing efficient CH. After each node computes the probabilistic value for its CH candidature, each node broadcast its probability. The SNs with highest probability are selected as CH candidates. Only $p\%$ CHs are elected in each round. The process of selecting CH is defined in Algorithm 1. We have designed a FIS for computing chance of each CH as shown in Fig. 4.5.

There are three input variables: number of member nodes, communication distance to CH node and fuzzy fitness value FF1 of CH node. The output variable is Chance of CH which determines the probability of CH to be chosen by non-CH node. The LV for input and output variables are depicted in Table 4.3. Membership

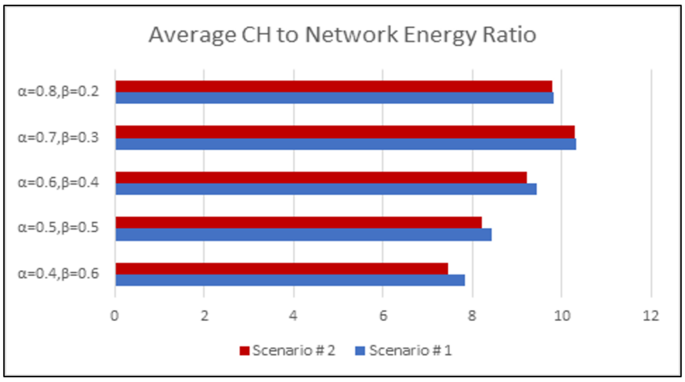


FIG. 4.4. *Experimental evaluation of α and β for average CH to network energy ratio*

Algorithm 1 Selection of CH

```
Tn ← Total nodes
k ← ID of SN
cluster_count ← 0
SN(k).Energy← current SN energy level
SN(k).ND ← Neighbouring nodes in communication range
SN(k).CC← communication cost if chosen as CH
SN(k).Type← N
Normal node
SN(i).DBS← Distance of SN to BS
for each node SN(k) do
    SN(k).FF1← Fuzzy(SN (k).Energy,SN (k). CC ) // Fitness Value1
    SN(k).FF2← Fuzzy(SN (k).ND,SN (k). DBS ) // Fitness Value2
    SN(k).Prob← α × SN (k).FF1 + β SN (k). FF2 ) // α and β are arbitrary constants
end for
for each node SN(k) do
    Broadcast SN(k).Prob
    if SN(i).type == "N" && SN(k).Energy>0 then
        if SN(i).Prob > rest of the nodes in Tn&& cluster count <p% then
            SN(i).Type ← "C" //SN is now CH
            Count_CH++ //Increment the count of CHs
        end if
    end if
end for
```

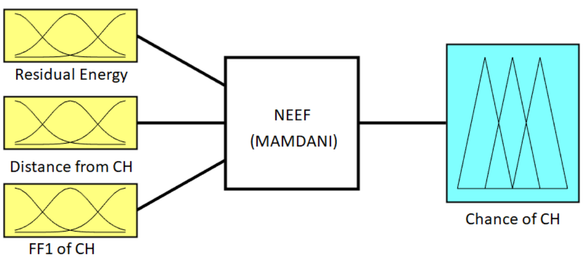
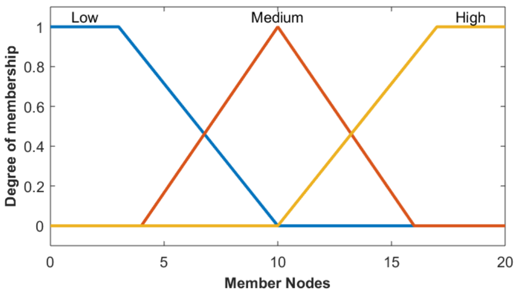


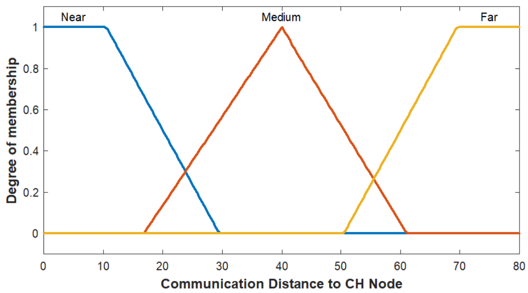
FIG. 4.5. *FIS for computing Chance of CH*

Table 4.3
Fuzzifier linguistic variables

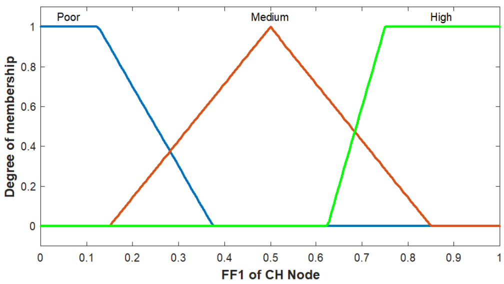
Variable Name	Linguistic Variable
Member nodes	Low(Lw),Medium(Mm),High(Hg)
Communication distance to CH node	Far(Fr),Medium(Mm),Near(Nr)
Fuzzy Fitness(FF) value 1	Poor(Pr),Medium(Mm),High(Hg)
Chance of CH	Very Strong(VStr), Strong(Str), Medium Strong(MStr), Medium(Mm), Medium Weak(MW), Rather Weak(RW), Weak(W),Very Weak(VW)



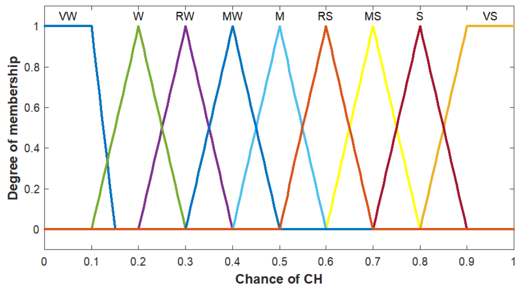
(a) Member nodes



(b) Communication distance to CH Node



(c) Fuzzy Fitness Value (FF1)



(d) Chance of CH

Fig. 4.6. *Membership Functions*

functions of input and output variables are depicted in Fig. 4.6. IF-THEN rules for mapping input to output variables are depicted in Table 4.4. Each non-CH node computes the chance of each CH candidates and the CH candidate with maximum chance is chosen as optimum CH by the node. The non-CH node sends join request to the optimum CH node and receives acknowledgement from CH node with TDMA slot for data collection during the round. The cluster formation process is illustrated in Algorithm 2.

4.3. Data dissemination stage. Once the selection of CHs is completed and clusters are formed, a data dissemination stage comes into play. Data is generated from the target area on periodic basis. After sensing the target area, SN forwards the data to the CH as per the TDMA slot for collision free communication. Once the CH collects data from all the cluster members, it aggregates the data and transmits it to the BS for further processing. In this way, one round is concluded in NEEF protocol.

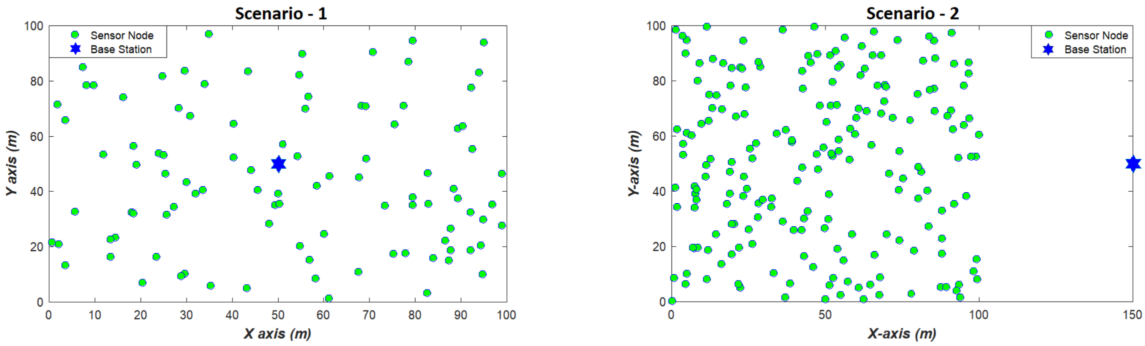
5. Simulation experiments and result analysis. NEEF is simulated and evaluated along with SCH-FTL [27] and DFCR [28] protocols using MATLAB. The field size is considered to be 100 x 100 m^2 with randomly scattered SNs. The operation of the network is split into rounds. For every round, CH selection, cluster formation and data dissemination take place. The parameters for simulation are described in Table 5.1which are kept similar to SCHFLT [27] and DFCR [28]. The performance metrics chosen for evaluation of proposed work are alive nodes per round, packets to the BS, average energy of network, stability period (FND),

Table 4.4
Fuzzy rules for computing Chance of CH

Rule No.	R_Energy	DBS	Density	Rank
1	Lw	Fr	Pr	VW
2	Lw	Fr	Mm	Vw
3	Lw	Fr	Hg	W
4	Lw	Mm	Pr	W
5	Lw	Mm	Mm	W
6	Lw	Mm	Hg	RW
7	Lw	Nr	Pr	RW
8	Lw	Nr	Mm	MW
9	Mm	Nr	Hg	MW
10	Mm	Fr	Pr	RW
11	Mm	Fr	Mm	RW
12	Mm	Fr	Hg	MW
13	Mm	Mm	Pr	RW
14	Mm	Mm	Mm	MW
15	Mm	Mm	Hg	MW
16	Mm	Nr	Pr	MW
17	Hg	Nr	Mm	Mm
18	Hg	Nr	Hg	RStr
19	Hg	Fr	Pr	Mw
20	Hg	Fr	Mm	Mm
21	Hg	Fr	Hg	RStr
22	Hg	Mm	Pr	RStr
23	Hg	Mm	Mm	MStr
24	Hg	Mm	Hg	Str
25	Hg	Nr	Pr	MStr
26	Hg	Nr	Mm	Str
27	Hg	Nr	Hg	Vstr

Algorithm 2 Formation of cluster in NEEF

```
Tn ← Total nodes
TN_CH ← Total CH nodes in a round
k,m ← ID of SN
for each node in TN_CH do
    Broadcast CH_MSG(SN(k)).ID,SN (k).Member Nodes, SN (k). FF1
end for
for each non_CH_Node in Tn do
    if SN(k).type == "N" && SN(k).Energy>0 then
        OPTIMUM_CH ← 0 // Initially No CH is Chosen as Optimum
        OPTIMUM_CH_CHANCE ← 0 // Initialising Chance of each CH to 0
        for m=1 to TN_CH list do
            if SN(m) is within Communication Range of SN(k) then
                Max_Chance= Fuzzy (SN (m).member nodes,distance to CH, SN (m). FF1)
                if Max_Chance > OPTIMUM_CH_CHANCE then
                    OPTIMUM_CH← m //ID of CH node
                    OPTIMUM_CH_CHANCE← Max_Chance
                end if
            end if
        end for
    end if
end for
SN (k).CH← OPTIMUM_CH // Optimum CH is chosen by SN
SN(k) will transmit a join request to OPTIMUM_CH node
OPTIMUM_CH node will Acknowledge SN(k) with TDMA slot.
```



(a) Network Structure for S#1 *(b) Network Structure for S#2*

FIG. 5.1. *Network structure.*

TABLE 5.1
Simulation Parameters and their values

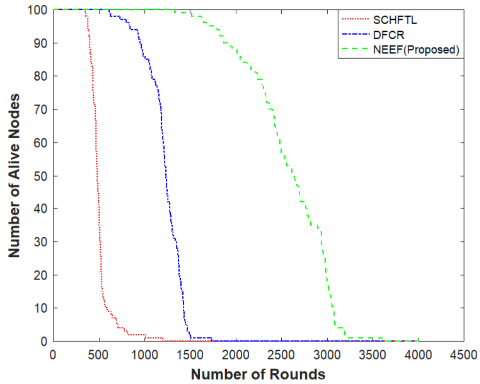
Parameters	Symbol	Values
Total SNs in Field	N	100,200
Amplifier energy for free space	ϵ_{fs}	$10pJ/bit/m^2$
BS location	BS	(50,50),(150,50)
Amplifier energy for multipath	ϵ_{mp}	$0.0013pJ/bit/m^4$
Energy of SN before deployment	E_o	$0.5J/1.0J$
Data packet Size	M	4000bits
Data Fusion	E_{DA}	5nJ/bit/report
Arbitrary constants	α, β	0.7,0.3
Percentage of CH probability	$p\%$	10
Electronic Circuitry	E_{elec}	$50nJ/bit$

QND, HND, average energy of chosen CHs. These metrics will evaluate the protocol from every perspective conforming the enhancement in lifetime of the network. We have carried out simulation more than 50 times and the results were normalised. The graphs depicted are instance of one of the simulations carried out so that clear picture about the performance of all the simulated fuzzy based protocols can be perceived.

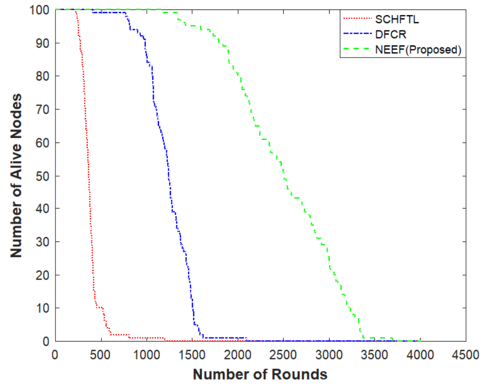
5.1. Network structure. In conducting simulation experiments, we have considered two network structure/scenarios as depicted in Fig. 5.1. In scenario 1 (S#1), the BS is positioned at the centre of the field and scenario 2 (S#2) considers the BS located at far off place from the field. The reason for choosing two scenarios is that this protocol can satisfy all the applications of WSN where the BS is either within the vicinity or beyond the vicinity.

5.2. Alive nodes. With the focus on longer lifetime with maximum coverage, alive nodes have huge impact on WSN. More the number of alive nodes, longer will be the lifetime of the network. Fig. 5.2 depicts the number of alive SNs in the field after each rounds for both the scenarios. It can be clearly witnessed that NEEF performs better than SCHFTL and DFCR protocol as it has more alive nodes after each round as equated to SCHFTL and DFCR for both the scenarios. In scenario 1, for up to 1500 rounds, almost all the nodes are dead for SCHFTL and DFCR protocols whereas more than 90% nodes are alive in case of NEEF protocol. For scenario 2, for up to 1500 rounds, more than 90% nodes are alive in the network for NEEF protocol whereas no node is alive for SCHFTL protocol and more than 95% nodes are dead in case of DFCR protocol. Obtained result from Fig.5.2(a,b) clearly unveil the balanced load distribution among the deployed SNs.

5.3. Throughput. Collecting information from the target area is the ultimate objective of WSN. Successful delivery of more information to the BS reveals better design of protocol. Fig. 5.3 exhibits the number of successful packet delivery to the BS during span of the network. We can see that that NEEF protocol

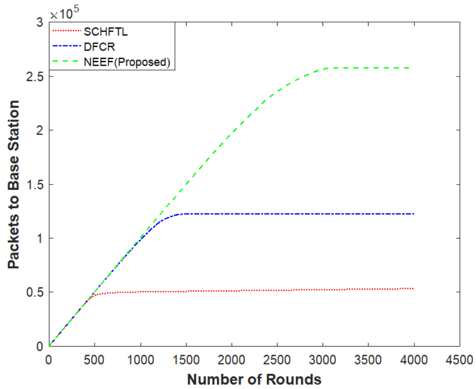


(a) S#1

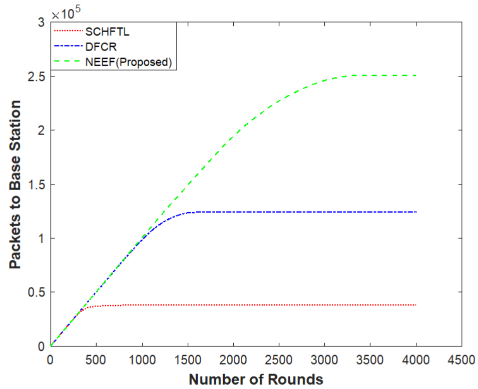


(b) S#2

FIG. 5.2. *Alive nodes w.r.t rounds*



(a) S#1



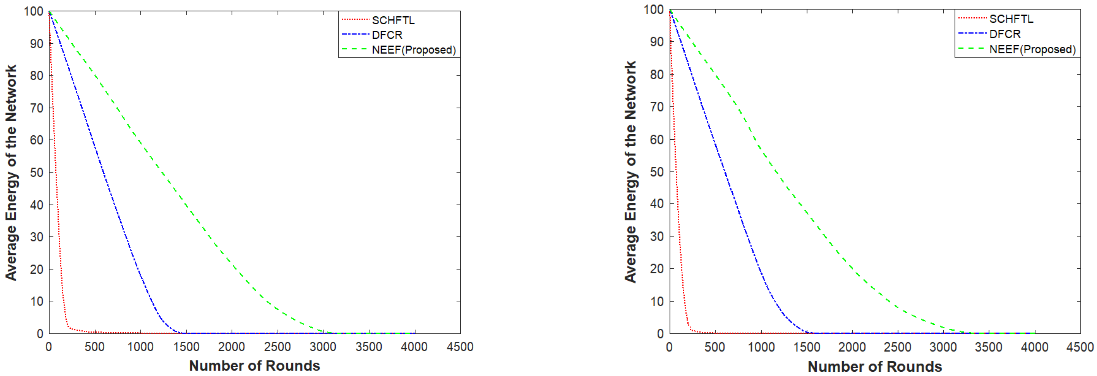
(b) S#2

FIG. 5.3. *Packets to the BS w.r.t. rounds*

has forwarded more packets to the BS as compared to SCHFTL and DFCR protocol. Since, more number of nodes are alive per round in NEEF protocol, therefore, more information is forwarded to the BS. Every WSN is expected to forward as much information as possible with longer lifetime and this purpose is served by NEEF protocol.

5.4. Average energy of network. The dissipation rate of energy of SN may affect the lifetime of the network. If the network is dissipating energy quickly then the lifetime will decrease resulting in incomplete coverage of target area. Fig. 5.4 discuss about average energy of network per round. It can be seen that average energy of NEEF protocol for each round is much more than SCHFTL and DFCR protocol for both the scenarios. The reason behind the better performance is the consideration of crucial parameters like communcation cost to be borne by SN if chosen as CH and its remnant energy level during the selection of CH. This balances the load resulting in more average energy of the network. Stability period or First node dead determines the reliability of the network [8]. If a protocol exhibit better stability period then it's clear that it has more reliability as it ensure the complete coverage of the network because all the SN are alive in the network till that stability period.

5.5. First Node Dead,Quarter Node Dead and Half Node Dead. FND ensures that the network is reliable as the deployed nodes are covering the target area intactly. QND and HND are checkpoints which determine the rate at which the nodes are expiring. Fig. 5.5 shows the rounds in which the simulated protocols have FND, QND and HND. The reason why we have not considered Last Node Dead (LND) is that after the



(a) S#1 *(b) S#2*

Fig. 5.4. *Average energy (J) per round*

(a) S#1 *(b) S#2*

Fig. 5.5. *First Node Dead, Quarter Node Dead and Half Node Dead*

death of 50% node, there is no reliability about the coverage of the target field. From experimental analysis, we have seen that some protocols continue up to 1000 rounds more with their last node which has no relevance as single node is incapable of covering all the target field. For FND, NEEF has improved over SCHFTL and DFCR by 278.63% and 116.09% for scenario 1. In case of scenario 2, the improvement of FND for NEEF is further increased having 398.85% and 172.81% over SCHFTL and DFCR respectively. If we talk about QND, NEEF has shown increment of 429.22% and 100.86% over SCHFTL and DFCR respectively for scenario 1 and 561.16% and 98.34% over SCHFTL and DFCR respectively for scenario 2. For Half Node Death, in case of Scenario 1, the obtained results are 440.69% and 114.08% better than SCHFTL and DFCR respectively and for Scenario 2, the improvements are 590% and 105.72% over SCHFTL and DFCR respectively.

5.6. Average energy of CH. This performance metric ensures that the nodes which are having better energy levels along with other primary and secondary factors are turned into CH. In Fig. 5.6, we have chosen average energy of CHs in lifetime of the network as one of metric because it depicts how energy bundled SNs are chosen to take the challenging role of CH. It is witnessed that the average energy of CHs for scenario 1 is improved by 986.34% and 59.25% as compared to SCHFTL and DFCR protocol. For scenario 2, NEEF performs 1104.91% and 67.93% better than SCHFTL and DFCR protocol. The cause of the poor performance of SCHFTL is that it has chosen some random values for the parameters like DOS, communication quality and total delay which does not give deep insight of the SN capability while selecting the CH candidate. In case of DFCR protocol, it considers the remnant energy and aloofness from the BS as crucial factors for election of CH where intra cluster communication cost is neglected which results in poor performance as compared to NEEF protocol.

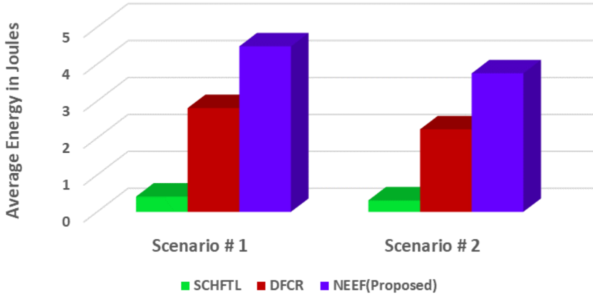


Fig. 5.6. *Average Energy of CH for both scenarios*

6. Conclusion. NEEF is proposed for resource constrained WSN. This protocol has considered two fuzzy fitness values obtained from primary and secondary factors fed to designed Fuzzy Inference System. Primary factors include remnant energy and communication cost whereas secondary factors considered are node density and distance to the base station. With experimental observations, primary and secondary factors are used in appropriate proportion for selection of best cluster head candidates. For balancing the cluster head role, non-cluster head members use fuzzy logic for choosing their cluster heads. NEEF exhibits tremendous improvement over SCHFTL and DFCR protocol in terms of protracted lifetime, stability period, and better average energy of chosen cluster heads and communication of more information to the base station. This protocol is suitable for applications where either the base station can be put at the centre or beyond the target field. In future, we will perform simulation experiments on mobile sensor nodes.

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