FL-HEED: Fuzzy Logic based HEED Protocol for Wireless Sensor Networks

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Abstract: *In this era of wireless sensor networks (WSNs) and IOTs, topological control for balancing load among sensor nodes necessitates an efficient scheme which can enhance the network lifespan and scalability. One of the major challenges in such schemes is to reduce the energy consumption so that utilization of battery power can be optimized. Moreover, existing schemes in the same domain considered some infrastructure based assumptions which make these schemes less efficient in current scenarios. This paper presents a new fuzzy logic based clustering protocol FL-HEED which is an extension of Hybrid Energy Efficient Distributed (HEED) protocol. It selects cluster heads (CH) based on three most familiar variables of network i.e. variability in distance from base station to nodes, coarser level of node numbers and the node's battery level with the desired threshold values for fuzzy logical control unit. The performance of the proposed approach is shown in terms energy, network lifespan, packet delivery ratio and throughput of the given network comparing with the existing HEED protocol. FL-HEED achieves significant improvement over traditional HEED for lessen the overhead and uniform distribution of CH. All the simulations are done over MATLAB.*

Keywords: Wireless sensor networks, HEED, Routing, Clustering, IOTs, In-network processing, Data-Aggregation.

I. INTRODUCTION

Recently, WSNs and IOTs are emerged as an important platform for various monitoring applications such as environmental monitoring, disaster control monitoring, border security surveillance etc. Sensor nodes perform three fundamental tasks sensing the physical phenomenon, processing over acquired signal and communicating the signal to the base station (BS) for further processing. Sensors are backed up by small batteries, so its operating capabilities rely on the efficient use of the power source supplied by these batteries. However, some sensors may have rechargeable batteries which can be charged with other source of power like solar energy, wind energy etc. But, in hostile environment, availability of these power sources is not guaranteed. So, it is not a viable solution to use these rechargeable sensors in applications where human intervention is not possible. This motivates the necessity of efficient schemes which reduces the power consumption for prolonging the network lifetime. Since, communicating a bit in WSN is more costly in comparison to sensing and processing. Thus, communication protocols are continuously being updated or new schemes are proposed by the research community. In order to reduce the energy expenditure and enhance the lifespan of network, one of the popular and widely accepted schemes is clustering of nodes. In clustering, the nodes in the close proximity or having similar properties gathered together to form a cluster of nodes. In each cluster, there exist two types of nodes: 1) One cluster head and 2) Member nodes. A node with the responsibility of CH acquire signals from its member nodes, process it to form a aggregated signal and communicate the aggregated signal to BS for further processing.

The existing schemes are categorized into two different categories: 1) Equal clustering approach and 2) Unequal clustering approach. In equal clustering scheme, all the CHs contain same number of member nodes and in unequal clustering scheme, member nodes varied in each CH. Although, equal clustering scheme provide reliability in network coverage as it is fairly possible in uniform distribution of nodes. But, in real world applications, uniform distribution of nodes is not desirable most of the time. In that case, uneven clustering comes into picture. However, it allows designing a clustered network where member nodes need not to send their information directly to BS, instead sends their information to CH which leads to minimization in energy consumption, but it also impose uneven load on some CHs having more number of member nodes. Moreover, in multi-hop communication paradigm, CHs near the BS deplete more energy in comparison to other CHs which results into early exhaustion in terms of energy. Although, various unequal clustering schemes present in the literature like LEACH, HEED, EECS etc. have shown improvement in different aspects but they lack in providing the reduction in overall energy consumption and stability simultaneously. Today, change in size of the networks, its cost to implement in hostile environment and shrinking size of sensors force researchers to rethink about communication strategies.

In this work, we propose a new routing scheme FL-HEED which is considered as an extension of popular HEED protocol and based on fuzzy logic for electing CHs. In FL-HEED, CHs are elected based on three parameters i.e. angular distance of node to base station (D_Θ), residual energy (R_E) and number of nodes in proximity of any node i.e. node degree (N_d). The proposed scheme decides size of the cluster on the basis of these parameters and the probability of becoming a cluster head is depend upon residual energy along with angular distance measure. The rules taking decision for a node to be a cluster head or not are fuzzy rules which help to eliminate other possible nodes. Despite the fact that it is an extension of HEED, the working of proposed scheme is completely different from existing HEED. Basically, how it will achieve stability and reduction in overall energy consumption.)

Rest of the paper is well thought out as: Section II presents the similar work done in the same domain, section III describe the system model and problem definition, the idea of the proposed work is elaborated and proposed approach is defined in section IV, section V discusses the results obtained through simulations and finally the concluding remarks are given in section VI.

II. RELATED WORK

LEACH [] is the classic clustering algorithm for which multiple variants have been developed. It has pure probabilistic model for cluster head election. The algorithm has two phases a) CH election phase b) steady state phase. In first phase of CH election each node selects a value between 0 and 1 which is dependent on the parameters like, the number of rounds for which a node has been elected as CH. Further, based on equation 1, a sensor 'm' from the set of non-CH nodes 'G' is elected as CH for round 'r' with a probability 'p'.

$$T(m) = \begin{cases} \frac{p}{1 - p * (r \bmod (1/p))}, & n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Then, elected node advertises its status and sensor nodes join the nearest CH (neighborhood is decided based on RSSI). TDMA is utilized for cluster member node to CH communication. The algorithm uses probabilistic methods for CH but suffers from scalability issues due to 1-hop communication distance between CH and BS. Also the criteria for CH election is based on probability only and not on other parameters.

HEED [] on the other hand takes sensor node's remaining energy into consideration. Also, average CH distance from member nodes is another criterion for CH election. Hence, its performance is better compared to LEACH in terms of energy.

EECS [] is the biased and unequal clustering algorithm where, each node competes for becoming cluster head within communication range and withdraws from competition as soon as it encounters a message from a higher energy node in vicinity. CH to BS communication is 1-hop hence; to compensate distant most CH is allotted minimum number of member nodes based on a weighted function. EEUC [] is another algorithm similar to EECS where cluster head competition message COMPETE_HEAD_MSG distribution is function of competing distance R compete such that the parameter has higher value for distant nodes and lower value for nearby nodes. Further, if the distance between BS and CH is more than a threshold then, multi-hop communication is followed from dedicated and aggregating CH to other CHs without any further aggregation. COCA [] is also an unequal algorithm which divides deployment region into units. Each node with higher energy from proximity nodes is elected as CH. Further, a unit can have more than one CH and the cluster size keeps reducing towards the BS.

Gupta [] has added fuzzy input parameters in LEACH like node energy, node concentration, and node centrality. Results for clustering and lifetime are better compared to conventional LEACH but it still faces issues like, centralized clustering is necessary, number of control messages increase and scalability is also poor. CHEF [] is another fuzzy based and distributed clustering algorithm for WSN. It has two input variables: residual energy and local distance (sum of all distance of a node from neighboring distance within a radius 'R'). Based on these inputs a de-fuzzified output is received to or not to elect a node as CH. This propose doesn't take CH to BS distance into account hence scalability is compromised. EAUCF [] is another distributed fuzzy based scheme having two fuzzy input parameters: residual energy and distance to BS. The output is again put to methods of competing radius and center of area approaches to get an optimum CH. More over EAUCF and CHEF don't take intra-cluster communication overhead into account as a drawback.

In [29], the fuzzy system has been used to elect cluster heads. The algorithm uses three fuzzy variables (Energy, centrality and concentration of a node) for selection of CHs. In this approach, the essential information is collected by the BSand then according to the rules of fuzzy logic system a node is elected as a CH. In [30] also the CHs are elected based on fuzzy logic rules. The fuzzy set contains the energy levels of nodes as well as their distances. In [30] a random number for each node is generated, and if the generated number is less than a specific threshold, the node might be discarded from becoming CH although it could be a qualified one. Authors in [31] use three linguistic variables to elect nodes as CH with attention on nodes having high probability, as well as high initial and final energy.

Overall, it is observable that no clustering algorithm achieves both i.e. reduction of energy consumption and increasing stability period. Hence, based on these two metrics DUCF is proposedthat achieves increase in stability period and load balancing in terms of power consumption.

III. Problem Description

Energy expenditure nature of sensor nodes in process of communicating observations from one node to another, primarily affects the overall network lifespan. One of the main reasons is resource scarcity, especially the limited battery power. Resource scarcity in terms of battery power in sensors leads to either faded signal or a complete shutdown of the network. Although, the same problem is targeted through establishing different mechanism such as multi-hop routing, clustered routing, distributed network routing, decomposition based routing etc. But, the mechanisms in the domain of clustered routing, generally considers a single parameter for selecting or deselecting the node for taking active participation in routing scheme. In this work, the below mentioned problems are based on two factors: 1) the existing mechanism which fail to provide energy efficient routing to these recently designed devices, and 2) Current hardware configuration of sensor /IoT devices

Biased clustering: As only single parameter is generally considered for clustering. However, it is true that the parameter acts random in nature but it possesses biased behavior due to pseudo randomness, and not a perfect randomness.

Early starvation situation and disconnected networks: Clustering in each round of data gathering unnecessarily depletes energy which leads to early starvation situation for some of the important nodes. This early starvation of nodes result into disconnected network.

Changing architecture and configuration of sensors: Advancement in sensor's technology and emerging IT market completely needs an adaptive clustering scheme which can be configured and can be changed time to time as the requirement changes. So, the work is focused on to provide an energy efficient routing solution which can adapt the present needs of devices and lift the limits of existing schemes.

IV. Network Model

Let a WSN represented as an undirected graphical model consisting 'N' sensor nodes is deployed in 2-D space of size L×L meter^2. The set S= {S1, S2…, SN} of these 'N' nodes are represented as the vertices of the graph G(S, E) where edge set 'E' consists the direct communication links between the nodes. The direct communication between two nodes 'S_i' and 'S_j' is possible if and only if they are within the communication range of each other and having edge between them, otherwise, follow multi-hop communication paradigm. The environment monitoring requires deploying the sensor nodes based on the some basic assumptions which are given as follows:

- All sensor nodes carry the same energy level and there is no ability to recharge them as deployment is considered in hostile environment.
- All nodes are homogenous in nature i.e. similar in properties like communication radius (R_C), Sensing radius (R_S), battery power level etc.
- The base station is considered to be static in nature and situated outside the target region.
- The sensor nodes are stable in respect to locations that means positions of sensor nodes are not changing.
- Base station is considered to have sufficient resources to process the information and to take appropriate actions.
- Received signal strength indicator (RSSI) helps to calculate the distance of sensor nodes.

V. PROPOSED FL-HEED MODEL

In FL-HEED, the fuzzy logic isused to improve the cluster head selection procedure and extend the lifetime of the HEED protocol. The simple and straightforward description of the proposed work is shown in the form of flowchart given in Figure 3. Three input parameters namely residual energy (R_E), angular distance(D_Θ), and node degree (N_d) were used to convert the crisp inputs into fuzzy sets. Each one of the input functions possesses three membership functions.

Different membership function is used to illustrate the different level of the input functions as shown in Table 1 aswell in Figure 4. The fuzzy system output shows one of the probability levels (the other probability valueis computed using traditional threshold calculation model) for each node to be chosen as a cluster head. The output function of our proposed approach which contains 5 membership functions is shown in Table 1 and Figure 4.

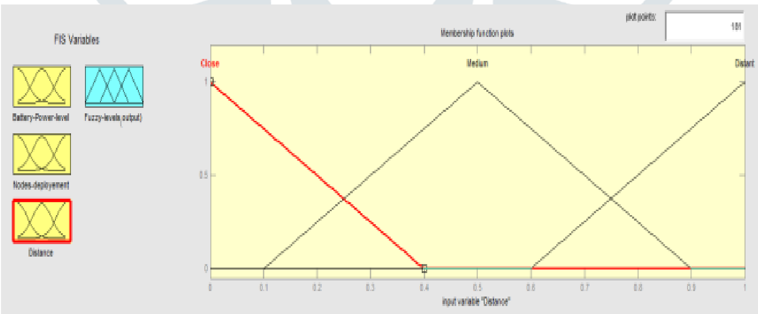

Figure2. Membership function for Distance input

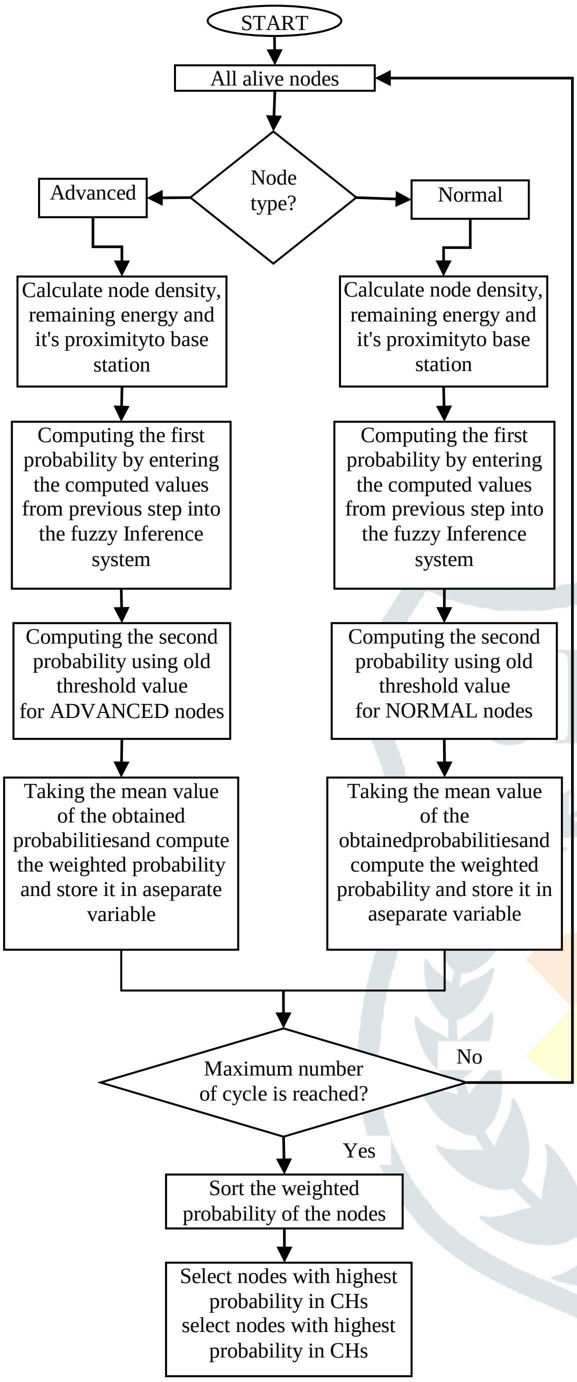

Figure2. The detailed flow chart of the proposed protocol

Table1. Fuzzy If-then rules

Input	Membership				
Residual energy	Very-Low	Low	Medium	High	Very-High
Nodes Deployment	Very-Low	Low	Medium	High	Very-High
Distance	Very-Low	Low	Medium	High	Very-High

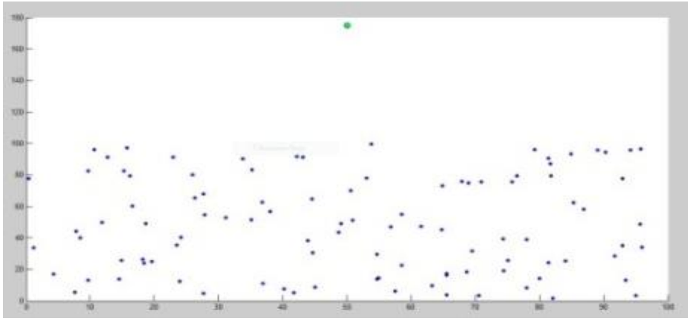

Fig.2. Number of nodes (100) deployment

Phase 1: Cluster head election

To choose nodes as CHs most efficiently in order to extend the lifetime of the network we first compute the battery power level, node deployment and distance to the base station, for each and every SN and then calculating the probability by considering fuzzy rule base given in Table 1. Subsequently the calculated probability for every node is stored in few variables.

The next step would be to compute the threshold value for each node (Equation 6, 7) and then storing them in separate variables. The two variant probabilities obtained from our fuzzy logic system and the threshold equations will be used to find the most suitable nodes as CHs. We finally calculate the weighted probability by considering the mean of the previous probabilities for each and every node and then sorting them according to their value, nodes having height weighted probabilities would be elected as the CHs. As we can see here we used the old threshold equations as well as considering other properties of each node (battery level, node density and distance to the base station) to elect the most suitable nodes as CHs in order to prolong the network lifetime and increase its efficiency. The working procedure of the protocol is given in figure 3 as detailed flowchart and also step wise details is given as follows:

Step 1. Calculating the battery level, distance and node density for each and every node

Step 2. Computing the first probability, by entering the computed values (step 1) into the fuzzy inference system

Step 3. Computing the second probability for each node using old threshold values. (Using equation 6 and 7)

Step 4. Using the mean value of the obtained probabilities of each node and compute the weighted probability for each node

Step 5. Sorting the weighted probabilities

Step 6. Election of nodes having highest weighted probabilities the CHs

Step 7. Repeat steps 1 to 6, for each cluster till the maximum number of cycle is reached.

Phase 2: Association of member nodes

After phase 1, each cluster head broadcasts the Join_CH message, containing the CH_id and its angular distance from BS, in its proximity. A node which receives join message from any of the CH transmits the Join Request back to the respective CH_id from where it received Join_CH message. Here, there may be more than one case where a node has to decide to which CH it has to be associated:

1) **Node receives a single Join request message from CHs:** In this case, node directly sends its Join Request massage to CH and there will be no conflict of interest. After receiving the Join Request massage, CH acknowledges the respective member node that the request is accepted.

2) **Node receives multiple Join request message from CHs:** In this case, node selects the CH with minimum angular distance from BS. As, lower the angular distance lower will be transmission power. Therefore, it reduces the power when CH transmits these messages to BS.

3) Node doesn't receive any of the Join request message from CHs: As in random deployment, it is possible that some nodes get deployed in a region from where it is not able to connect to other nodes. But, it doesn't mean that these nodes are not the part of clustering procedure. In that case, a node which doesn't get any of the Join request message, nominates itself as an independent CH and send acknowledgement to BS directly.

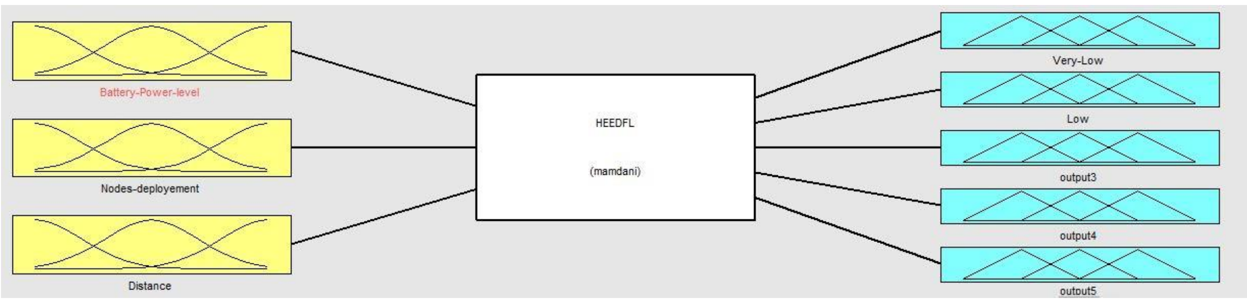

Fig.4. Membership function of Residual energy, Angular distance of nodes to BS and Degree of a node

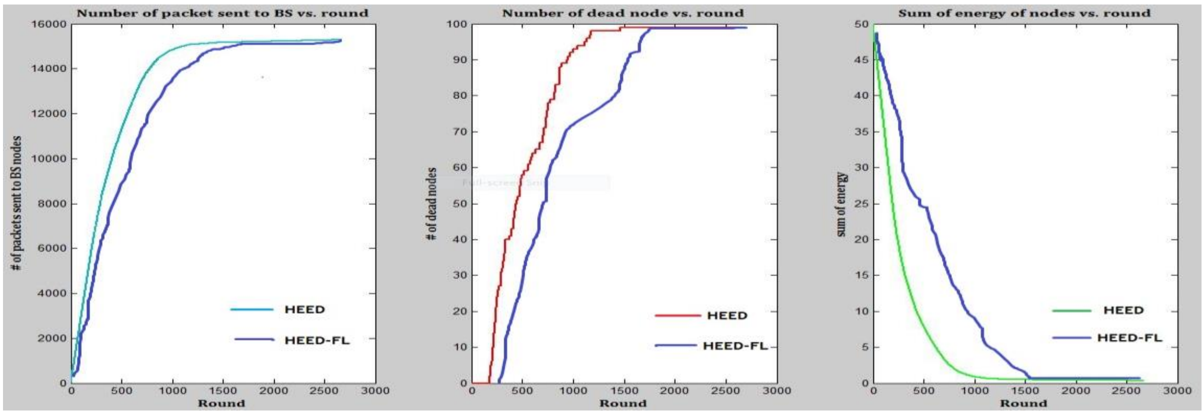

Fig.5. Different output constraints vs. rounds

VI. SIMULATION AND RESULTS

In order to evaluate the performance of the HEED-FLand compare it with HEED, simulation tests have been carried out in MATLAB (2014a) [10]. 100 nodes have been deployed and distributed randomly within an area of 100*100 meter. Energy model used here is the same as in HEED protocol. A list of parameters related to simulation setup is given in Table 2.In case of HEED protocol 25 %of the total nodes are advanced nodes having 100 % moreenergy than the normal ones and for HEED-FL protocol 25% ofthe nodes deployed are advanced with 100% more energy thannormal nodes, 15% nodes are intermediate nodes with 40%more energy than normal nodes.

Figure 5 depicts the total number of dead nodes with respects to the functioning of the network in different rounds.ConsideringTable 3,it is clearly observed thatin the proposed HEED-FL the death of nodeshave been extended comparing with HEED protocol. Therefore the proposed algorithm improved the nodes lifetime and as well as the network lifetime significantly.

Table 2. Parameters of Simulation setup

S. No.	*Parameters*	*Value*
1.	Environment Size	100*100
2.	Number of nodes	100
3.	Packet Size	3500 bits
4.	Election Probability valueof Cluster-heads (P)	0.15
5.	Initial energy per node (E_0)	0.6J

Table 3. Comparison of algorithms results

Algorithm	*Number of packets send to BS (rounds 1000)*	*Number of dead nodes (rounds 1000)*	*Sum of energy of nodes*
FL-HEED	13900	72	9.0
HEED	14800	100	1.0

To analyze the Residual energy of network can be helpful to determine the efficiency of an algorithm in terms of energy. The Figure 5 shows the comparison of energy consumption of HEED and HEED-FL protocols. As we observe the curve of HEED-FL is much better than the compared protocols in terms of sustainability till the more rounds. Thus it has a improved performance in terms of balancing and distributing of the overall energy.

In term of throughput, it suggests the number of packets which have been sent to the base station/sink. Considering Figure 5 we observe that our proposed algorithm has a higher throughput comparing with HEED routing protocol.

VII. CONCLUSION

In this paper, the HEED protocol for routingis extended using fuzzy logic. This is achieved by utilizing the residual energy in the network, node's degree and their angular distance from BS. The proposed FL-HEED scheme utilizes these three parameters R_E, N_d and D_Θ for fuzzy logic system. Since, nodes with high residual energy requires less energy in communication with other nodes, N_d ensures the connectivity in the network and D_Θ ensures the reduction in energy expenditure from CH to BS. So, FL-HEED not only reduces the energy in in-network transmissions i.e. from nodes to CHs, but also from CHs to BS. The significance of the results can be seen from the results that FL-HEED shows more stability and runs for a longer time. Hence, the lifetime of the network is extended in comparison with the HEED protocol. The results also signifythat the throughput of the network isimproved compared with the mentioned protocol.

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