Indian Journal of Science and Technology, *Vol 9(37), DOI: 10.17485/ijst/2016/v9i37/94772, October 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Fuzzy based Hierachical Unequal Clustering in Wireless Sensor Networks

S. Srividhya[1*] , V. Ganapathy[1] and V. Rajaram[2]

[1]Department of Information Technology, Faculty of Engineering and Technology, SRM University, Kattankulathur - 603203, India; srividhya.sw@kt.srmuniv.ac.in, ganapathy.v@ktr.srmuniv.ac.in
[2]Department of Information Technology, Sri Venkateswara College of Engineering, Sriperumbuthur – 602117, Tamil Nadu, India

Abstract

Objectives: Sensor nodes in Wireless Sensor Networks are battery powered and non rechargeable, and hence in most of the real time applications energy consumption is a major problem. The lifetime of the network also depends upon the energy consumption model which may affect the entire performance of the networks. The main aim of the proposed Hierarchical Unequal Clustering Fuzzy Algorithm (HUCFA) is to reduce the energy consumption of over all networks. **Methods/Statistical Analysis:** Clustering is an important technique used for energy efficient data communication in WSN. Fuzzy logic is applied in the proposed algorithm to choose the cluster head, which enhances the energy efficiency. To choose a better cluster head, the characteristics of the nodes are taken as input for fuzzy inference system. Based on the fuzzy rules, best nodes are selected as cluster heads. Fuzzy Logic Toolbox in Matlab R2010a is utilized for the simulation. **Findings**: Total Energy Consumption of the network (TEC) in HUCFA is 7.05% less when compared to LEACH. Standard deviation of energy distribution among all the clusters in the HUCFA is 10.46% less than that of LEACH protocol and 0.79% less than Hierarchical Unequal Clustering Algorithm. **Application/Improvements:** The proposed HUCFA using Fuzzy Logic is found to be better and more energy efficient for the applications involving low powered sensor nodes which is proved through simulation results.

Keywords: Clustering, Energy Efficieny, Fuzzy, Sensor

1. Introduction

Wireless Sensor Networks are tremendously dispersed networks of minute, lightweight wireless Sensor Nodes (SNs). The network can be categorized into homogeneous and heterogeneous type. The homogenous network is built upon with the nodes of the same capability. Heterogeneous network consists of nodes of different capability. Sensors are used to monitor the environment based on the desired physical parameters. Some of the real time applications of WSN are industrial measurements, resource, climate, solar and power plant monitoring and event detections.

Most of the WSNs have been intended in such a way that the SNs sensing the surroundings then transmit their generated information to the outer Base Station (BS). Energy consumption is high in this case when all SNs communicate directly with the BS. Clustering[1,2] supports a way of transmitting data to the BS using multiple hops. In clustering, Cluster Head nodes (CH) collect the information from their members and aggregate them. Only CH nodes forward that collective information to the BS. This way of clustering[3] reduces the overall energy consumption.

Clustering in wireless sensor networks can be classified into equal and unequal clustering. Equal clustering guarantees the same number of cluster members for all the clusters in the network. All CH nodes communicate with the BS in a multi-hop manner through other CH nodes. The CH closer to the BS relay all the collected information to the BS. In this case there may be a chance for those relays CH nodes to die early. To avoid this situ-

**Author for correspondence*

ation unequal clustering has been proposed. Inorder to achieve unequal clustering we use fuzzy logic tools. Most of the papers consider any two of the following input parameters for applying fuzzy if-then rules. The parameters include the Distance to the Base Station (DBS), Local Distance (LD), Residual Energy (RE), Density (D) and Node Degree (ND). Some are considering a chance of a node to become cluster head(C) as output parameter or the competence Radius (R) of cluster head.

Low Energy Adaptive Clustering Hierarchy (LEACH)[4] employs an equal clustering technique. The monitoring network is divided into groups called as clusters. It elects a CH node based on local decisions. CH has been chosen in a probabilistic manner based on threshold values. The CH node collects information from the normal nodes in its cluster. CH aggregates the data from its members and forwards the aggregated information to BS. In LEACH, there may be a chance of selecting a lower energy node as CH node.

Hierarchical Energy Efficient Distributed clustering (HEED)[5] considers the balance energy level of SNs for the probabilistic selection of CH nodes. The degree of the CH nodes or distance to its nearby neighbor nodes is used to select the CH when two nodes are competing for CH. HEED provides a better performance when compared to LEACH.

LEACH with Centralized Chain (LCC)[6] is a modified form of LEACH. CH nodes are selected by the same procedure as in LEACH. It forms a super cluster for the CH nodes. It chooses one super CH Leader among super cluster member nodes. By means of greedy approach, it builds a series connection between the super cluster members to BS via the CH Leader. Super CH Leader aggregates the data from CH nodes. Finally, the super CH Leader sends the aggregated data to the BS directly.

Cluster Head Election using Fuzzy (CHEF)[7] is an unequal clustering protocol, which elects the cluster head in a centralized manner under the supervision of BS. It uses three fuzzy descriptors for its fuzzification process such as node concentration, RE and node centrality for electing the CH. BS generates fuzzy rules and calculates the crisp output representing the chance for a node to become CH.

Energy Efficient Coverage Aware Data Collection(EECDC)[8] in WSN forms the Maximal Independent Set (MIS)and then selects the effective CH. Network communication is divided into inter and intra groups. Intercommunication is handled by using multi-hop between CH to BS.

Energy Efficient Unequal Clustering (EEUC)[9] uses a probabilistic approach to choose the tentative CH. Tentative CH nodes participate in the CH competition. EEUC considers the node's residual energy for CH selection.

Energy Aware Unequal Clustering using Fuzzy logic (EAUCF)[10] deals with unequal clustering and uses multi-hop routing. Unequal clustering delays the first node die time when compared to equal clustering used in LEACH. Fuzzy rules are utilized for selecting the coverage distance of CH nodes based on two input variables which are distances to the BS and residual energy. Moreover, it combines the advantages of unequal clustering and fuzzy logic approaches.

Improved Fuzzy Unequal Clustering (IFUC)[11] uses input parameters for the FIS for each node are their distances to BS, energy level and local density. The chances of all the nodes becoming cluster head and their communication radii are calculated as fuzzy outputs. Higher chance CH nodes are selected finally as CHs. CH nodes send an initial message to all the members within their competence radius. All the non-CH nodes communicate with the nearby CH. Further, the Ant Colony Optimization technique is used to construct an energy-efficient path between CH nodes and BS.

Energy Aware Distributed Clustering approach (EADC) uses fuzzy logic to select the cluster head node. Based on the remaining energy, tentative nodes are selected as cluster heads. Fuzzy logic is applied for those tentative cluster heads based on the two input parameters which are node degree and centrality. FIS produces fuzzy cost as an output. Every non cluster head node selects the best CH node to communicate based on the fuzzy cost. Low fuzzy cost cluster head nodes are selected as permanent cluster head nodes.

Energy Efficient Fuzzy Logic Cluster Formation Protocol[12]also performs the election for choosing the CH nodes. Here, tentative CH nodes are selected first. All the remaining nodes calculate the three input parameters such as energy level of the CH, the distance between the BS and the CH, and the distance between the CH and the node. Based on the above parameters, the member nodes calculate the probability of each CH to become the permanent CH. If the chances are the same for two CH nodes, then fixing the one that is nearer to the BS as CH.

2. Fuzzy Approach

Fuzzy Logic (FL) mainly consists of four major parts such as fuzzifier, an inference system, a rule base and a defuzzifier. The input parameters are usually crisp, which are converted into fuzzy linguistic variables. Fuzzy Deision Block (FDB) is made up of Fuzzy Inference System (FIS) and Rule Base. It provides fuzzy output based on the rules. After defuzzification it is converted in to crisp output. This paper proposes a hierarchical structure of the network and follows unequal clustering protocol using fuzzy logic. The unequal clustering yields better results when compared to equal clustering.

3. HUCFA Preliminaries

Some of the features of HUCFA are as follows,

- All SNs have same initial energy.
- The BS is located outside the field area to be monitored.
- The tentative CH election is based on a probabilistic manner.
- FL is used to select final CH nodes from the tentative CH list.
- The size of the clusters reduces gradually with the increase of distance to the BS.
- The number of clusters increases gradually with the increase of distance to the BS.

4. Energy Model

The free space radio model is used to calculate the energy in free space[10]. Equation 1 characterizes the amount of energy needed for forwarding 'L' bit of data to a node at a distance D. Equation 2 stands for the energy needed to receive 'L' bit of data.

$$E_{tx}(L,D) = L^{*} E_{ele} + L^{*} e_{fs}{}^{*} D^{*} D \qquad (1)$$

$$E_{rx}(L) = L^{*} E_{ele} (2)$$

E_{ele} → Energy Consumption/bit in transceiver circuit.

e_{fs} → Energy degenerated/bit in RF amplifier

5. HUCFA

The proposed HUCFA is described as shown in Figure 1 and is based on unequal clustering. It uses the local information to form clusters and choosing the CH nodes. HUCFA is divided into three phases. They are,

- Node Creation and Grid formation
- Cluster Head Election Phase
- Data gathering Phase

5.1 Node Creation and Grid Formation

Nodes are deployed uniformly in the sensing area. Monitoring area is divided into three horizontal layers based on the distance of the layer to the BS. Each layer is split into grids. The grid located nearer to the BS will be having more number of CH nodes, which guarantees the uniform energy consumption among the CH nodes.

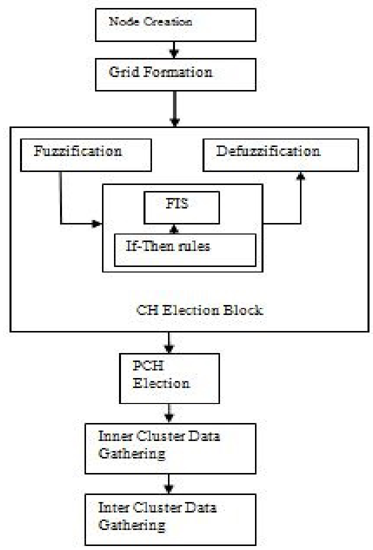

Figure 1. HUCFA work flow.

5.2 Cluster Head Election Phase

Consider every grid as a group and nodes in that group assumes themselves assume as Tentative CHs (TCH). They themselves go for election to become PCH. Instead of electing a TCH to become PCH based only on residual energy, the proposed HUCFA undergoes for fuzzification. The parameters are energy; node degree and distance of the node from the sink are chosen as crisp inputs for fuzzification. Each of these three input variables has to take the equivalent fuzzy linguistic variable. Poor, better and V. good are the linguistic variables assumed for the RE and high, medium and low are fuzzy set variables for ND. Far-away, midway, near by are the fuzzy variables chosen for DBS. The crisp inputs are sent to FDB. Inside FDB, rule set and FIS are available. Steps are listed below to perform fuzzification.

- All TCH nodes calculate their input fuzzy attributes such as *residual energy, node degree and distance from the sink*. These calculations are done based on the well defined formulas in the metrics part.
- Nodes send their fuzzy values of the three attributes to the sink.
- The sink is having a higher energy than the other nodes. The sink is holding the fuzzy control logic.

[Sink is calculating the fuzzy output by means of FIS (Fuzzy Inference Engine)].

- Set input and output parameter as given in Table 1 and Table 2.
- Frame the fuzzy rules as given in the Table 3.
- Sink applies the node parameters to the above FIS and concludes whether that node will become the cluster head or not based on the chance.
- Sink intimates all the TCH nodes about the PCH selection.
- All the remaining nodes nearer to the PCH become the members of that PCH.

Table 1. Fuzzy input parameters

Input Parameter	Range	Membership Function	Linguistic Variable
Energy Level (In Joule)	[0 1]	Trapmf	Poor
		Trimf	Better
		Trapmf	Vgood
Node Degree	[0 1]	Trapmf	Low
		Trapmf	Medium
		Trapmf	High
Distance from sink (In meters)	[0 100]	Trapmf	Near
		Trimf	Midway
		Trapmf	Far-away

Table 2. Fuzzy output parameters

Output Parameter	Range	Membership Function	Linguistic Variable
Eligibility as cluster head (In %)	[0 100]	Trapmf	Ineligible
		Trimf	Partially Eligible
		Trapmf	Eligible

Table 3. Rule base for different input linguistic variables

S. No	Energy Level	Node degree	Distance from sink	Chance for selecting as CH
1	Vgood	High	Near	Eligible
2	Better	High	Near	Eligible
3	Vgood	High	Midway	Eligible
4	Better	High	Midway	Eligible
5	Vgood	High	Far-away	Eligible
6	Better	High	Far-away	Eligible
7	Vgood	Medium	Near	Eligible
8	Better	Medium	Near	Eligible
9	Vgood	Medium	Midway	Eligible
10	Better	Medium	Midway	Partially Eligible
11	Vgood	Medium	Far-away	Partially Eligible
12	Better	Medium	Far-away	Partially Eligible
13	Vgood	Low	Near	Partially Eligible
14	Better	Low	Near	Partially Eligible
15	Vgood	Low	Midway	Partially Eligible
16	Better	Low	Midway	Partially Eligible
17	Vgood	Low	Far-away	Partially Eligible
18	Better	Low	Far-away	Ineligible
19	Poor	High	Midway	Ineligible
20	Poor	High	Near	Partially Eligible
21	Poor	High	Far-away	Ineligible
22	Poor	Medium	Near	Ineligible
23	Poor	Medium	Midway	Ineligible
24	Poor	Medium	Far-away	Ineligible
25	Poor	Low	Near	Ineligible
26	Poor	Low	Midway	Ineligible
27	Poor	Low	Far-away	Ineligible

5.3 Data Gathering Phase

After the cluster formation, the PCH node sends its ready status to its member nodes. The member nodes after receiving the notification from PCH, it transmits their sensed information to their corresponding PCH node within a stipulated time period. The information gathered by the PCH nodes may include repeated information since the nodes from nearby positions may sense the same data. PCH follows an aggregation scheme based on Equation 3. The aggregation ratio is chosen by the user. Aggregation scheme aggregates the packets to calculated length. Here the length of the packet depends on aggregation ratio and the number of data. The proposed work uses aggregation ratio of 10% as in[10] and is followed to achieve the desired level. Length of aggregated data is calculated as per Equation 3.

$$L_{AG} = L_{RE} + (L_{RE} * R_{AG} * n) \qquad (3)$$

L_{AG} is the aggregated packet length,

L_{RE} is the packet length from members,

R_{agg} is the aggregation ratio and

n is the total number of nodes in the cluster.

The member nodes transmit their data to their PCH nodes in the respective grids. The PCH node aggregates its member node's data and forwards them to the next level grid PCH node which is nearer to its location. Thus the PCH nodes in the grid closer to BS act as router nodes to their higher level grid nodes. Also the rapid energy depletion of CH nodes nearer to BS is avoided by increasing the number of clusters and also it achieves unequal clustering.

5.4 Experimental Setup

In general, uniform distribution of nodes is followed in civilian related applications. HUCFA is also tested in uniform distribution of nodes in the monitoring area as shown in Figure. 2.The simulation parmeters are listed in Table 4. The performance of the proposed work is compared with the performance of other three protocols namely LEACH, HierarchialUneual Clustering Algorithm (HUCA) and HUCA with Direct Diffusion (HUCADD). In HUCFAenvironmental area (100*100) is comprised of grids of various sizes at each level and the location of BS is at the position (50,150). The number of nodes in each grid as well as at each level differs. All the members send theirdata to their corresponding PCH nodes. PCH nodes in the last level send their aggregated data to BS though-upper level PCH nodes using multi-hop communication. PCH nodes nearer to BS is having a lesser number of members in their own clusters inorderto relay the data from lower level PCH nodes to BS.

6. Results and Performance Measures

As per the protocolsmentioned in the experimental setup, simulations are carried out and the total energy consumption and standard deviation for each of the protocols is analyzed and shown in Figures 3 and 4 respectively. Figure 3 shows the Total Energy Consumption (TEC) of the network for a single round for all four protocols. TEC in Direct diffusion is high when compared with clustering protocols LEACH, HUCA and HUCFA.TEC in HUCFA is 7.05% less when compared to LEACH. Standard deviation of energy distribution among all the clusters in the proposed work is 10.46% lesser than LEACH and 0.79% less than HUCA. Figure 5 shows the energy consumption of each of the clusters in all the protocols. The energy consumption is less in 70% of the clusters using the proposed HUCFAprotocol as compared to other three with other three protocols.

Table 4. Simulation parameters

Parameters	Values
Monitoring area	100*100 m^2
R_{AGG} –Aggregation Ratio	10%
L – Number of bits	4000
E_{elec} – Electronics energy	50nJ bit^{-1}
ε_{fs} – Power loss in free space	10pJ bit^{-1}
D – Distance between transmitter and receiver	in meters

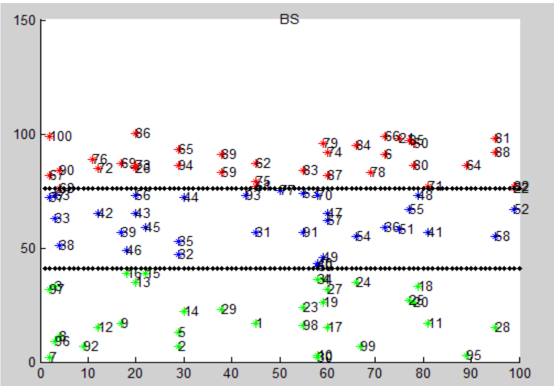

Figure 2. Network arrangement.

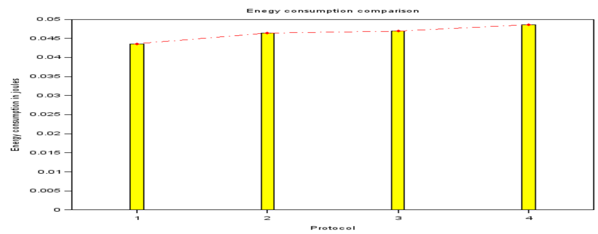

Figure 3. Total Energy Consumption in network (1-HUCFA, 2-HUCA, 3-LEACH, 4-HUCFADD).

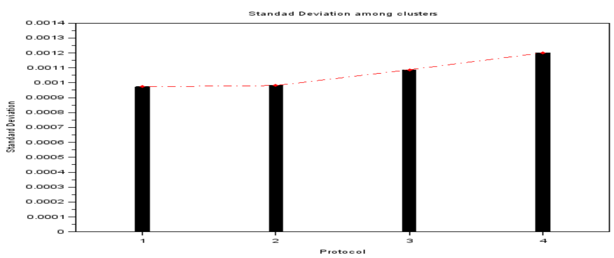

Figure 4. Standard Deviation among all clusters in the network (1-HUCFA, 2-HUCA, 3-LEACH, 4-HUCFADD).

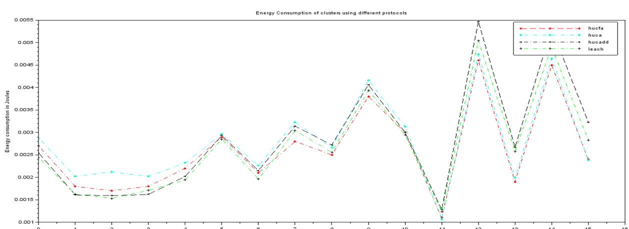

Figure 5. Individual Energy Consumption by each of the clusters in the network.

7. Conclusion

Clustering classification in wireless sensor networks based on Fuzzy Logic is proposed. Here Cluster Heads depend on the characteristics of the sensor nodes. Fuzzy Logic Toolbox in MatlabR2010a is utilized for the simulation of the proposed HUCFA protocol. Inside the FIS, fuzzy rules are framed based on the node characteristics such as residual energy, node degree and distance of the node to the base station. Chances of each and every node to become the PCH are the fuzzy output from FIS. The nodes having the highest chances finally become the PCHs. All the member nodes communicate with their nearest PCH. Then hierarchical arrangement of clusters is done and all clusters are relaying the information to the base station. In terms of TEC, the performance of the proposed HUCFA is found to be much improved when compared to LEACH, HUCA and HUCADD protocols. When the TEC of the entire netwok is less for a single round of communication then the network lifetime is found to improve in the subsequent rounds of communication. The depletion of energy in each of the clusters in HUCFA decreases uniformly whereas the depletion of energy is not uniform in the other three protocols considered for comparison. Since the first CH node death time is delayed, the reclustering time is extended which improves the network lifetime. In our future work we intent to use Genetic algorithm for selecting a best cluster head in order to improve the overall network lifetime.

References

1. Liu T, Li Q, Liang P. An energy-balancing clustering approach for gradient-based routing in wireless sensor networks. Journal of Computer Communications. 2012; 35(17):2150–61.
2. Abbasi AA, Mohamed F, Younis Y. A survey on clustering algorithms for wireless sensor networks. Computer Communications. 2007; 30(14-15):2826-41.
3. Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E. Wireless sensor networks: A survey. Journal of Computer Networks. 2002; 38(4):393-422.
4. Hac A. Wireless Sensor Networks Designs. John Wiley and Sons Ltd; 2004. p. 1-410.
5. Younis O, Fahmy S. HEED: A hybrid, energy-efficient, distributed clustering approach for Ad Hoc Sensor networks. IEEE Transactions on Mob Computing. 2004; 3(4):660–9.
6. Li B, Zhang X. Research and improvement of LEACH protocol for wireless sensor network. International Conference on Information Engineering (ICIE); Hangzhou. 2012. p. 251-4.
7. Kim J, Park S, Han Y, Chung T. CHEF: Cluster head election mechanism using fuzzy logic in wireless sensor networks. 10th International Conference on Advanced Communication Technology; Ganawon–DO. 2008. p. 654–9.
8. Baranidharan B, Akilandeswari N, Santhi B. EECDC: Energy efficient coverage aware data collection in wireless sensor networks. Indian Journal o f Science and Technology. 2013; 6 (7):1-5.
9. Li CF, Ye M, Chen GH, Wu J. An energy-efficient unequal clustering mechanism for Wireless sensor network. IEEE International Conference on Mobile Adhoc and Sensor Systems Conference; Washington DC. 2005. p. 596–640.
10. Bagci H, Yazici A. An energy aware fuzzy unequal clustering algorithm for wireless sensor networks. Proceedings of the IEEE International Conference on Fuzzy Systems; Barcelona. 2010. p. 1-10.

11. Mao S, Zhao C, Zhou Z, Ye Y. An improved fuzzy unequal clustering algorithm for wireless sensor network. Mobile Network Applications. 2013; 18(2):206-14.

12. Gupta I, Riordan D, Sampalli S. Cluster-head election using fuzzy logic for wireless sensor networks. Proceedings of the 3rd Annual Communication Networks and Services Research Conference; 2005. p. 255–60.