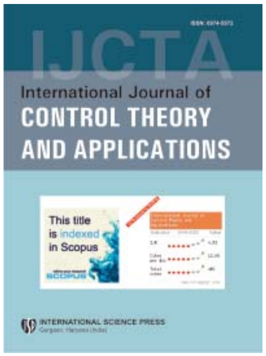

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Combined Fuzzy Logic and Ant Colony Optimization Techniques for Energy Efficient Data Transmission in Wireless Sensor Networks

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Abstract: One of the most important problems to be solved in wireless sensor network is the minimization of node energy consumption. Clustering is the most widely accepted method in wireless sensor network to prolong the network lifetime. The nodes that are nearer to base station can transfer their data directly to base station, but the far away nodes utilize multi-hop communication for transmitting data. This leads to high energy consumption to the nearby nodes of sink and generates hot spot problem in the network. To resolve these issues and to extend the network lifetime, we propose a protocol Fuzzy and Ant Colony Combined Energy Efficient Unequal Clustering (FACEUC). FACEUC uses fuzzy logic with distance to BS, residual energy and neighbor node proximity as input variables for computing various sized competition radius and for selecting CH in the network. FACEUC creates smaller sized clusters and larger sized clusters when the nodes are nearer and far away from BS respectively. FACEUC uses Ant Colony Optimization for the efficient intra-cluster communication. To transfer the data from a source node, FACEUC considers the relay CH's (*i*) distance to BS (*ii*) residual energy and (*iii*) queue size. Performances of FACEUC are compared with the existing protocol FAMACROW and the obtained results show that operation of FACEUC is better than FAMAZROW in terms of number of nodes live in the network, residual energy of nodes and packet delivery ratio.

Keywords: *Clustering, fuzzy logic, cluster head, residual energy, wireless sensor network, ant colony optimization.*

1. INTRODUCTION

Recent significant advances and research development in Wireless Sensor Networks (WSN), the deployment of sensor nodes in many fields such as military applications, monitoring large environmental area , disaster prevention, and national border surveillance and so on [1]. Sensor nodes are located within the sensing area and the main functions of sensor nodes are data sensing, data collection, data processing and data communication. Most of the sensor nodes are equipped with non-rechargeable battery power and it leads to high energy expenditure. Therefore, the most important factor to be considered is to minimize the energy consumption and prolong the network lifetime [2]. To conserve energy of the sensor nodes and improve scalability, clustering is proposed in WSNs [3]. The nodes in the network are partitioned into a number of small groups, called clusters.

The cluster members in each cluster select the highest energy nodes node as cluster head (CH) and CH is responsible for performing data collection, aggregation and transmission in each cluster. In cluster based network, only CH is allowed to communicate with the base station (BS) or sink. The cluster members send their data to their corresponding CH and CH aggregates the member data along its own data. By utilizing single-hop or by multi-hop communication, CHs transmit the aggregated data to BS.

Most of the clustering protocol considers residual energy of nodes for selecting a CH in a cluster and CH responsibilities can be rotated among the nodes in a cluster to balance energy consumption. For the selection of CH, these algorithms do not consider the distances of the nodes from BS [4]. Due to the heavy relay traffic, the nodes that are nearer to the BS drain their energy faster than the far away nodes. To resolve this problem and to extend the lifetime of the nodes that are nearer to BS, unequal clustering algorithms have been proposed in [5]. In unequal clustering, clusters of different sizes, *i.e*., different numbers of nodes in each cluster, are formed. The clusters close to the BS are of smaller sizes than the clusters that are far away from the BS. To optimize some routing problems in WSN [6], Ant colony optimization (ACO) algorithms have been successfully applied in WSN. ACO has emerged as a leading meta heuristic method for the solution of combinatorial optimization problems.

In this paper, we propose a protocol Fuzzy and Ant Colony Combined Energy Efficient Unequal Clustering (FACEUC) to prolong the network lifetime. FACEUC uses fuzzy logic with distance to BS, residual energy and neighbor node proximity as input variables for creating various sized competition radius clusters and for selecting initial-CH in the network. The final-CHs are selected from the initial-CH which lies within the same competition range. FACEUC creates smaller sized clusters near to BS and larger sized clusters when the nodes are far away from BS. FACEUC uses Ant Colony Optimization for the efficient selection of relay CH. FACEUC considers (*i*) distance to BS (*ii*) residual energy and (*iii*) queue size for the selection of a relay CH. It will be shown that the combined optimization technique utilized proposed protocol reduces energy consumption, extends lifetime and increases packet delivery ratio.

The rest of this paper is organized as follows. Section II presents the description of related work. The proposed protocol FACEUC and its operation are explained in Section III. Simulation results and discussions are given in Section IV and finally concluded the paper with future directions.

2. RELATED WORKS

To extend the lifetime of network, various number of cluster based routing protocols are proposed [7-8]. The most widely accepted clustering protocol in WSN is LEACH [9]. CH selection in LEACH is based on the probability model and residual energy of nodes. Each CH can directly communicate to BS using single-hop communication. Computational intelligence (CI) algorithms based ant colony optimization [10], neural networks [11], fuzzy logic [12] and genetic algorithm [12] is used in WSN for solving various problems in WSN. Cluster formation in WSN is based on fixed rules and it leads to the reduction of network lifetime. Single parameter based CH election will lead to unenviable results. Most of the clustering protocols select CHs based on highest energy and it leads to the higher intra-cluster communication.

To increase the lifetime and for efficient selection of CH, WSN makes use of Fuzzy Logic (FL). The CH selection in CHEF [14] is a distributed manner. The fuzzy input variables used for CH election are local distance and residual energy of each node. Local distance is the total distance between the tentative CH and the nodes within a predefined constant competition radius. Energy Aware Distributed Dynamic Clustering protocol (ECPF) is proposed in [16]. ECPF selects tentative CHs in the network, based on the residual energy of nodes. Node degree and node centrality are the input parameters of FL for selecting the final-CH in the network. Fuzzy Logic Cluster Formation Protocol (FLCFP) [15] uses CH energy, distance between CH and BS and distance between CH and nodes as fuzzy input parameters for cluster formation in the network. Based on the maximum fuzzy output value, non-CH members join to nearby CHs.

WSNs utilize Ant Colony Optimization (ACO) [17] to reduce energy consumption by selecting optimal path from source node to BS. ACO based routing algorithm is proposed in [18] for comparing two ant colony-based routing algorithms in terms of energy consumption in different scenarios. An energy aware ant colony algorithm EEACA is proposed in [19] for energy efficient routing in wireless sensor networks. The ant selects a next node in EEACA by considering the following factors (*i*) distance from sink (*ii*) the residual energy of next node and (*iii*) average energy of the path. In [20], Fuzzy and Ant Colony Optimization Based Combined MAC, Routing, and Unequal Clustering Cross-Layer Protocol for Wireless Sensor Networks (FAMACROW) are proposed. FAMACROW employs fuzzy logic for CH selection with input variables as communication link between nodes, residual energy and number of neighboring nodes as input variables. FAMACROW creates unequal clusters in the network so that the clusters nearer to BS have smaller size than the clusters which are far away from BS. For inter-cluster communication, FAMACROW uses ACO technique by considering the following parameters (*i*) distance from BS to current CH (*ii*) residual energy (*iii*) queue length and (*iv*) delivery likelihood.

By analyzing the existing protocols, we propose a protocol namely Fuzzy and Ant Colony Combined Energy Efficient Unequal Clustering (FACEUC) for unequal cluster formation in the network and for energy efficient inter-cluster communication. Fuzzy logic based approach is used for calculating competition radius and for selecting CH by considering residual energy, distance from BS and neighbor node proximity as input parameters. FACEUC uses ACO technique for inter-cluster communication. FACEUC selects a relay node based on (1) residual energy of the relay node (2) distance from the current CH to relay node and (3) neighbor node proximity of the relay node.

3. PROPOSED FACEUC OPERATION

Fig. 1 shows the architecture of FACEUC and Fuzzy Inference System (FIS) of FACEUC is shown in Fig. 2. The working principle of FACEUC is illustrated as flowchart in Fig. 3.

3.1. Network setup

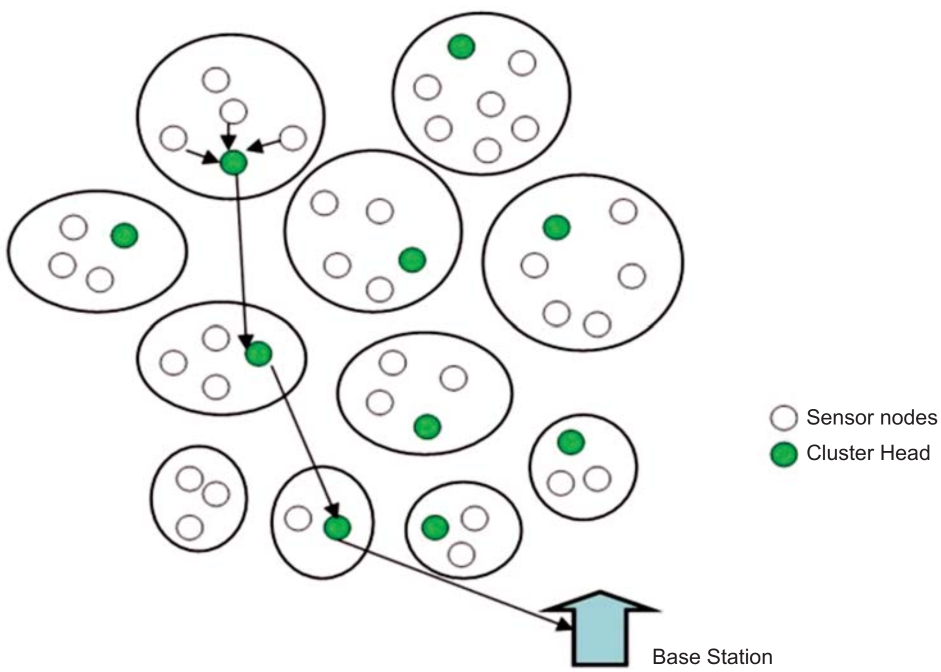

Figure 1: Fuzzy Logic inference system of FACEUC

1. **Energy Model:** N nodes are placed in NxN sensing area of FACEUC. Sensor nodes and BS are static after the deployment. The location of BS is within the sensing field. The nodes are not aware about their location. The nodes can calculate the distance between the nodes based on received signal strength. The CH can aggregate data from cluster members and transmits to the BS. FACEUC uses free space ε_{fs} and multipath fading ε_{mp}, for data transmission in the network. The amount of energy spent by a transmitter for transmitting *l*-bits of data to a distance *d* is given in Equation 1.

$$E_T(l, d) = \begin{cases} l\,E_{elec} + l\,\varepsilon_{fs}\,d^2, d < d_0 \\ l\,E_{elec} + l\,\varepsilon_{mp}\,d^4, d \geq d_0 \end{cases} \quad (1)$$

Equation 2 represents the energy required for receiving *l*-bit message.

$$E_R(l) = l\,E_{elec} \quad (2)$$

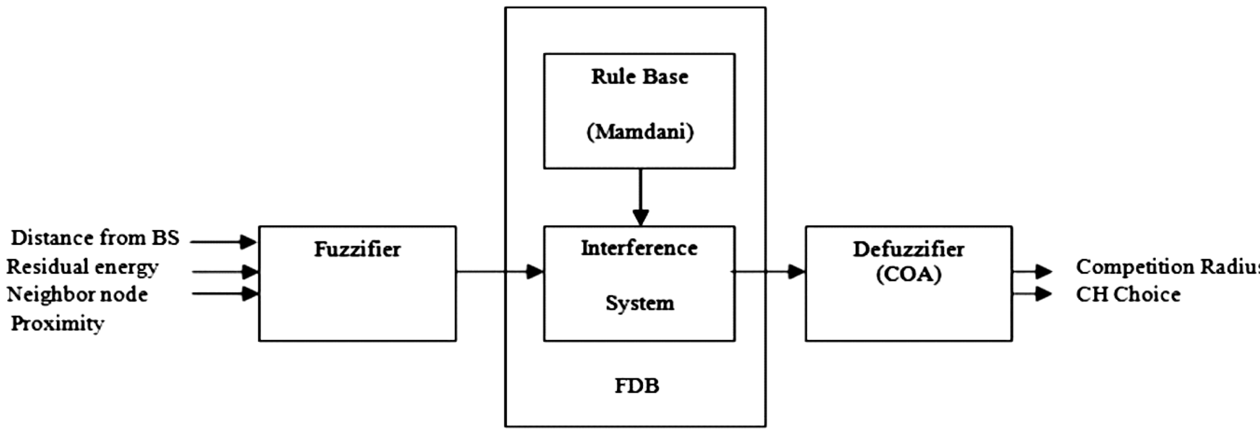

Figure 2: Fuzzy logic interface system of FACEUC

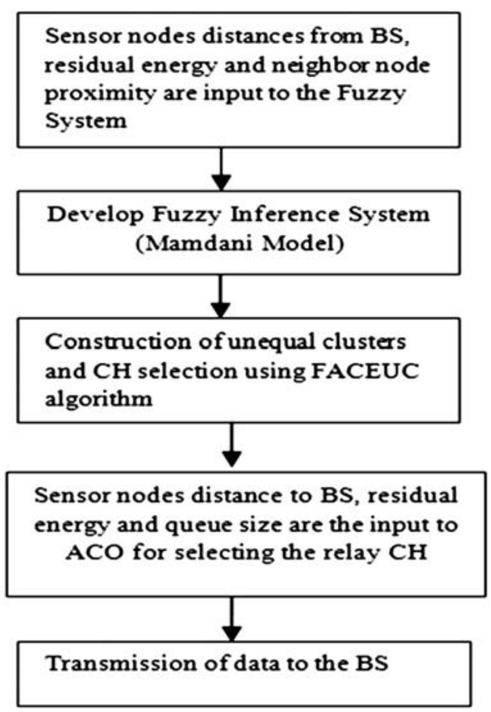

Figure 3: Flow chart of ECUCF

3.2. Unequal Cluster Setup

1. **Initial-CH Selection:** FACEUC uses the basic principle of LEACH to create unequal clusters in the network. Each node in the network generates a random number using the Eq. 3. If the random number is above the threshold value (TV), FACEUC assigns that particular node as initial-CH. FACEUC makes use of Fuzzy Logic approach to generate unequal clusters in the network.

$$TV = \frac{P}{1-\left(P^{*}\, r\, mod\left(\frac{1}{p}\right)\right)} \tag{3}$$

where P is desired percentage of cluster head (*e.g.* P = 0.05) and *r* is current round number. FACEUC makes use of Fuzzy Inference System (FIS) with Mamdani model [17] for the selection of CHs in the network. The FIS of FACEUC is shown in Fig. 2 and it mainly consists of (*i*) a fuzzifier (*ii*) an inference system (*iii*) a rule base and (*iv*) a defuzzifier. The fuzzifier maps the crisp input into corresponding membership functions. The outputs of fuzzifier are applied to Fuzzy Decision Block (FDB). FIS and rule base are included in the FDB. Based on the given fuzzy rule base, FDB generates fuzzy outputs. By using defuzzification methods, fuzzy output is converted into crisp outputs. The three linguistic variable used for calculating the competition radius are *distance_from_BS*, *residual_energy* and *neighbor_node_proximity*.

Because of the following fuzzy parameters, the competition radius of FACEUC changes dynamically in the network.

1. **Distance_from_BS:** The fuzzy linguistic variables used for representing distance_from_BS are close, medium and far. Figure 4 represents the fuzzy linguistic input variable distance_from_BS. The boundary variables close and far are represented by trapezoidal membership function and the intermediate variable medium is represented by triangular membership function.

2. **Residual_energy:** The remaining available energy in the node is the Residual_energy. A node should have minimum residual energy to participate the network processing such as sensing, aggregation and data transmission. In a cluster, FACEUC chooses a node as CH, if its residual energy is comparatively higher than the other cluster members. Fig. 5 illustrates the fuzzy set that for the input variable Residual_energy. Low, medium and high are the fuzzy linguistic variables used for representing Residual_energy. Trapezoidal membership function is used for representing the linguistic variables low and high. Medium is represented by triangular membership function.

3. **Neighbor_node_proximity:** Neoghbor_node_ proximity [20] of any node '*n*' is defined as follows:

$$\text{Neighbor}_{\text{node}_{\text{proximity}(n)}} = \frac{1}{N_{\text{Total}}}\left[\sum_{i=1}^{N_{\text{Total}}-1} \text{dist}(n, i)\right] \tag{4}$$

where N_{total} is total number of neighboring nodes that can be reached by the node '*n*' within the competition radius. Dist (*n*, *i*) is the distance between node *n* and its neighboring node *i*. Each node calculates its *Neighbor_node_proximity* using Eq. (4) and the neighbor node information is stored in Neighbor Information Table (NIT) during initial-CH selection phase. Fig.6. represents the fuzzy input variable node *Neighbor_node_proximity*.

Figure 7 shows the fuzzy output variable competition radius and the two extreme cases in the calculation of competition radius are given below:

1. If the initial-CH is far from BS and high residual energy and low neighbor node proximity, then it has very large competition radius.

2. If the initial-CH is close from BS and low residual energy and high neighbor node proximity, then it has very small competition radius. The remaining possibilities of the competition radii fall between these two extreme cases.

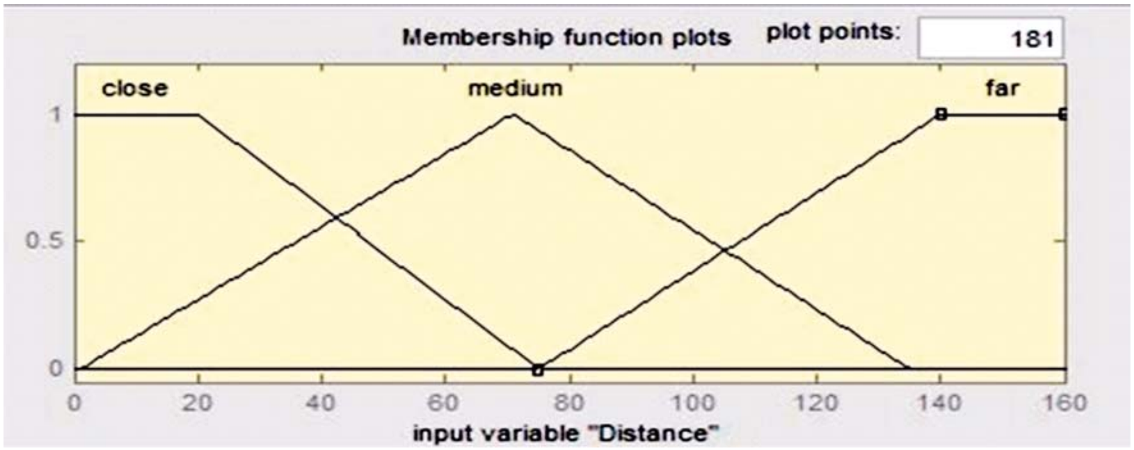

Figure 4: Fuzzy set for fuzzy input variable distance_from_BS

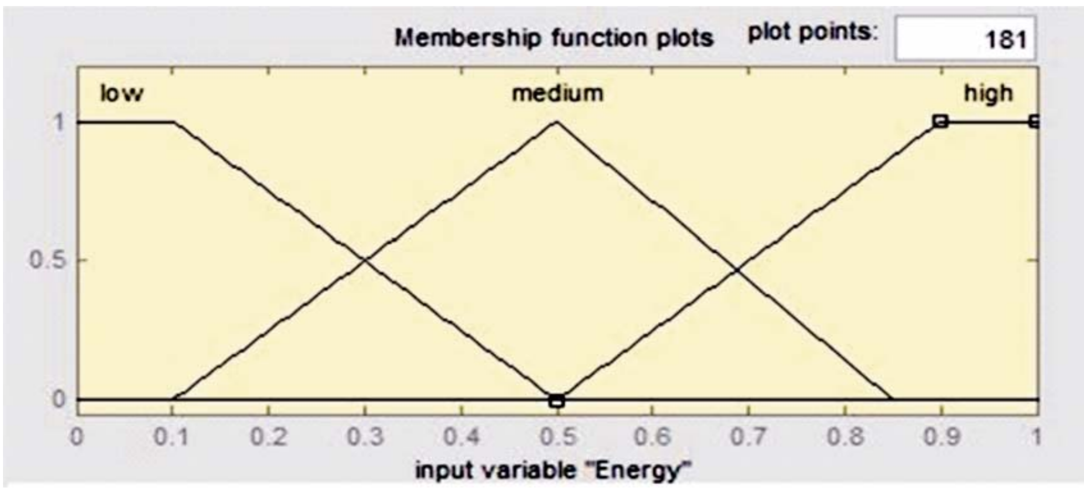

Figure 5: Fuzzy set for fuzzy input variable Residual_energy

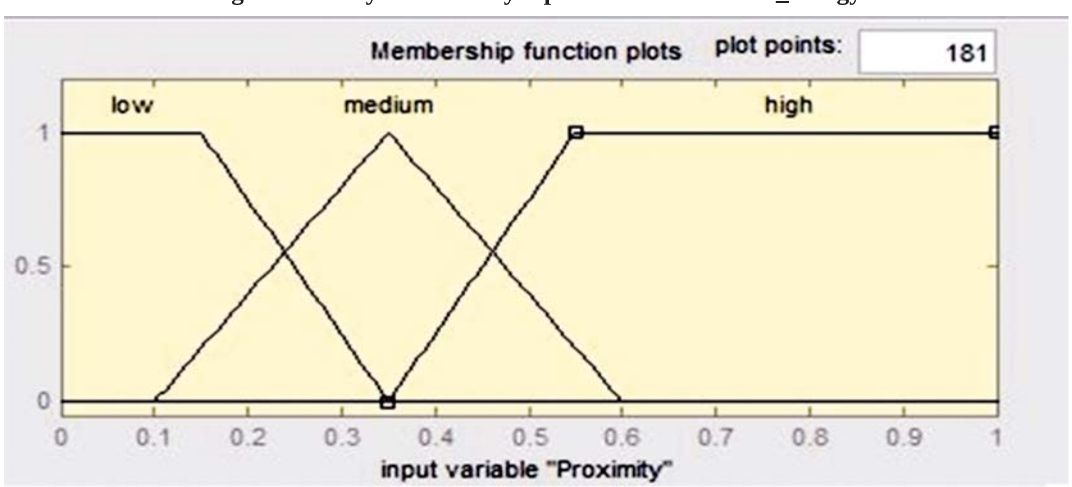

Figure 6: Fuzzy set for fuzzy input variable Neighbor_node_proximity

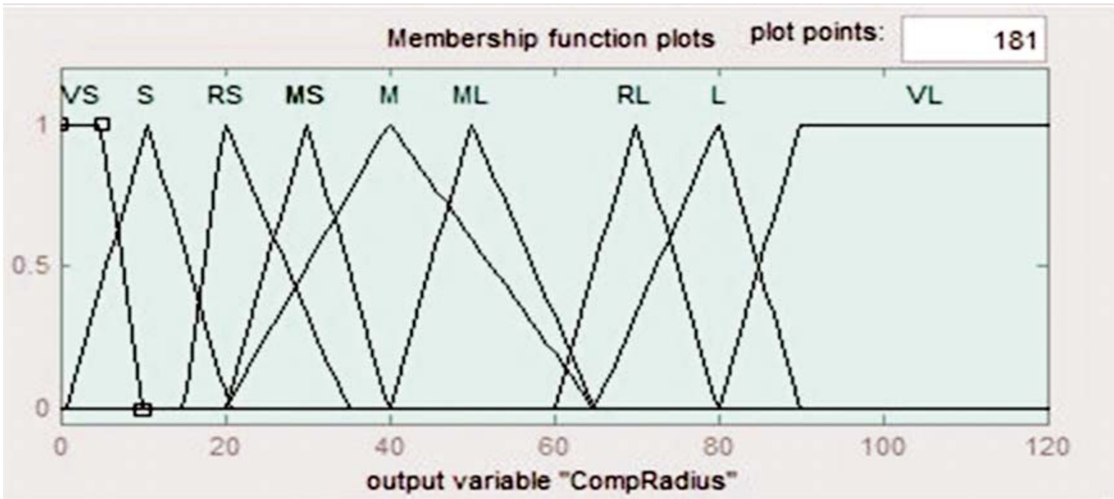

Figure 7: Fuzzy set for fuzzy output variable competition radius

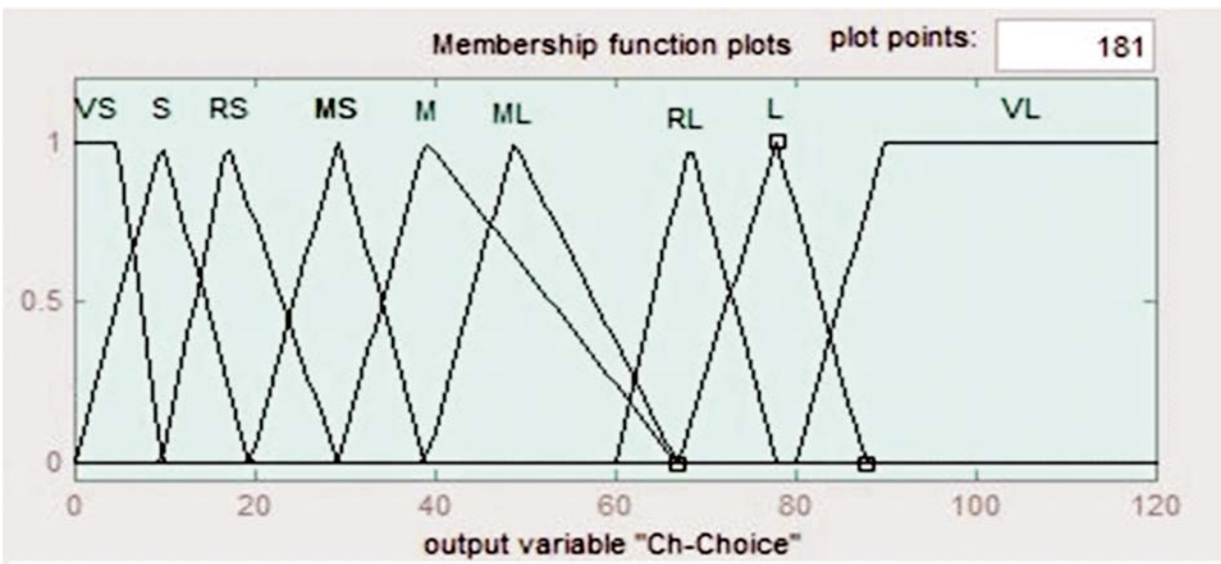

Figure 8: Fuzzy set for fuzzy output variable CH choice

2. **Final-CH selection:** Table 1 shows the fuzzy if-then rules used for selecting the final-CH in FACEUC. The fuzzy input variables used for selecting the final-CHs are distance_from_BS, residual_ energy and *Neighbor_node_proximity*. Figure 8 shows the fuzzy output CH selection. The linguistic variables used for the output variable cluster head choice are very large, large, rather large, medium large, medium, medium small, rather small, small and very small. The trapezoidal function is used for very small and very large. The other linguistic variables use triangular membership function. FACEUC selects final-CH within a cluster based on the following rules:

   a) If the node Distance_from_BS is low and Residual_energy is high and Neighbor_node_ proximity is low then the choice for CH selection is very large.

   b) If the node Distance_from_BS is high and node Residual_energy is low and Neighbour_node_ proximity is high then choice for CH selection is very small. The remaining chances to become CH falls between these two cases.

3.3. Data transfer to BS

After the CH selection in the network, FACEUC enters into data transmission phase using the following steps.

Step 1: Each CH broadcasts a *create_route* message including distance_to_BS, node ID, residual energy and queue size to all nearby CHs for selecting the relay CH. The neighbor CHs which receives *create_route* store the information into the transmission table of the CH node. A CH s_i chooses a relay CH s_j if the node s_j satisfies the following condition.

$$P_{RELAYCH}(s_i) = \{s_j \mid (\text{queue}(s_j) > \text{queue}(s_i) \text{ AND queue}(s_j) > TH_{queue};\ \text{dist}(s_i, s_j) \le TH_{dist};\ \text{dist}(s_j, BS) < \text{dist}(s_i, BS)\} \quad (5)$$

Table 1
Fuzzy Rules for CH Selection

Distance	*Residual Energy*	*Node Proximity*	*Competition Radius*	*CH Choice*
Close	Low	High	Very Small	Very Small
Close	Low	Medium	Small	Very Small
Close	Low	Low	Rather Small	Very Small
Close	Medium	High	Rather Small	Small
Close	Medium	Medium	Small	Small
Close	Medium	Low	Medium Small	Rather Small
Close	High	High	Small	Rather Small
Close	High	Medium	Medium Small	Rather Small
Close	High	Low	Medium	Rather Small
Medium	Low	High	Rather Small	Medium Small
Medium	Low	Medium	Medium Small	Medium Small
Medium	Low	Low	Medium	Medium Small
Medium	Medium	High	Medium Small	Medium
Medium	Medium	Medium	Medium	Medium
Medium	Medium	Low	Medium Large	Medium Large
Medium	High	High	Medium	Medium Large
Medium	High	Medium	Medium Large	Medium Large
Medium	High	Low	Rather Large	Medium Large
Far	Low	High	Medium Large	Rather Large
Far	Low	Medium	Rather Large	Rather Large
Far	Low	Low	Large	Rather Large
Far	Medium	High	Rather Large	Large
Far	Medium	Medium	Large	Large
Far	Medium	Low	Large	Large
Far	High	High	Very Large	Very Large
Far	High	Medium	Very Large	Very Large
Far	High	Low	Very Large	Medium Large

The first condition in Eq. 5 selects a relay CH node based on the queue size. The queue size of the considered relay CH should be large enough to store the data from the source node and the length of queue should be greater than threshold queue size TH_{queue}. The second condition makes sure that the considered relay CH is within a threshold distance TH_{dist} from the source CH. TH_{dist} determines the maximum possible distance between the current CH and the relay CH. The current CH will send data directly to BS, if there is no relay CHs satisfies the first condition *i.e*. $P_{RELAYCH}$ will be an empty set. FACEUC makes use of the combination of the above two conditions for energy efficient and uniform relay CH selection in the network.

Step 2: An ant *i*s placed at each CH at regular intervals to determine a path to the BS. Each ant determines relay CH by using the Eq. 6.

$$P^k_{ij} = \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}(t)]^\beta}{\sum_{s \in p\ RELAYCH(s_i)} [[\tau_{is}(t)]^\alpha [\eta_{is}]^\beta} \tag{6}$$

where P^k_{ij} is he probability with which an ant k chooses to move from a node s_i to a node s_j. $P_{RELAYCH(s_i)}$ is a set from which relay CH is to be chosen by k^{th} ant and pheromone trail value of edge (s_i, s_j) is represented by $\tau_{ij}(t)$. α determines relative influence of pheromone trail and β checks heuristic information. η_{ij} is given in Eq. 7.

$$\eta_{ij} = \frac{REQ_j}{\sum_{s \in Prelay\ CH(s_i)} RQ_s} \tag{7}$$

where, residual energy queue REQ is the ratio between residual energy and the current queue length of the node. High residual energy and a shorter queue size is achieved by the larger value of REQ. η_{ij} guarantees that selected relay CH is (*i*) nearer to the source CH (*ii*) high residual energy and (*iii*) smaller packet queue length. The path (s_i, s_j) will be highly considered, if more number of ants passes through that link (s_i, s_j).

Step 3: The source CH selects a relay CH if the relay CH is near to source CH, high residual energy and low queue capacity. The source CH can store the information about the selected relay CH which is already visited by the ant. To find the best efficient path to BS, FACEUC repeat steps 2 and 3 until the source CH selects the relay CH.

Step 4: The ants from the source node will pass through the selected relay CH nodes to collect path information and finally reach BS. In FACEUC, BS begins to analyze data after the arrival of k^{th} ant. The path created by the k^{th} ant will be $S\{S_0, S_1, S_2, \ldots, S_m\}$ and the information collected by the k^{th} ant is $\{(S_0, d(s_0, s_1)), (S_1, d(s_1, s_2)), (S_2, d(s_2, s_3)),., (S_{m-1}, d(s_{m-1}, s_m))\}$ where S_0 is source CH and S_m is destination (BS).

4. EXPERIMENTAL RESULTS

Table 2
Simulation Parameters

Parameter	*Value*
Area	1000 *m* x 1000 *m*
Sensor nodes	1000
Initial energy	0.5 J
E_{elec}	50 *n*J/bit
ε_{fs}	10 *p*J/bit/m^2
ε_{mp}	0.0013 *p*J/bit/m^4
Packet size	500 bytes
α, β, γ	0.3333

We have evaluated the performances of the proposed protocol FACEUC and the existing protocol FAMACROW using Fuzzy Logic Toolbox and Ant Colony Optimization in MATLAB. 1000 sensor nodes are randomly deployed over an area of (1000 x 1000) m^2. BS is located within the sensing field and initial energy of each sensor node is 0.5 J. The network is simulated with a bandwidth of 1 Mbps. The size of each data packet is 500 bytes. Table IV shows the simulation parameters used for designing FACEUC.

4.1. Number of alive nodes in each round

Figure 9 shows that the proposed protocol FACEUC performs better than the existing protocol FAMACROW because of the following methods. FACEUC makes use of Fuzzy Logic approach with input parameters such as *Distance_from_BS*, *Residual_energy* and *Neighbor_node_proximity* for generating unequal clusters in the network and for selecting the CH. FACEUC forms small sized clusters near to BS and large sized clusters if the nodes are far away from BS. The extended network lifetime is obtained in FACEUC due to the energy efficient selection of a CH, unequal cluster formation and ACO based data delivery to BS.

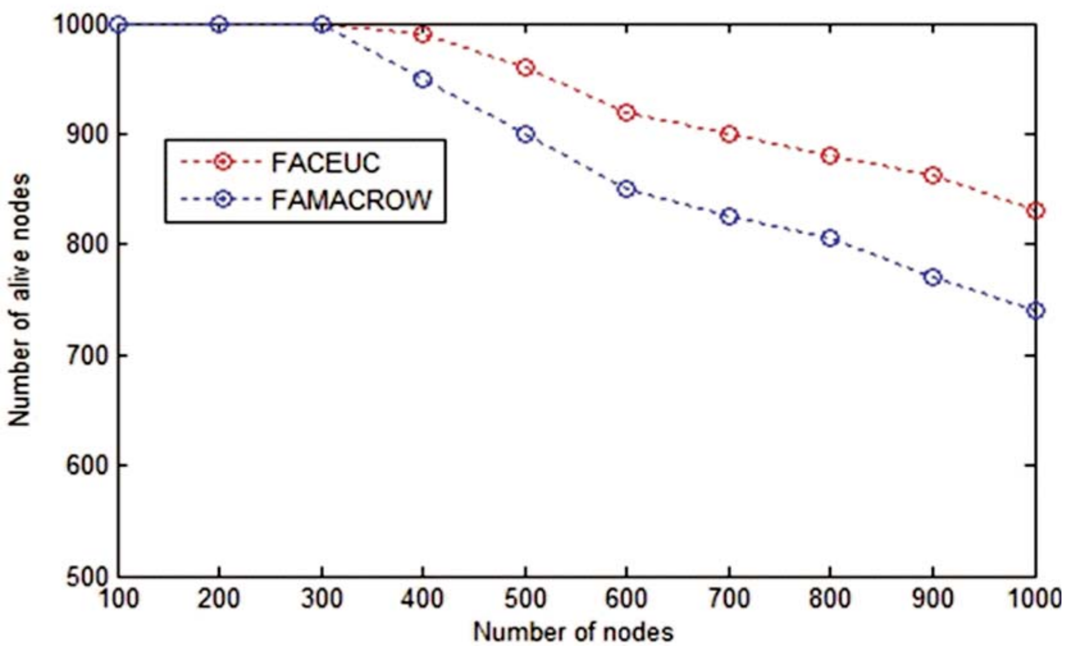

Figure 9: Number of alive nodes in each round

4.2. Residual energy of nodes in each round

Figure 10 illustrates that the number of living nodes in FACEUC is larger than the number of living nodes in FAMACROW. At the end of simulation round, no nodes are exist in FAMACROW, but the network in FACEUC has contains live nodes. This is because; FACEUC employs FL for creating the unequal clusters and for selecting the CH. The input parameters used for creating unequal clusters and for selecting CH are *Distance_from_BS*, *Residual_energy* and *Neighbor_node_proximity.* Far away CHs make use of ACO for the efficient selection of relay CHs and for data delivery to BS.

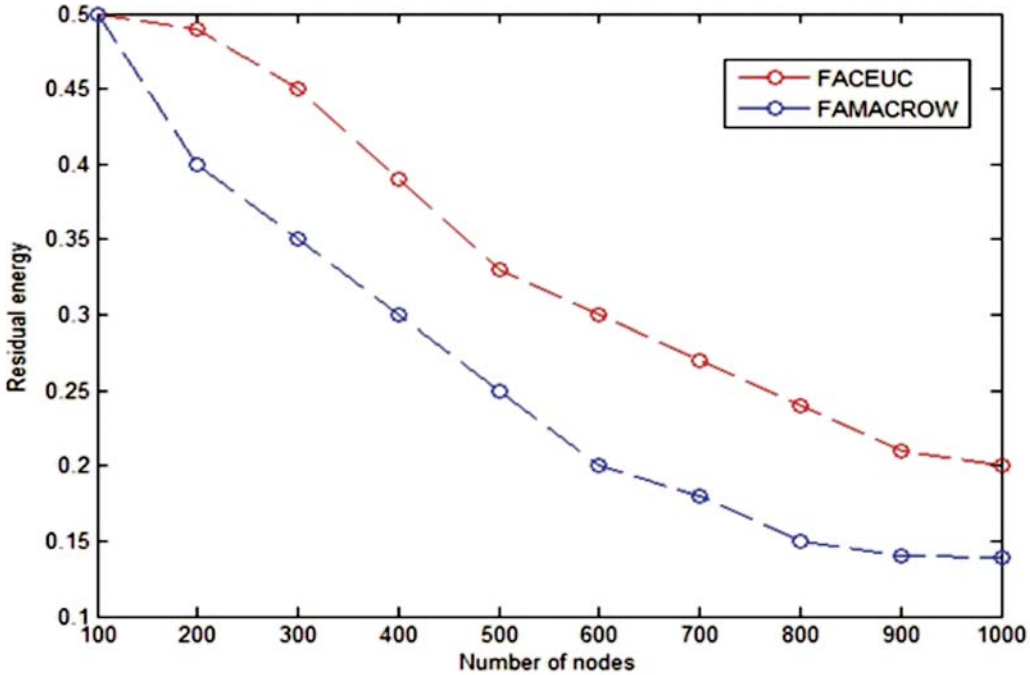

Figure 10: Residual energy of nodes in each round

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4.3. Packet delivery ratio (PDR) in each round

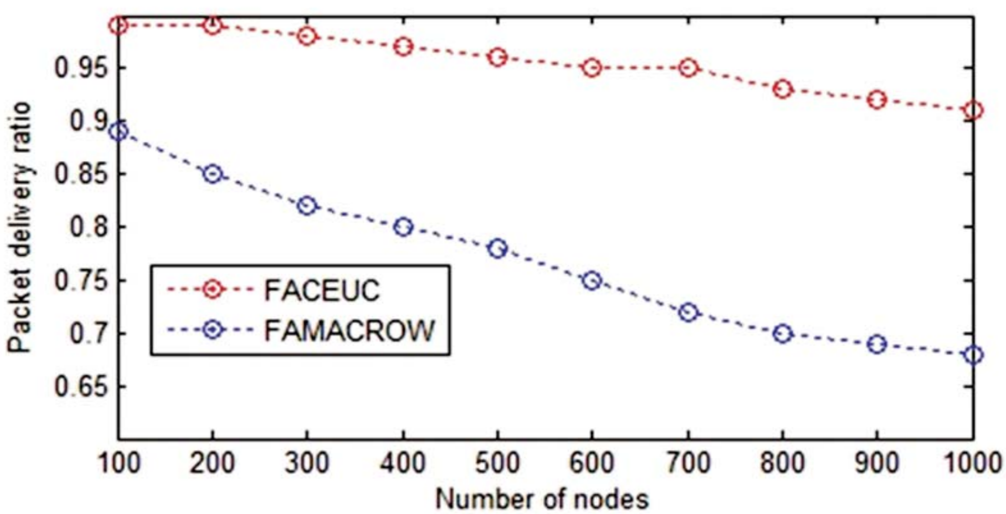

Figure 11: Packet delivery ratio in each round

Figure 11 shows the PDR is comparatively higher in FACEUC compared to FAMACROW. Selection of a relay CH for inter-cluster communication in FACEUC is based on ACO and by considering *distance from BS, residual energy and queue length*. FACUC uses Fuzzy Logic for the selection of CH in the network. FACEUC assigns TDMA schedule to cluster members within cluster for collision free intra-cluster data transmission. FACEUC forms unequal clusters to extend the lifetime of nodes which are nearer to BS. The optimization techniques Fuzzy Logic and ACO in FACEUC minimizes the packet loss ratio during inter and inter-cluster data transmission.

5. CONCLUSION

To extend the network lifetime and enhance energy efficiency, we have proposed a protocol namely Fuzzy and Ant Colony Combined Energy Efficient Unequal Clustering (FACEUC). FACEUC employs artificial intelligent techniques such as Fuzzy Logic and Ant Colony Optimization for extending the network lifetime. FACEUC uses Fuzzy Logic for forming unequal sized clusters and for selecting CHs in the network. Node distances from BS, neighbor node proximity and residual energy are the fuzzy input parameters for forming the unequal size clusters and to select a CH in FACEUC. For inter-cluster communication and efficient selection of relay CHs, FACEUC makes use of Ant Colony Optimization. ACO based relay CH selection is based on 1) distance between the current CH to relay node (2) queue size of the relay node and (3) residual energy of the considered relay node. FACEUC has given improved results in increasing the number of live nodes, extending the network lifetime and increasing the residual energy of nodes on each round. To raise the performance of WSN, future work is to employ genetic algorithm for optimal selection of cluster head and relay node in the network.

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