A Fuzzy Based Clustering Protocol for Energy-efficient Wireless Sensor Networks

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***Abstract*—Minimization of energy consumption is one of the most important research areas in Wireless Sensor Networks. Nowadays, the paradigms of computational intelligence (CI) are widely used in WSN, such as localization, clustering, energy aware routing, task scheduling, security, etc. Though many fuzzy based clustering techniques have been proposed earlier, many of them could not increase the total network life time in terms of LND (Last Node Dies) with comparing to LEACH. In this paper, a fuzzy logic based energy-aware dynamic clustering technique is proposed, which increases the network lifetime in terms of LND. Here, two inputs are given in the fuzzy inference system and a node is selected as a cluster head according to the fuzzy cost (output). The main advantage of this protocol is that the optimum number of cluster is formed in every round, which is almost impossible in LEACH (low-energy adaptive clustering hierarchy). Moreover, this protocol has less computational load and complexity. The simulation result demonstrates that this approach performs better than LEACH in terms of energy saving as well as network lifetime.**

Keywords- sensor network; fuzzy logic; network lifetime; clustering

I. INTRODUCTION

A wireless sensor network (WSN) consists of a large number of distributed sensor devices those are used to collect data from the environment to monitor different types of environmental or physical conditions [1], [2]. In WSN, the sensor nodes have some limitations in terms of energy supply, bandwidth and computational capabilities [2], [3]. The limitation of energy supply makes it indispensable for the sensor nodes to preserve energy to increase life time of the network. So, energy minimization is one of the most important topics in the arena of WSN research in order to prolong the network's life time [1], [2], [3]. Energy consumption in sensor network can be classified as "useful" and "wasteful" [4]. Useful energy consumption can take place due to transmitting or receiving data, processing of query requests and forwarding the queries/data to neighboring nodes. Wasteful energy can take place due to overhearing, idle listening to the media, retransmitting due to packet collisions and generating/handling control packets [4], [5].

The sensor nodes transmit their data directly to the Base Station (BS) in direct communication WSN; whereas in cluster based WSN, the whole network divided into individual clusters [4]. Each node communicates with its Cluster Head (CH) that transmits the aggregated data to the desired BS. Clustering in WSN can be classified as centralized and distributed protocol [6]. In case of large scale sensor networks, centralized approaches is more inefficient than distributed approach, as collecting of all data at the central BS is both energy and time consuming; but in distributed approach, a sensor node becomes a CH or a member of a cluster based on the clustering algorithm [4]. On the other hand, clustering protocols can also be classified as static and dynamic. During static clustering, clusters are formed permanently, while operations are performed by round basis in dynamic protocol, clusters are formed for a round and generally reformed for the next round [4]. The typical representative dynamic clustering protocol is low-energy adaptive clustering hierarchy (LEACH) protocol, where randomized rotation of CH is done to distribute the energy dissipation evenly over the network [1], [7], [8]. The main feature is that LEACH is fully distributed, which prolongs the network lifetime. However, it has also some drawbacks. One of the most important weaknesses of LEACH is load unbalance, i.e. as the CHs are selected randomly, some nodes may be selected as CHs, which are in close proximity of each other [1], [4]. This specifies the fact that the CHs are not evenly distributed over the network, which constrains to maximize the energy efficiency.

The application of Computational Intelligence (CI) in WSN can be used to resolve various challenges in this arena [2]. Fuzzy logic is one of the most important paradigms in CI technique. Fuzzy logic can be used for real-time decisions in WSN. Different parameters can be merged according to the predefined fuzzy rules and making decision based on the output result is a vital application of fuzzy control [4]. Typically, various clustering parameters are combined by fuzzy rules to make a decision for selection a CH during fuzzy-clustering in WSN. Lee and Cheng [1] proposed a clustering technique using fuzzy logic, which uses two input parameters (residual energy and expected residual energy) in the fuzzy inference system (FIS). Its performance is better than LEACH in terms of FND (First Node Dies) and HNA (Half of Nodes Alive), however the LND (Last Node Dies) time, i.e. total lifetime is the same as LEACH. Recently, Taheri et al. [4] proposed an energy-aware distributed dynamic clustering protocol (ECPF), which uses multi-hop communication along with fuzzy technique. Here, the clustering process is divided into three phases. In first phase, neighbor information is updated and fuzzy output is computed. During second phase, each node waits until finish the delay time to hear the CH-message from any other sensor nodes. If it cannot, it declares itself as a tentative-CH and broadcast CH-message within its cluster range. In the next iteration, if this particular node has the minimum cost among the tentative-CHs within its area, it becomes the final-CH and broadcasts the message. In third phase, the nodes take final decision to join in a cluster. Although ECPF shows better performance than existing protocols (LEACH, HEED, etc.), it has more computation complexity. Another fuzzy based clustering is proposed in [9], where five descriptors are used in FIS. Comparing to other fuzzy-clustering, as it uses more fuzzy inputs, it has more computational load. Bagci and Yazici [10] proposed another fuzzy based protocol named as EAUCF (Energy-Aware Unequal Clustering with Fuzzy), where the selection of tentative CH is almost like LEACH. Then the competition radius of the tentative CH is calculated using fuzzy logic. Here, two fuzzy descriptors (distance to the base station and residual energy) are used. This technique uses the idea to reduce the cluster size when it becomes nearer to the BS [1], [10]. EAUCF shows better performance than LEACH, when FND and HNA are considered. However if LND is considered, LEACH shows better performance. Another clustering technique is proposed in [11], where two-level fuzzy logic is implemented to select the cluster head. In the first level (named as local level), energy and number of neighbors are the two inputs to the FIS. During the second level (global level), If the qualification is higher than a predefined value, that node will be reevaluated based on three inputs (centrality, proximity to BS and distance between CHs) in the second level FIS. Here, the performance is better in smaller area than the larger area. As it has two fuzzy inference systems, it has more complexity as well as computational load. Moreover, for larger area and higher number of sensors, its life time is same as LEACH in terms of LND.

Maximum fuzzy-clustering techniques [1], [4], [10], [11] use two stages, i.e. firstly tentative CHs selection is done and after that final CHs selection takes place. Some of the fuzzy-based clustering algorithms [1], [10], [11] could not show better performance than LEACH in terms of LND. This paper proposes a clustering technique for WSN using fuzzy logic, which has higher network lifetime than that of LEACH in terms of LND. Here two parameters are used as fuzzy inputs and according to the output result a node is selected as a CH or a member.

The rest of this paper is arranged as follows: Section-II gives the description of the proposed system model, section-III presents the simulation result and lastly there is a concluding discussion in Section-IV.

II. System Model

A. *Preliminaries*

The following system model is assumed for the proposed sensor network:

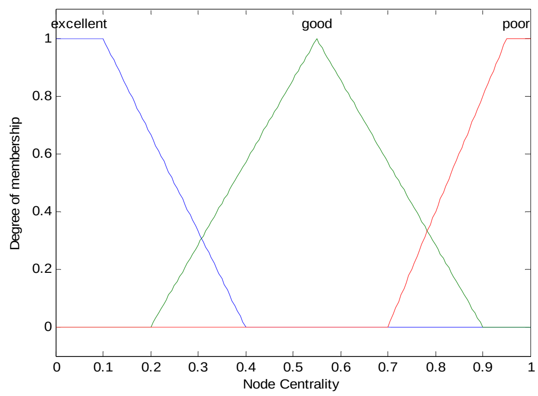
- The base station and sensor nodes are assumed as stationary after deployment.
- The sensor nodes are not provided with GPS-capable antennas, i.e. they are location-unaware.
- The nodes have the same initial energy and left as unattended after deployment, i.e. battery recharge is not feasible. However the BS has not these types of limitations in terms of energy, memory and computation.
- The nodes are capable to control the transmission power according to the distance.
- Radio links are symmetric, i.e. two nodes A and B can communicate using the same transmission power in every situation.
- Distance can be calculated based on the wireless radio signal strength.
- Generally, the node failure is considered due to energy depletion.

B. *Fuzzy Inference System*

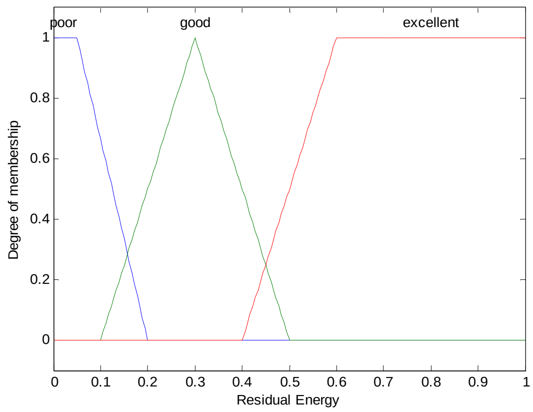
In this algorithm, a fuzzy logic system is used, where two inputs are used to calculate the fuzzy cost (output). Here, most commonly used fuzzy inference system is used for defuzzyfication, i.e. Mamdani method and centroid method are used in this FIS. The fuzzy cost is obtained using the if-then rules and the range of the value is 0 to 50.

Residual energy and node centrality are the two inputs of this FIS. Here, node centrality is the value to indicate that how central the node is among its neighbors. It is calculated by adding all distances from a node to its neighbors. Hence, the lower value of the node centrality indicates that the corresponding node requires lower energy as a CH. The fuzzy sets for the input variables are shown in Fig.1 (a) and Fig.1 (b). In both cases, the trapezoidal membership function is used for the linguistic variables 'excellent' and 'poor', whereas triangular membership function is used for 'good'. One the other hand, there is only one output (fuzzy cost) for this FIS, which is shown in Fig.1 (c). Nine linguistic variables are used for this fuzzy cost. Like the inputs, 'Exc' (excellent) and 'VP' (very poor) are represented by using trapezoidal membership function and triangular membership function is used to symbolize other linguistic variables. The fuzzy rules are listed in Table I.

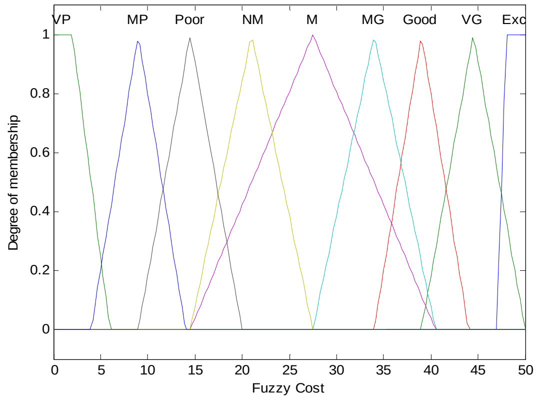
Proposed Algorithm



(a)



(b)



(c)

Figure 1. Fuzzy sets: (a) Node centrality, (b) Residual energy, (c) Fuzzy cost.

The algorithm performs its task by round basis and the round can be classified into two phases. First phase is clustering phase, where clusters are formed and second phase is data transfer phase. Before starting the general rounds, there is an initial round. Only for this initial round (first round), the BS selects CHs randomly. If a node is selected as a CH, it broadcasts the message of being a cluster head for this current round using the CSMA (MAC) protocol. Then after receiving this advertisement message, the non-CH nodes take decision to choose the suitable CH for this round. This decision is taken according to the received signal strength of the advertisement messages. After the formation of clusters, a TDMA schedule is created on the basis of the number of nodes in the corresponding cluster as well as each node is assigned a time slot. Each node calculates its node centrality and residual energy as well as sends the value to the BS. The algorithm flow is shown in Algorithm 1.

During data transfer phase, the sensor nodes collect the information and transmit data to CHs. After receiving all the data, CHs aggregate the received data and send those to the sink or BS. At the end of each general round, after calculating the residual energy and node centrality, the nodes send the values to the BS through corresponding CHs. So, BS has two sets of values for each node. One is node centrality and another is residual energy. BS calculates the fuzzy cost based on these two input variables. For each round, BS selects 5% of the alive nodes as the cluster head based on the fuzzy cost.

TABLE I. FUZZY MAPPING RULES

Rule	Residual energy	Node centrality	Fuzzy cost
1	excellent	excellent	Exc
2	excellent	good	VG
3	excellent	poor	good
4	good	excellent	MG
5	good	good	M
6	good	poor	NM
7	poor	excellent	poor
8	poor	good	MP
9	Poor	poor	VP

Exc-excellent, VG-very good, MG-medium good, M-medium, NM-near medium, MP-medium poor, VP-very poor.

Algorithm 1. Proposed fuzzy based clustering

I. Initial Round

1. BS selects CHs randomly and broadcast the *CH_msg* (CH message)
2. Cluster formation and data transfer take place
3. Each node calculates the *residual energy* and *node centrality* and sends them to BS through CH
4. End

II. General Rounds

1. *fuzzy cost* ← calculated by BS using *node centrality* and *residual energy*
2. BS selects CHs based on the value of *fuzzy cost* and broadcast the *CH_msg*
3. Cluster formation and data transfer take place
4. Each node calculates the *residual energy* and *node centrality* and sends the values to BS through CH
5. End

C. Radio Model

Here the radio energy dissipation takes place according to (1) and (2), which are the same as LEACH [7], [8]. To transmit an l-bit data at a distance d, a node spends the energy,

$$E_{Tx}(l,d) = E_{Tx\text{-}elec}(l) + E_{Tx\text{-}amp}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2 ; d < d_0 \\ lE_{elec} + l\varepsilon_{mp}d^4 ; d \geq d_0 \end{cases} \quad (1)$$

where, $d_0 = \sqrt{\varepsilon_{fs} / \varepsilon_{mp}}$ and to receive this message it spends the energy,

$$E_{Rx}(l) = E_{Rx\text{-}elec}(l) = lE_{elec} \quad (2)$$

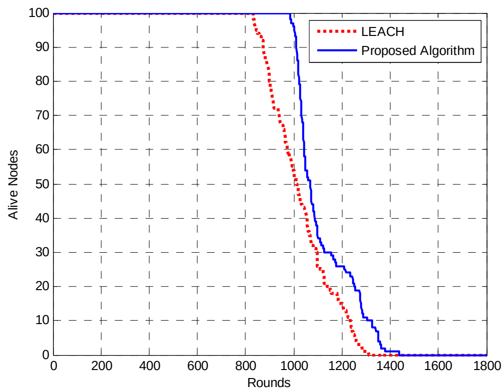
E_{elec} is the electronics energy, which depends on factors, such as digital coding, filtering, modulation and spreading of the signal [1]; $\varepsilon_{fs}d^2$ and $\varepsilon_{mp}d^4$ are the amplifier energy, which depends on the transmission distance and the acceptable bit-error rate.

III. SIMULATION RESULT

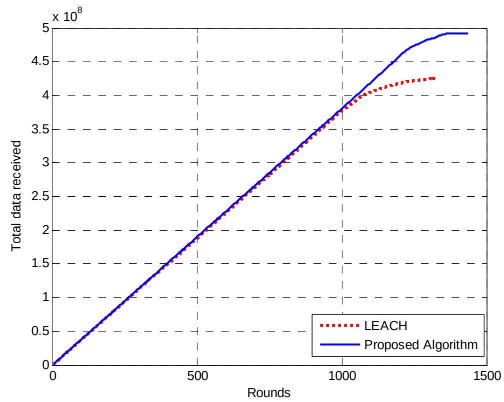
Here, 100 nodes are placed randomly between (x=0, y=0) and (x=100, y=100). The location of BS is (50, 175). The simulation parameters are described in Table II.

TABLE II. SIMULATION PARAMETERS

Parameter	**Value**
Number of nodes	100
Field size	100m ×100m
Location of the BS	(50,175)
data packet size (l)	500 bytes (4000 bits)
electronics energy (Eelec)	50 nJ / bit
εfs	10 pJ/bit/m2
εmp	0.0013 pJ / bit / m4
Energy for aggregation (EDA)	5 nJ / bit / signal



(a) in terms of alive nodes according to number of rounds



(b) in terms of total data received by the BS

Figure 2. Comparison of the proposed algorithm with LEACH

The performance of the proposed algorithm has been compared with LEACH, which is shown in Fig. 2. The performance is shown by round basis with respect to alive nodes in Fig. 2(a). Here, it is observed that if LND is considered, about 11.5% round is increased by this proposed algorithm. So, comparing to LEACH, the total lifetime of the WSN can be increased by 11.5% with this proposed algorithm, which is certainly more energy efficient. Fig. 2(b) and Fig. 3 depict that this fuzzy based algorithm has better performance than LEACH in terms of FND (First Node Dies), HNA (Half of Nodes Alive) and LND (Last Node Dies). The amount of data received by the BS is shown in Fig. 2(b). It is noticeable from Fig. 3 that Comparing to LEACH, about 22.5% more data can be processed by this clustering technique, if FND is considered; whereas about 16.4% and 15.8% more data are received by the BS during HNA and LND respectively. Most of the fuzzy-clustering protocols did not select the CH directly, i.e. first tentative CHs are selected and after that final CHs are selected [1], [4], [10], [11]. Some techniques used many linguistic descriptors to take the decision, which increases the computational load [9], [11]. But this proposed clustering technique selects the CHs directly based on the fuzzy cost, which has less computational load.

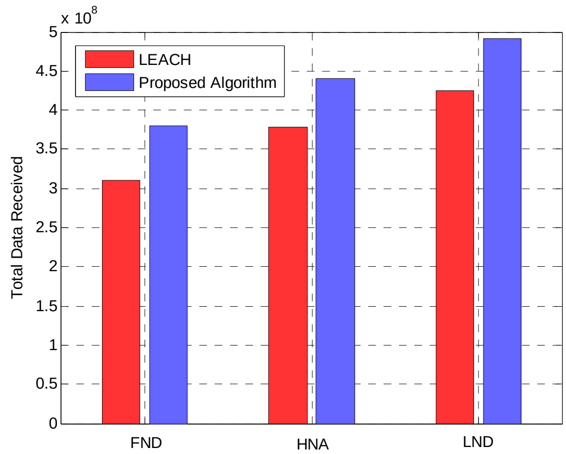


Figure 3. Comparison of total data received by BS during FND, HNA and LND.

IV. CONCLUSION

Total lifetime is an important issue, which is directly related to the energy. In this paper, an energy efficient dynamic clustering protocol is proposed for WSN, which uses fuzzy logic to select the cluster heads. Here, the cluster head selection is centralized, but the data collection is distributed. Comparing to LEACH, this approach can prolong the sensor network lifetime and also can achieve the optimum number of clusters in every round. This algorithm is simple as well as it has less computational load. So, this algorithm can be efficiently used in larger WSN. For future work, the performance can also be compared with other well known protocols, such as LEACH-C (LEACH-Centralized), HEED (Hybrid Energy Efficient Distributed). Moreover, further research will be continued to expand this algorithm to meet the requirements of QoS (Quality of Service) for WSN. The sensor nodes are stationary in this proposed algorithm; so another research can be done to apply this technique to the mobile sensor nodes.

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