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MUCH: Multi-Criteria Cluster Head Delegation Based on Fuzzy Logic

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Abstract: WSNs are composed of limited-power sensors. Replacing or recharging sensors, especially when deployed in places where human intervention is risky, is an important challenge. Therefore, and since communication is the major energy consuming operation [1], ensuring an energy efficient usage is a major concern. Clustering is one of the techniques used for this purpose [2]. It decreases the number of sensors which take part in transmission thereby assist in power consumption [3]. The sensors are organized into clusters. Each Cluster has a Cluster Head (CH) to which only other cluster members send data. CHs gather information and send it to a base station for processing. We propose an method for CH selection based on multiple criteria (distance to base station, distance to cluster members, energy cost and number of rounds) using fuzzy logic. Simulation results show that MUCH decreases the energy consumption comparing to LEACH thus increases the network lifetime.

Keywords: Wireless sensor networks, Clustering, Energy Consumption, Fuzzy logic, Cluster-head election.

I. INTRODUCTION

WSNs have gained an increasing interest in many fields such as medicine, agriculture, environmental monitoring, tracking, etc [4, 5, 6]. They are composed of limited-power sensors that have limited transmission range, processing and storage capabilities, called sensor nodes [7, 8]. They typically depend on batteries for power and need to stay alive for the longest time possible to sense the environment and report data, especially if they are deployed in rough places where human intervention is risky. Research works show that communication is a major energy consuming operation in WSNs [1] hence battery power depletion is a major concern. Many techniques were proposed to achieve an efficient usage of energy by improving the efficiency of data collection and routing. Clustering is one of these techniques.
The basic idea of clustering is to organize (virtually) the nearby sensors into groups called clusters. Every Cluster has a node called Cluster head (CH) to manage the cluster, the remaining nodes act as Cluster Members (CM). They sense data and forwarded it to the CH in their cluster who in turn sends it to a base station for processing. The main advantage behind clustering [9] is to make only the cluster head communicate with the base station, which allows to the remaining nodes to preserve their energy by switching to sleep mode. This minimizes the number of transmissions as well as the non-needed replicated data. Consequently, it reduces the power consumption in the network and increases the network life time [2] [10]. How to organize the cluster and select the cluster head has attracted considerable attention in WSNs. A variety of clustering protocols have been proposed to achieve energy efficient data routing [11, 12, 13, 14, 15, 16]. The rest of the paper is organized as follows. Section2 presents different related protocols for wireless sensor networks. Section 3 describes the proposed Cluster-Head election method. Section 4 shows the simulation results. Section 5 concludes this paper.

II. LITERATURE REVIEW

Many algorithms have been proposed to select cluster heads in WSN. LEACH [11] (Low-Energy Adaptive Clustering Hierarchy), is a reliable clustering and routing protocol, it selects CHs randomly using a probabilistic selection method. Each node n chooses a random number between 0 and 1. If the number is less than a bound $T(n)$ it becomes the cluster head for the current round. $T(n)$ is defined as:

$$T(n) = \begin{cases} \dfrac{P}{1 - P * \left(r \bmod \frac{1}{P}\right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \qquad \text{(eq.1)}$$

where, P, r and G are respectively the cluster-head probability, the number of the current round and the set of nodes that have not been cluster-heads in the last 1/P rounds. A round refers to the interval between two consecutive cluster formation processes.

The drawback in LEACH is that each node uses local information (independently of the other nodes) to decide itself whether or not to become cluster head. Consequently unbalanced distribution of CHs could occur [17]. Since the CHs

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are selected randomly, some areas may contains one or more CHs close to each other and other areas could be left with no CHs. Moreover, there is no optimization in terms of energy consumption; CHs may be located far from the nodes in the network which causes other nodes to consume more energy to send data to it [18]. Authors in [16] proposed a clustering scheme which uses fuzzy logic for cluster head selection. Three input parameters were used for the fuzzy system: distance, node density and battery level. In PEGASIS [13], the CH is considered as the nearest node to the BS. Each node communicates only with a close neighbour and takes turns transmitting to the base station. Data are aggregated from node to node, and eventually the CH transmits to the BS. One of the drawbacks of PEGASIS is that it doesn't treat the nodes on the basis of the remaining energy and there is no consideration of node distance from BS.
In [12], the clustering task relies on two factors, the distance factor from a node to BS and the energy factor that is based on the residual energy of a sensor and the average energy of the whole network. Another distance based algorithm is proposed in [15], it selects the CH that has the shortest distance to the BS and to all the other nodes within the cluster. However, it doesn't take into consideration the energy level of the CH. In our work, we consider three parameters (described the following section) to elect cluster heads using fuzzy logic. The first is based on the distance of a node to the BS and its distance to the other nodes within the cluster, the second parameter is the energy cost of node to be CH, and finally the number of rounds the node has been chosen as CH. From these parameters every node gets a weight and sends it to the cluster head that decides to whom it will delegate the cluster head mission in the coming round.

III.OUR PROPOSED SOLUTION

A. Energy Model
The energy consumption model we use is adopted from [11, 14, 19]. Each sensor consumes energy E_{Tx} for transmitting L-bit data over distance d and E_{Rx} amount of energy to receive L-bit data:

$$E_{Tx}(L,d) = \begin{cases} L * E_{elec} + L * \varepsilon_{fs} * d^2 & (d < d_0) \\ L * E_{elec} + L * \varepsilon_{mp} * d^4 & (d \geq d_0) \end{cases} \qquad \text{(eq.2)}$$

$$E_{Rx}(L) = L * E_{elec} \qquad \text{(eq.3)}$$

where E_{elec}, ε_{mp}, ε_{fs} are the parameters of transmission and reception circuits. The values are as follows: $\varepsilon_{mp} = 0.0013\ \text{pJ/bit/m}^4$, $E_{elec} = 50\ \text{nJ/bit}$ and $\varepsilon_{fs} = 10\ \text{pJ/bit/m}^2$.
d_0 is the distance threshold, $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$.
The total amount of energy to send a message is $E_{Fx}(L,d) = E_{Tx}(L,d) + E_{Rx}(L)$.

B. System Model
In this work, every cluster member N_i in a cluster computes its weight W_i that is chosen based on three parameters (described below) using fuzzy logic. It sends its weight to the current CH. After receiving all the weights, the CH chooses the node that has the lowest weight to be its delegate for the next round.
The three parameters are:
a) d_i : The difference between the distance from node $N_i(x_i, y_i)$ to the base station BS (x_{bs}, y_{bs}), denoted by d_{bsi} (eq.4) and the cumulative distance from N_i to the members nodes within the same cluster, denoted by d_{bsi} (eq.5). Hence, $d_i = |d_{bsi} - cd_i|$.

$$d_{bsi} = \sqrt{(x_i - x_{bs})^2 + (y_i - y_{bs})^2} \qquad \text{(eq.4)}$$

$$cd_i = \sum_{x=1}^{\text{nb nodes in the cluster}} d_{ix} \qquad \text{(eq.5)}$$

Where d_{ix} is the distance from node N_i to the other nodes N_x within the cluster.

b) E_i : The energy cost for node N_i to be CH. It is the energy consumed when N_i communicates with the base station (denoted by E_{Fbs}) added to the energy consumed when it communicates with the remaining member nodes within the same cluster, plus the energy consumed to complete the aggregation, denoted by E_{ip}. Thus,

$$E_i = E_{Fbs} + \left(\sum_{k=1}^{nb\ of\ CM\ nodes} E_{Fk}\right) + E_{ip} \qquad \text{(eq.6)}$$

If the value of E_i increases the chance for node N_i to be cluster head decreases.

c) T_i : The number of times node N_i has been chosen as cluster head. If the value increases, the chance for node N_i to be selected again as CH decreases.
The above three parameters are the inputs for our proposed fuzzy system. The output is the weight of the node to be cluster head. The node that has the lowest weight in a cluster will be elected as CH.

C. Fuzzy Control
The fuzzy logic system (FLS) [20] is an inference scheme which mimics the human thoughts. It basically consists of four main parts: a fuzzifier, some fuzzy IF-THEN rules, a fuzzy inference engine and a defuzzifier, as shown in Fig. 1.

- Fuzzification Module- It maps the system inputs [6], which are crisp numbers, into fuzzy sets. Then, it determines the degree to which these inputs belong to each of the appropriate fuzzy sets. In our work, the inputs fuzzy variables are d_i, E_i, T_i described in the previous section, they are converted to the fuzzy values by membership functions [Fig. 2, Fig. 3, Fig. 4].
- Fuzzy rule base- It is simply a series of IF-THEN rules that relate the input fuzzy variables with the output fuzzy variables using linguistic variables. The rule base we have consists of 27 rules listed in Table 1.
- Inference Engine- It simulates the human reasoning process by making fuzzy inference on the fuzzified values and IF-THEN rules.
- Defuzzification Module- It transforms the fuzzy set obtained by the inference engine into a crisp value. There is a single output fuzzy variable, namely, weight in our work, which determines the cost for a node to be selected as cluster head.

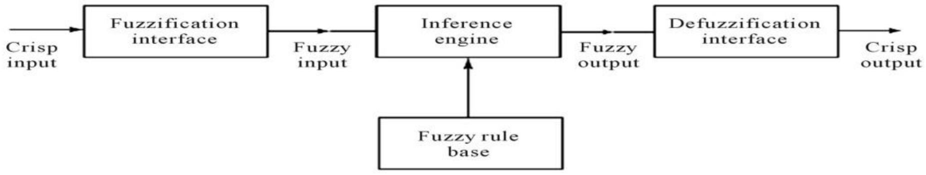

Fig. 1. Fuzzy model

We have used the most commonly used fuzzy inference technique called Mamdani method [21] that does not require complicated calculations due to its simplicity. The objective of our fuzzy-logic-based cluster-head election is to determine an energy optimized routing, such that the network lifetime is maximized. The fuzzy rule base in Figure 5 is chosen in a way not only to minimize energy consumption but also to balance data traffic among sensor nodes effectively. To choose the best node to which the current CH delegates the CH-mission, all the nodes are compared on the basis of their weight and the node with the lowest weight is then elected as cluster-head. Later, each node in the cluster associates itself to the elected cluster-head and starts transmitting data. The fuzzy rules in our system are listed in Table 1. The notation '-' in a rule R_i means that the corresponding input doesn't influence on the weight.

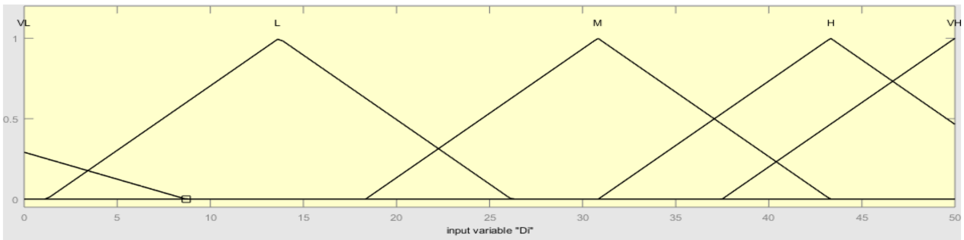

Fig. 2. Membership function for d_i

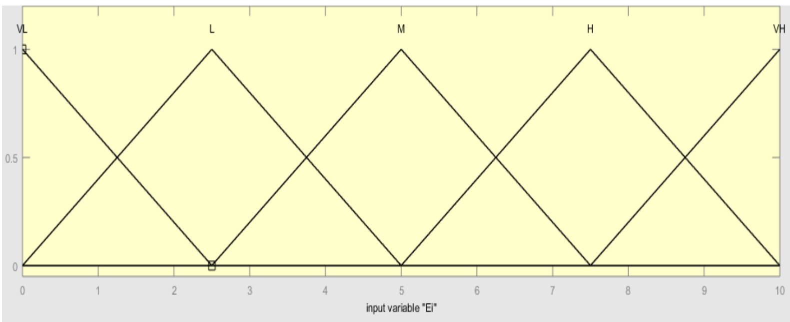

Fig. 3. Membership function for E_i

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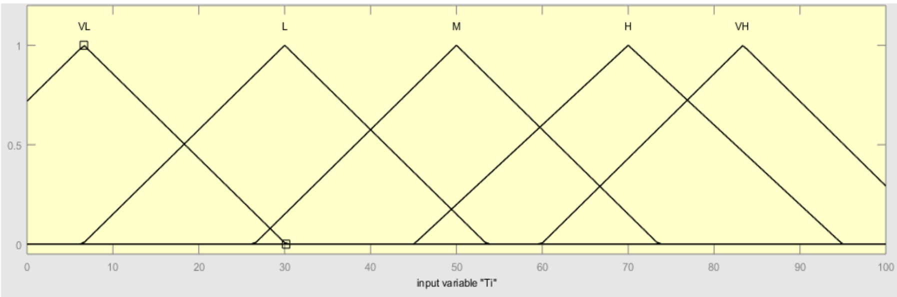

Fig. 4. Membership function for T_i

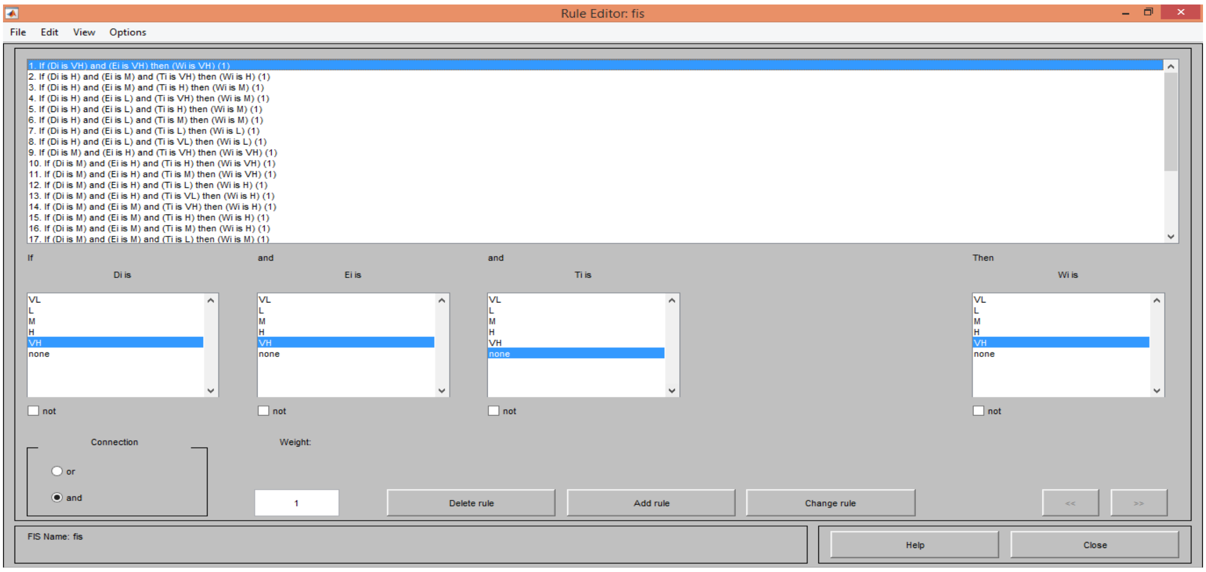

Fig. 5. Fuzzy rule base

TABLE 1. FUZZY RULES IN OUR MODEL (VL=VERY LOW, L=LOW, M=MEDIUM, H=HIGH)

$Rule_i$	**d_i**	**E_i**	**T_i**	**W_i**
1	VH	VH	-	VH
2	VH	H	-	H
3	VH	M	VH	M
4	VH	L	VL	M
5	VH	VL	VH	M
6	H	M	VH	H
7	H	M	H	M
8	H	L	VH	M
9	H	L	H	M
10	H	L	M	M
11	H	L	L	L
12	H	L	VL	L
13	M	H	VH	VH
14	M	H	H	VH
15	M	H	M	VH
16	M	H	L	H
17	M	H	VL	H
18	M	M	VH	H
19	M	M	H	H
20	M	M	M	H
21	M	M	L	M
22	M	M	VL	M
23	M	L	-	M

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24	L	H	-	H
25	L	M	-	M
26	L	L	-	L
27	L	VL	-	VL

IV. SIMULATION

A. Basic assumptions

In our simulation, we have a rectangular sensor network which consist of one static base station and several sensor nodes. The nodes send data to the respective cluster-heads, which in turn compresses the aggregated data and transmits it to the base station. We made the following assumptions:

- All sensor nodes, including the Base station, remain immobile once deployed.
- All sensor nodes are homogenous, location-aware and energy constrained.
- Each sensor node has a unique identifier (ID), and the same initial energy.
- Links are symmetric.
- The base station is located at the center of the network.
- In each round, a Cluster Head delegates the mission to the Cluster Member that has the lowest weight.

We compared our algorithm with LEACH. The focus has been on the number of packets transmitted to the BS and the energy consumption in the entire network and the number of dead nodes in each round.

B. Simulation parameters

We used MATLAB to evaluate the performance of your algorithm. Below are the parameters of the simulation:

TABLE 2. SIMULATION PARAMETERS

Parameters	Value
Network Size	100m*100m
Number of nodes	100
Location of base station	Center
Location of nodes	random
Aggregation energy E_{DA}	5 nJ/bit
Initial energy	0.5 J
E_{elec}	50 nJ/bit
ε_{mp}	0.0013 pJ/bit/m^4
ε_{fs}	10 pJ/bit/m^2
Number of rounds	100

The network consists of 100 nodes randomly distributed over an area of 100X100 meters. This simulation is conducted at 100 rounds. We have applied 0.5J initial energy in every sensor node. Figure 6 shows the remaining energy in the network in each round. We noticed that the energy preservation is increased using our approach. The energy gain is mainly related to the reduction in transmission cost.

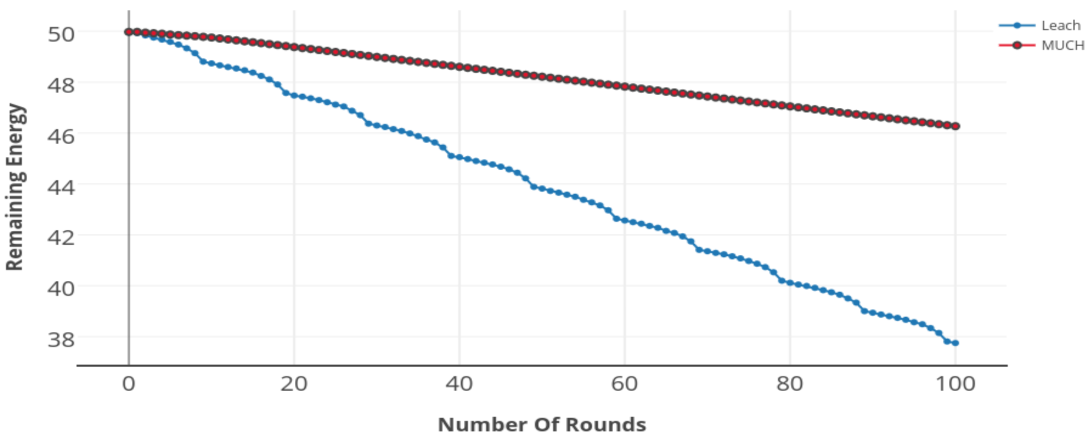

Fig. 6. Remaining energy in the network in both LEACH and MUCH

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Figure 7, shows that the number of packets sent to the BS is decreased by 45%, from ~2900 packets in LEACH to ~1600 Packets in our work (MUCH). This results in a much longer network lifetime.

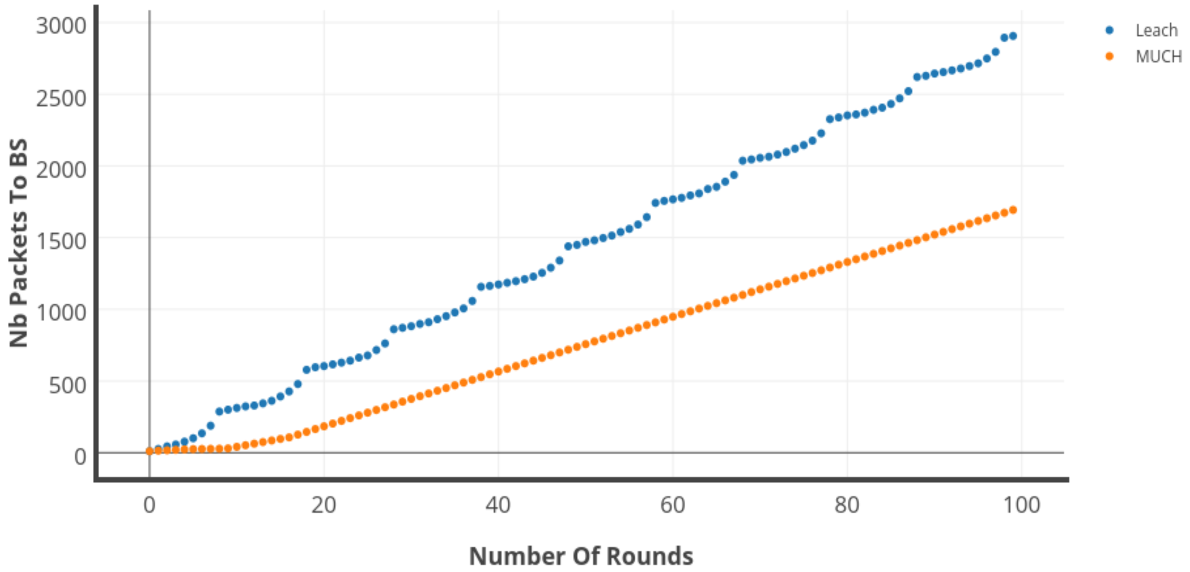

Fig. 7. Number of packets transmitted to the base stations in each round

Figure 8, represents the number of dead nodes in each execution round of LEACH and in our proposed solution MUCH. As indicated in this figure, our work improves the first dead node and the total number of nodes in each round.. the fist dead node in LEACH was at round 173 while in MUCH it was delayed to round 380.so the sensor nodes death in MUCH begin later Than LEACH .This results in a much longer network lifetime.

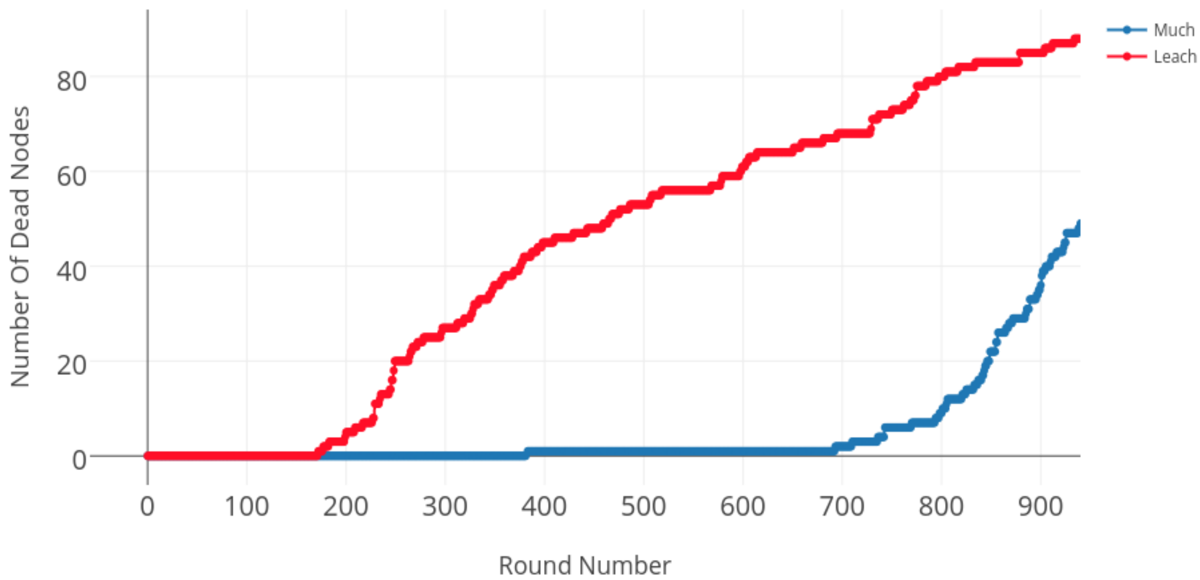

Fig. 8. Number of dead nodes/round in MUCH and LEACH

V. CONCLUSION

Clustering is a one of the techniques that can be used to reduce the energy consumption in WSNs and increases the network lifetime. In this paper, we proposed an energy efficient protocol for WSN that uses fuzzy descriptors to elect cluster heads. The election is based on three parameters that gives weights to nodes. The node that has the lowest weight in a cluster is elected to be its cluster head. Simulation results show that our work produces better results than LEACH in terms of energy consumption, number dead nodes and network lifetime.

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