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Energy-Efficient Fuzzy-Logic Based Cluster Selection for Heterogeneous Nodes in Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks is an aspiring technology when it comes to sensing/monitoring tasks. The field, seeing its applicability in numerous fields, is a continuous research area such that all its limitations can be resolved and performance increased. Among the many issues, the issue considered the most and in the paper is energy efficiency. Clustering is the most plausible solution for the same. Criteria for CH selection directly correspond to the performance of the network. Fuzzy logic for this selection is a much appreciated approach. This paper proposes a fuzzy logic based clustering which includes mobility as a factor for heterogeneous sensor nodes. The protocol, compared with some popular clustering protocols on basis of some criteria give reduced energy consumption and maximum network lifetime as desired.

Keywords- Wireless Sensor Network, Energy Efficiency, Clustering, Cluster Head Selection, Fuzzy logic

I. INTRODUCTION

Wireless Sensor Networks are the most efficient technology for tasks like target detection, enemy intrusion, environment sensing, border surveillance to name a few. These are heavily used in various applications like health care, military, defense, security, industrial processes etc. A number of sensors deployed randomly or manually perform the sensing task. The sensed data is transferred to the interested party, formally called as the base station. Each node participating in the sensing has limited resources in terms of energy, memory, processing capability and bandwidth. The nodes run on irreplaceable/non-chargeable batteries which if dead in the middle of a sensing task, causes the failure of the node and the network altogether since a portion of the Region of Interest (RoI) remains uncovered. Relying on a fixed energy supply and performing the three tasks of sensing, processing and transferring, the networks need energy-aware protocols. Whereas individual sensing by nodes add to the energy consumption, nature of node deployment (random or specific), nature of nodes (homogeneous or heterogeneous), sensing environment (static/dynamic), mode of communication (single/multi hop) are some other factors responsible for the high energy consumption of the network.

A better approach is to assign aggregator nodes responsible for collecting sensed data from a bunch of nearby nodes, aggregate data and transfer it to the BS. With clustering as a direct application of data aggregation, the selection of aggregator nodes is same as finding cluster representatives, formally called as cluster heads in WSNs. Some of the many advantages of clustering are load balancing, reduced message and communication complexity, reduced collisions, reduced failures maximized network lifetime and ensured connectivity. A variety of energy aware clustering protocols have been proposed over the years seeing the benefits of the approach [1,2,3]. Each protocol differs from the other in terms of the selection criteria of cluster heads. Some protocols base their decisions on probability [1,4], some consider energy of nodes [2,5], while the others consider a whole different way of selection. Among one of the ways is applying fuzzy logic to the selection process. Fuzzy logic enables working in real-time environments which is not always practical. Simple fuzzy if-then rules help to evaluate which nodes in the network can be elected as CHs. A set of input variables are fuzzified, evaluated of the output variable is done using fuzzy if-then rules followed by defuzzification of the output variable into a single crisp number. Each variable is taken according to the objective of the clustering and has equivalent fuzzy linguistic variables for the process. A variety of fuzzy logic based cluster head selection techniques have been proposed, some popular being works by [4,6,7,8].

Recently, Julie and Selvi [8] proposed a fuzzy-logic based cluster selection relying on factors like residual energy, mobility factor and transmission range of each node of homogeneous nature. Our proposed protocol extends the fuzzy logic selection of Julie and Selvi on heterogeneous nodes and a dynamic environment. At the end of fuzzy logic based selection, the tentative CH nodes are randomly selected instead of sequential selection based upon a fixed proportion of cluster heads needed in the network. The mode of communication can be single-hop or multi-hop. Reselection is done after every round of the protocol. The scenario taken in consideration is similar to sensing of a filed with sensors placed manually on animals moving randomly in that field.

The organization of the paper is as follows. Section II gives details about the fuzzy logic applied by Julie and Selvi. Section III discusses the characteristics of WSNs considered for the proposal, the working and formal description of the proposed protocol. Section IV lists the experimental results with comparison to various popular static clustering protocols.

II. FUZZY LOGIC IN NFEACS

The fuzzy logic for cluster head selection by Julie and Selvi [8] takes three input variables – Transmission Range, Residual Energy and Mobility Factor to compute output variable Chance. Chance helps decide the network that which nodes can be elected as CHs. Each of the considered input variables have to take an equivalent fuzzy logic variable out of Low, Medium and High. The output variable Chance also has the same three output linguistic variables. Trapezoidal membership is chosen for the high and low linguistic variables whereas for the medium variable, triangular membership function is chosen. The variable high refers to a node with the maximum transmission range > 10 m. A brief description of each of the input and output variables is given below.

The three input variables are

- ***Mobility Factor:*** Mobility factor decides the speed of a sensor node in the network. A high speed may cause movement of the sensor node outside its cluster. A low mobility is therefore required.

- ***Residual Energy:*** Residual energy of a node refers to the remaining energy of a node at any given instant of time. For a node to be a CH, the residual energy should be sufficiently high in order to fulfill the added responsibilities of data collection, aggregation and transfer.
- ***Transmission Range:*** Transmission range refers to the distance uptil which a sensor node can sense the data packet. CHs should possess a high transmission range for easy transfer of data to even a far located BS.

The output variable is

- ***Chance:*** Chance represents ability of a node to be elected as a CH. A higher chance corresponds to a high probability of a node of becoming a CH.CHs are selected based on a defuzzified crisp output value of the output variable.

A set of 16 fuzzy if-then rules are used for computing the chance of a node. Table 1 lists the fuzzy if-else ladder used in NFEACS.

TABLE 1

FUZZY LOGIC IN NFEACS

Mobility factor (speed/sec)	**Transmission range(m)**	**Residual energy(J)**	**Cluster Head Chance**
Low	High	Low	Medium
Medium	Medium	High	High
Medium	Low	High	Medium
Medium	High	High	Low
Medium	Medium	Medium	Low
Medium	Low	Medium	Low
Medium	High	Medium	High
Medium	Medium	Low	High
Medium	Low	Low	Medium
Medium	High	Low	High
High	Medium	High	High
High	Low	Medium	Medium
High	High	Medium	Medium
High	High	Medium	High
High	Medium	Low	Medium
High	Low	Low	Low

III. PROPOSED CLUSTERING SCHEME

3.1 Characteristics of WSNs considered

We consider a scenario of sensing an environment with sensor nodes placed manually on a congregation of animals. The animals move in the provided area (area to be sensed) randomly with different speeds. Each sensor node is having equal energy and transmission range prior to the start of the sensing task.. The effective transmission range may however vary with situations. By situations, we refer to an animal entering a cave, resting under a tree, going underwater where the sensor nodes may not be able to sense or communicate with the nearby nodes. All the animals at the end return to the same end point/base station. From this, the characteristics can be summarized as.

1. Energy of all the sensor nodes is initially the same.
2. All the nodes have to transfer the data to the same BS at the end of the sensing task.
3. All nodes may move around the RoI at a certain speed and the speed of each node may vary.
4. Direction of movement of nodes is arbitrary.
5. Transmission range, same initially, may vary according to different scenarios.

3.2 Proposed Clustering Scheme

Our proposal considers a network with heterogeneous nodes sensing in a dynamic environment. Using a node's residual energy, transmission range and mobility factor and applying fuzzy logic of NFEACS, the chance of a node is computed. Out of the nodes with a high value of chance, only 5% of the total population of nodes is selected as cluster heads. The selection process is done randomly. When a node becomes a CH, it advertises its status to all the nodes lying under its transmission range. On receiving such advertisements, the neighboring nodes or the non CHs decide the cluster which they will be a part of based on which CH is nearest to them. The CHs are then responsible for aggregating the data from these nodes, processing it and sending it to the BS. Transfer of data to the BS can be done directly by a CH or using multiple hops.

Since the nodes are constantly moving, the entire process of election, sensing, aggregation and transfer is repeated after each round of the protocol. With changing rounds, the nodes will have changed positions and the cluster formation will also vary.

IV. SIMULATION RESULTS

4.1 *Simulation Setup*

The proposed algorithm is compared with LEACH [1], CHEF [4] and DUCF [7]. While LEACH is a popular standard clustering protocol, CHEF and DUCF are fuzzy logic based distributed clustering protocols. But all these three protocols have to be adapted for testing in heterogeneous setting of mobile sensor nodes. The characteristics of WSN assumed are already mentioned in previous section. The simulation parameters of scenarios considered for experiments are listed in Table 2. Every simulated scene has equal height and width and one base station randomly located within the area. For every set of parameters, all algorithms are given 50 runs and the average performance is recorded in the form of following factors.

- ***First Node Die:*** The round at which first node dies is noted to give an idea how fast a node is exploited as compared to others. A lower value indicates highly imbalanced energy consumption.
- ***Half Node Die:*** The round at which half of total nodes die is marked because many researchers hold that network dies when half of the nodes are dead. Thus, this value indicates how long a network is alive.

- ***Rounds:*** The number of rounds executed of an algorithm before the network is dead indicates network life. We assume network is dead when three-fourths of the nodes are dead. A higher number of rounds mean that the protocol runs longer and is indirectly more energy efficient.
- ***Energy Consumption Per Round:*** This is the amount of energy consumed in executing one round of a protocol including the energy consumed by all nodes for communication (transmission and receiving of data and control packets). High energy consumption is not favorable.
- ***Time Consumption Per Round:*** Though time taken by any algorithm to run, as an absolute measure is irrelevant as it differs with implementation style. Yet, for comparison purpose, it can serve as an indicator of computation cost of a protocol.

The radio model of energy of [9] is followed. To transmit l −bits of message from a node to another, E_{tx} is the transmission energy and E_{rx} is the reception energy and is calculated as

$$E_{tx} = l * E_{elec} + \varepsilon_{fs} * d^2, \text{ if } d < d_o \qquad (1)$$

$$E_{tx} = l * E_{elec} + \varepsilon_{mp} * d^2, \text{ if } d > d_o \qquad (2)$$

$$E_{rx} = l * E_{elec} \qquad (3)$$

For our experiments, d_o is taken to be the range of transmitting node.

The desired percentage of CH in LEACH and CHEF is set to 2% and for DUCF and proposed, it is 5% of total nodes.

TABLE 2

SIMULATION PARAMETERS AND VALUES

Parameters	**Values**
l	4000
E_{elec}	50 nJ/bit
ε_{fs}	10pJ/bit
ε_{mp}	0.0013 pJ/bit
Initial energy per node	1J
Data packet size	500 bytes
Control packet size	25 bytes
Nodes	100-250
Deployment Area	75X75 m^2 to 200X200 m^2
Maximum Range	16m-22m
Maximum Speed	16 /sec to 22 m/sec

4.2 Results

Experiments are conducted by varying parameters such as the number of nodes, simulation area, range of nodes and the speed of nodes. Correspondingly, performances of the LEACH, CHEF, DUCF and the proposed protocol are evaluated on the basis of the considered factors. Fig 2,3,4,5 and 6 illustrate comparison between the four protocols on the basis of First Node Die, Half Node Die, Number of Rounds, Energy Consumption per

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Round and Time Consumption Per Round on (a) varying number of nodes, (b) deployment area, (c) Range of nodes and (d) Speed of nodes.

The proposed protocol outperforms the other protocols in each scenario. Highest values of First Node Die, Half Node Die, Number of Rounds and lowest values of Energy Consumption Per Round and Time Consumption Per Round very well portray the efficacy of the protocol.

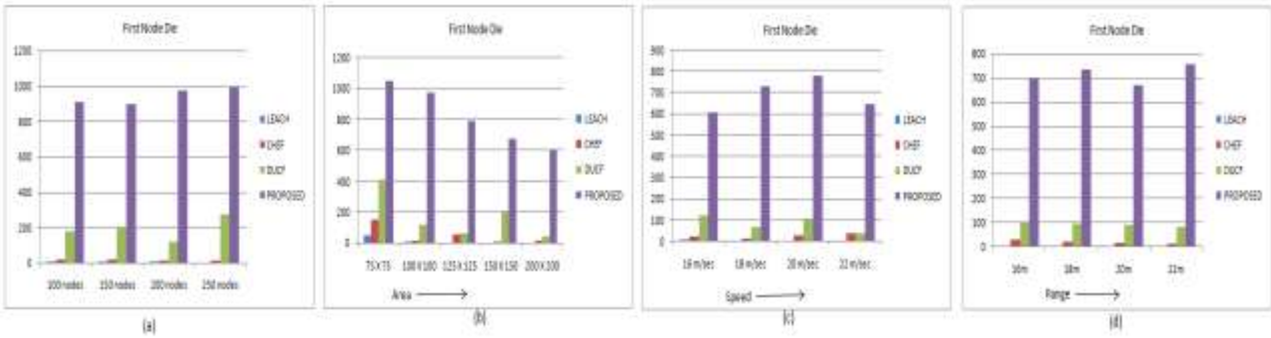

Fig 1 First Node Die values of protocols with changing parameters

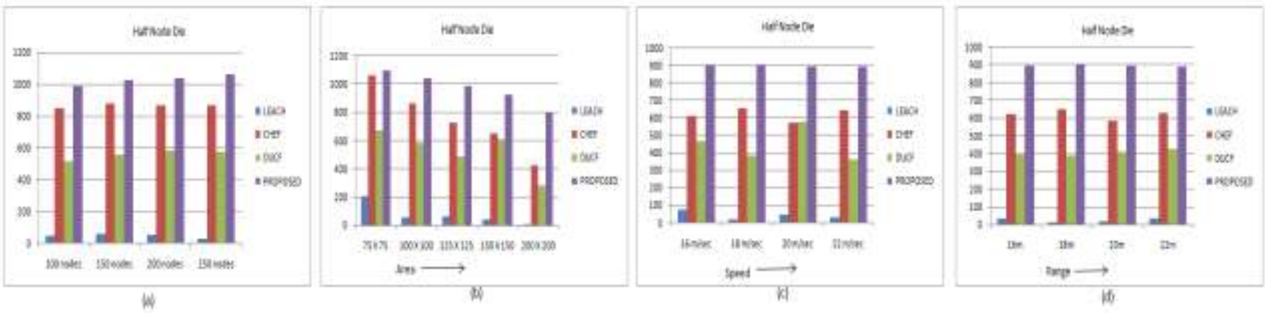

Fig 2 Half Node Die values of protocols with changing parameters

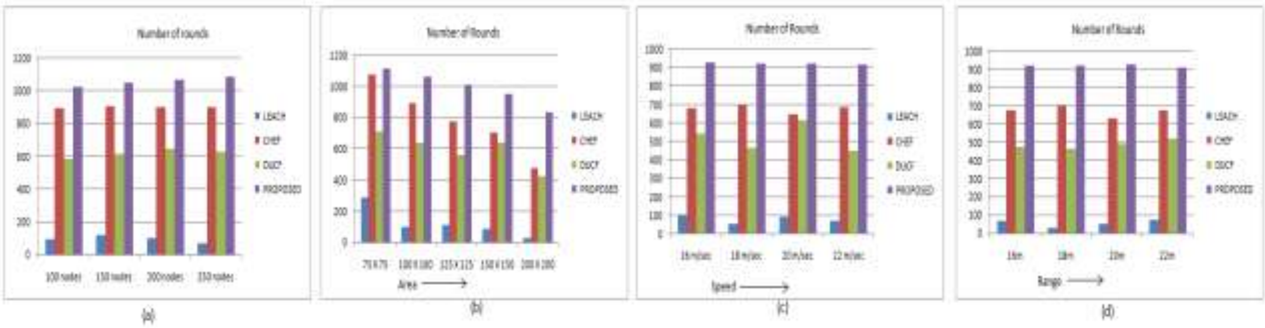

Fig 3 Number of rounds of protocols with changing parameters

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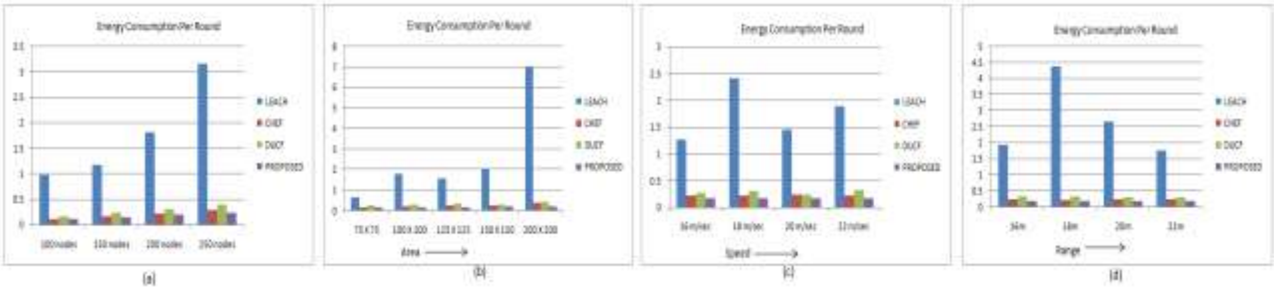

Fig 4 Energy Consumption Per Round of protocols with changing parameters

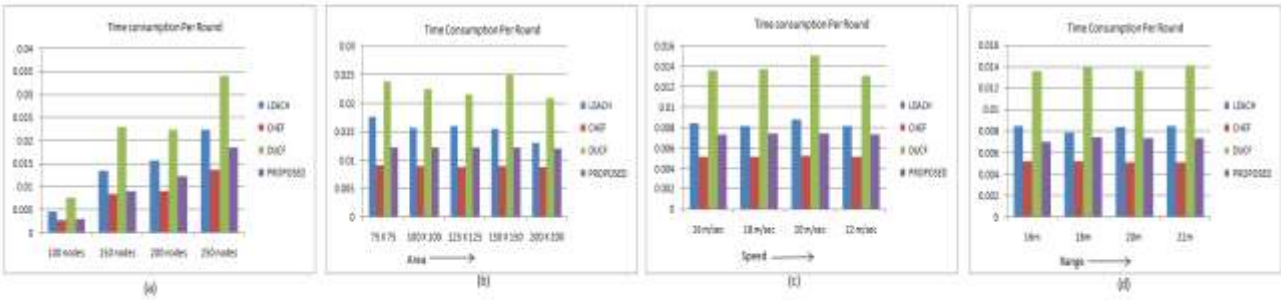

Fig 5 Time Consumption Per Round of protocols with changing parameters

VI. CONCLUSION

Wireless Sensor Networks find an increasing application in many fields. Yet the advancement in hardware technology cannot cross the energy barrier. The limited energy of the sensor nodes requires that routing and communication protocols be developed to ensure balanced energy consumption. A major approach of energy efficient communication protocols is to select CHs which aggregate data of member nodes and send to BS. The selection technique of CHs plays major role in energy consumption pattern of the network. Use of fuzzy logic to decide a node to be elected as CH is rather new. This paper has proposed a fuzzy logic method to select CHs in WSNs which have heterogeneous mobile nodes. Proper fuzzy linguistic variable are taken to consider residual energy, speed and range of a node to decide its chances of being a CH. The popular protocols for static homogeneous nodes like LEACH, CHEF and DUCF are adapted for the setting and compared against the proposal. Simulation experiments in various scenarios prove the proposed protocol to be better than others in all scenarios.

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