Energy Efficient Routing Protocol to Extend Wireless Sensor Network Lifetime

T. Ercan, M. Asim

***Abstract*—In Wireless Sensor Networks (WSNs), the sensor nodes have limited energy resources with their mostly irreplaceable batteries. This makes to encourage design protocols that are energy efficient to provide a longer network lifetime. This paper proposes a method to divide the sensor network into equal-size grids namely regular geometric shaped clusters, selecting Cluster Head (CH) and Vice Cluster Head (VCH) for each grid by using Fuzzy Logic System (FLS). Since the CH being the central node and performing additional tasks in the cluster often results in early energy drain, the VCHs are introduced here as additional internal resources to replace CHs in the network. Unlike other typical hierarchical routing protocols, the CHs are not changed per each round; rather they are replaced on-demand in order to reduce energy consumption. We analyze and compare our proposal in the MATLAB with the well-known cluster-based protocol, LEACH and its modified version MODLEACH. The results show a significant improvement in network throughput, energy consumption and network lifetime.**

Index Terms—**Cluster head, fuzzy logic system, grid, vice cluster head, wireless sensor network.**

I. INTRODUCTION

IN WSNs, most of the energy is consumed during communication processes. The sensor nodes sense and gather information from the environment and transmit them separately to the sink. The energy resources for sensor nodes are of finite capacities. Many energy efficient routing protocols have been presented to address this problem. Mainly they are divided into two categories; flat routing protocols and hierarchical routing protocols [1].

In flat routing protocols, all the nodes perform same tasks in the network and have similar functions. Data is usually flooded in the network and is transmitted in a multi-hop fashion to the sink. Flat routing protocols perform well in small-scale networks but they are not effective for large-scale networks because all sensor nodes generate high data processing and use more bandwidth [1]. Some famous examples of flat routing protocols are SPIN (Sensor Protocols for Information via Negotiation) [2], Directed Diffusion [3], Rumor Routing [4] and Gossiping [5].

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On the contrary, in hierarchical routing protocols, different nodes perform distinct tasks. They are arranged in groups or clusters and each cluster has a CH, whose task is to collect data from their member nodes and send them to the Base Station (BS). Generally, the node with highest energy level in a cluster is selected as the CH. Hierarchical protocols work in rounds, where a round usually includes; making of clusters, selecting CHs and delivering the collected data to the sink. This type of routing protocols are proved more energy efficient than flat based routing protocols [1] [6].

The functions of CHs in a hierarchical routing protocol are greater than a normal node. It includes; overhearing, receiving, data aggregation and transmission of packets to the sink. The tasks of CHs in cluster-based networks are not just limited to the respective clusters, they are also involved in routing of the data from their neighbor CHs. Particularly, the CHs located near the sink are most prone to energy exhaustion because of their role as an intermediate node for the other part of network that can't reach the sink directly. These tasks are energy consuming and they make the lifetime of a CH shorter as compared to the normal nodes [7] [8].

In this study, we propose an alternative VCH for CHs, when they suffer from energy dissipation. The current CH selects the next VCH. After this selection, VCH does not take part in any process until its energy level dissipates to a threshold level. Later, the VCH is notified from CH and replaces the CH's functions. It will select a new VCH for itself. Fuzzy Logic System is used to calculate the ranks of the nodes and according to ranks, CHs and VCHs are selected. Its decision making process is based on two parameters; residual energy and centrality. The highest-ranking node is selected as the CH and the second highest as VCH.

The remaining part of the article is organized as follows. Section II discusses the VCH and its usage with a literature review. The proposed mechanism with details is explained in section III. The simulation results are analyzed and discussed in section IV. Finally, section V concludes the paper.

II. VICE CLUSTER HEAD

The concept of VCH in the literature is presented to extend the network lifetime and handle the nodes in a cluster after the inability of the current CHs to perform. Mostly, the node having second highest residual energy in a cluster is selected as the VCH and it replaces CH's functions in case of its energy drain. The protocols that utilizes VCHs are proved more energy efficient with a better throughput.

LEACH [6] as a famous example of hierarchical routing protocol, has inspired many reformations in this area. It works in rounds, where a round includes; setup phase and steady state phase. In setup phase, some nodes are selected to become CHs based on the predefined conditions, then, the nearby nodes join them to form clusters. In steady state phase, the CHs collect and aggregate the data from their cluster members and send them to the BS. The CH selection process takes place in each round. However, [9] avoids this often CH selection per round in order to reduce energy consumption, by introducing a VCH in each cluster. The VCH takes over CH's place when it begins to consume too much energy. In this way the duration of steady state phase is increased and the extra energy that is consumed in setup phase is avoided, which results in networks lifetime extension.

Similarly, [10] presents VCHs in its clusters. The VCHs are selected by the CHs based on their energy levels. The VCH does not participate in any process until the energy level of CH decreases to a certain threshold value (such as, 10%). On getting the call, VCH starts working as the new CH and announces itself in the cluster.

Reference [11] uses VCH in LEACH-C [12] protocol to improve its performance. VCH is selected by the CH and replaces the CH when its energy level decreases to a minimum value. Likewise, [13] improves the performance of LEACH by introducing a VCH in the network and it takes over CH's function when the CH dies. Some other protocols like [14] and [15] follow the same method as well and utilize the VCHs after the death of CHs.

In the proposed method, VCH is the node having highest rank after CH in a cluster. The ranks are calculated by FLS based on two parameters; energy level and centrality. The VCH sleeps after its selection in order to avoid energy dissipation until it gets a wakeup call from the CH. The CH sends this call when it consumes $1/10^{th}$ of its initial energy. The VCH then starts functioning as the new CH.

III. Proposed Mechanism

Our proposed mechanism runs two phases; setup phase and transmission phase. The setup phase includes; division of nodes into grids, selection of CHs and VCHs for each grid by using FLS. In the transmission phase, CHs collect sensed data from their cluster members, aggregate and transmit them to the BS. They are further explained in details as follows.

A. *Making of Grids*

The grids are established to divide the network into equal sized areas with a group of nodes. This method gives a fair distribution of the load across the network. The size of grids are defined according to the signal range of sensor nodes, as calculated in [16] and [17]. The CH of a grid should be able to reach all its member nodes and as well as to the neighbor CHs. The CHs in cluster-based routing protocols are used as intermediate nodes to re/route the packets from distant CHs that cannot reach the BS directly. Therefore, the CHs should be accessible from each other. Fig. 1 shows a network with randomly deployed nodes, grouped into grids and each grid have a CH and a VCH. MATLAB is used to run and display the values in the figure according to the input values taken from Table1.

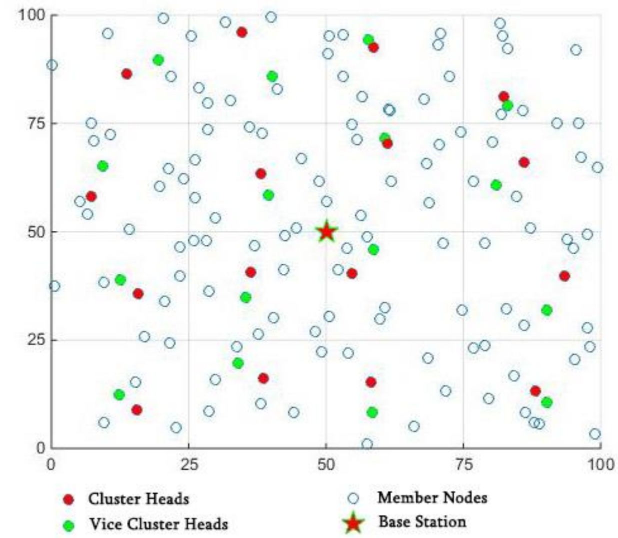

Fig.1. Grid formation

B. *CH Selection*

The selection of CH only takes place in the setup phase; later this process is avoided in order to reduce the energy consumption that is caused during the selection process. FLS is used to select the CHs, and its decisions are based on two parameters; residual energy and centrality.

1) *Residual Energy*

The existing energy level of a node to become CH is important to evaluate, because a CH has more energy consuming tasks to perform than a normal node. Ref [9] and [10] consider only energy level as the primary parameter for CH selection. However, we consider the centrality as well as the energy level to get results that are more appropriate. As stated in [18] and [8], the residual energy (RE) of a node can be calculated when the consumed energy (CE) is subtracted from the initial energy (IE) (see equation (1)).

$$RE = IE - CE \tag{1}$$

2) *Centrality*

Centrality is the sum of square distances of a node with respect to the other cluster members as stated in [19] [20]. The distances between the nodes are calculated by using the distance formula, from equation (2). The most central node in a cluster has minimum distance from other cluster members and it will cause them to consume less energy. Therefore, centrality is considered an important parameter for CH selection, so that the member nodes can communicate with CH conveniently.

$$D = \sqrt{(N_x - M_x)^2 + (N_y - M_y)^2} \quad (2)$$

3) Fuzzy Logic System

In our study, FLS is used to arrange the sensor nodes into ranks because of its spontaneity and energy efficiency [18] [8]. FLS works with linguistic variables and divides the input values into different levels according to their ranges such as, in this study, the both inputs i.e. residual energy and centrality are divided into three levels; *Low, Medium and High*, ranging from 0 to 0.5 J (Fig. 2) and the centrality is divided into three levels; *Close, Medium and Far*, ranges between 0 and 400 m (Fig. 3) respectively. From these input variables, the nodes are categorized into five different levels, as the fuzzy output such as; *Low, Low Medium, Medium, High Medium and High*, ranging between 0 and 1 (Fig.4).

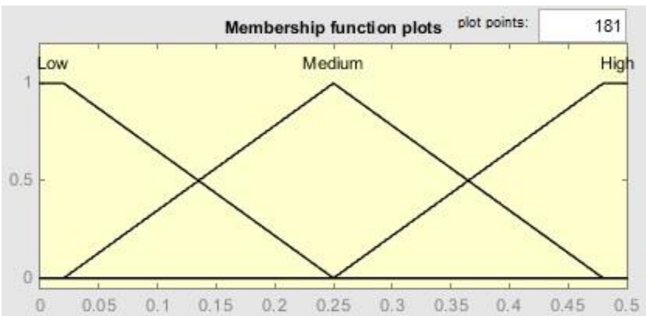

Fig.2. Membership functions for residual energy

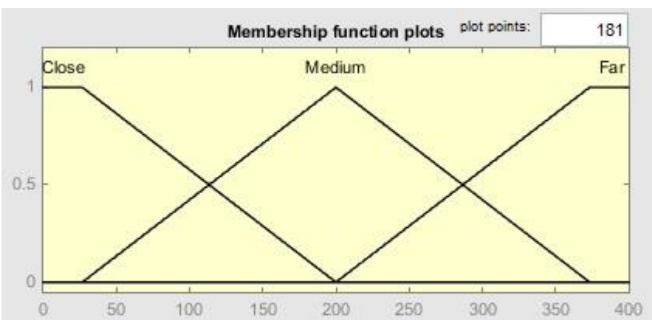

Fig.3. Membership functions for centrality

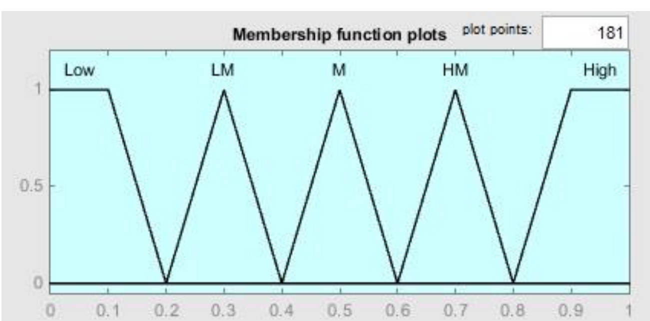

Fig.4. Membership functions for rank

C. VCH Selection

The node with the highest rank in a cluster is selected as the CH. After selection, the CH announces itself in the cluster by broadcasting a message. The member nodes send ACK messages along with their ranks. The CH chooses the node with the highest rank as the VCH and declares it. VCH after its selection does not participate in any task; it simply waits for a notification call from the CH if its energy level decreases to a threshold level (the threshold energy is taken as the 1/10th of initial energy). When getting the call, the VCH replaces CH's functions and announces itself in the cluster as the new CH. The member nodes send the ACK message with their ranks again, as they did before. The new CH selects the highest-ranking node as the new VCH in the same way it was selected.

By employing the method the setup phase is not run repeatedly, rather the CHs are changed on-demand. This gives a great energy boost to the network, as demonstrated from the simulation results. The entire working mechanism of the proposed method is explained in Fig. 5.

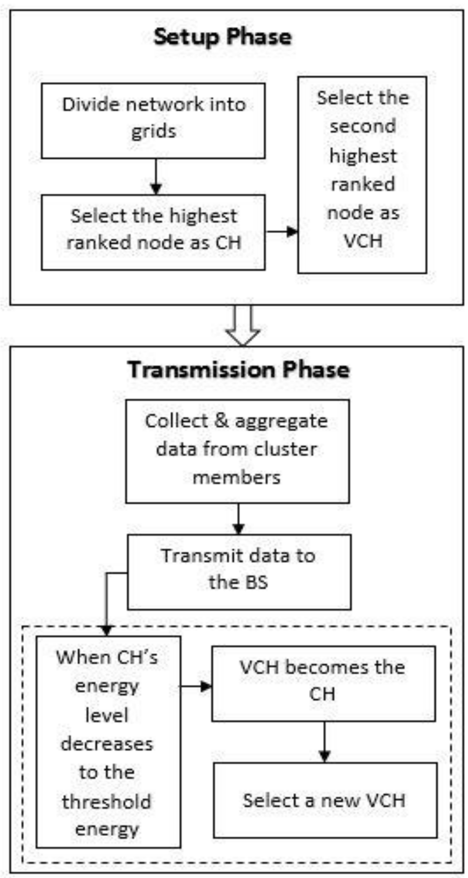

Fig.5. Model of the proposed method

IV. SIMULATION RESULTS AND DISCUSSION

The simulations are performed in MATLAB and the results are compared with LEACH and MODLEACH [21] as far as we could find the related performance values in the literature. MODLEACH is a modified version of LEACH. Unlike LEACH, it does not change the CHs in each round unless their energy level decreases below a certain threshold value. It gives a better performance compare to the LEACH. The authors in [22] proposed using a VCH enabled in the cluster with two purposes; guard the CH against failure for energy drain and reduce the clustering frequency. Its function is different from our method, however, the authors compared with their results with LEACH again. Reference [23] also proposed to use a second cluster head. However, the authors named the cluster heads as master and vice cluster heads and claimed they could work together on data collection, fusion and transition. They also proved a longer network lifetime for large-scale sensor networks. We believe that our method outperforms both LEACH and MODLEACH, by consuming less energy, delivering higher data rate and extending network lifetime in a VCH proposed scenario.

The experiments are performed in an area of 100 by 100 m, where the BS is placed at the center of the network along with 100 sensor nodes. The simulation parameters are listed in the Table I.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Field size	100m x 100m
Number of sensor nodes	100
BS location	50m x 50m
Initial energy (Eo)	0.5 J
Transmission Energy (E_{TX})	50 nJ/bit
Receiving energy (E_{RX})	50 nJ/bit
Packet Length	4000 bits
Free space amplifier (Efs)	10 pJ/bit/m2
Multipath amplifier (Emp)	0.0013 pJ/bit/m2
Data aggregation (EDA)	5 nJ/bit

The longer a node takes to die, the higher will be its lifetime. From the Fig. 6 it can be seen that the first node dies at 1563 rounds and the last node dies after 4340 rounds, which is about 64.4% and 51.8% higher than MODLEACH and LEACH respectively.

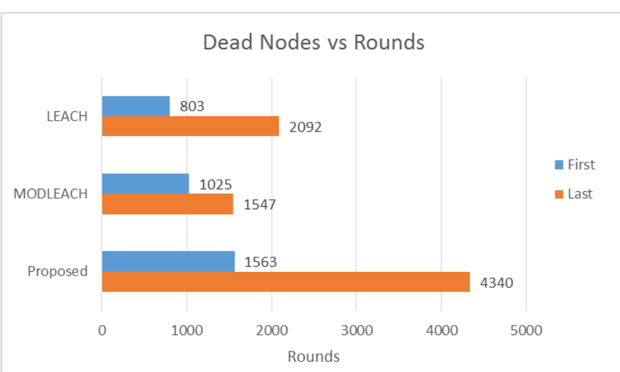

Fig.6. Network lifetime

The proposed approach is able to perform for a longer time because of its lower energy consumption per round. It consumes about 12.8%, 24.4%, 38.5% and 51.3% energy at rounds 325, 650, 975 and 1300 respectively (from Fig. 7). However, MODLEACH consumes 26.5%, 53%, 79.6% and 98.8% while for LEACH it is 27.3%, 54.7%, 81.2% and 99.2% respectively. From the listed numbers, it can be observed that the other two protocols likely consume twice as much energy as ours.

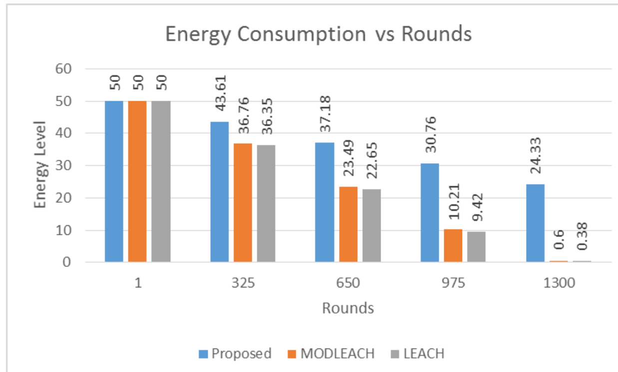

Fig.7. Energy consumption

The throughput of a network depends on number of packet delivered to the destination. Fig. 8 shows packet delivery ratio to the sink according to the rounds. MODLEACH and LEACH have higher delivery in the first 1000 rounds, but this number decreases with the increase of number of rounds. Their number of packet does not change after 3000 rounds, that shows there is no more alive nodes left in the network. However, in our protocol it raises at rate of 29.5%, 59%, 87.8%, 99.9% and finally 100% with respect to the total number of delivered packets until 5000 rounds with a difference of 1000 rounds.

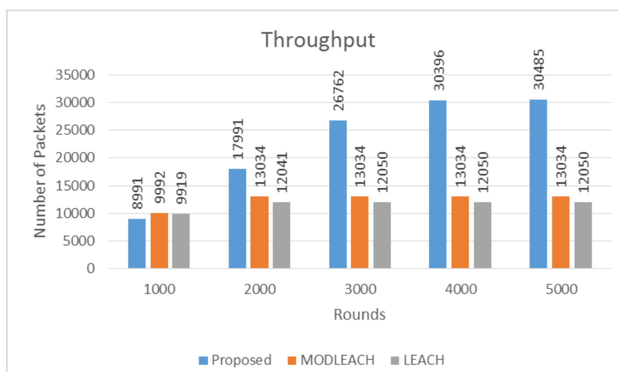

Fig.8. Throughput

V. CONCLUSION

In this study, we proposed a method to improve the performance of wireless sensor networks by using the network resources. The nodes are divided into grids and a CH and a VCH is selected for each grid by using the fuzzy logic system.

The VCH does not participate in any process after its selection until the energy level of the CH decreases to a threshold level. The VCH then becomes the CH and selects a new VCH for itself as its backup. By continuing this order, there will always be a CH in the cluster to manage its member nodes.

The process of selecting CHs can be improved in the future by adding more parameters to FLS, such as, number of neighbor nodes, density of network and speed of the nodes in case of a mobile network. It will result in selecting the optimal nodes as the CHs, and ultimately causing less energy to consume for communications tasks.

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