A Novel Cluster-based Routing Protocol with Extending Lifetime for Wireless Sensor Networks

Jalil Jabari Lotf
Department of Computer Engineering
Islamic Azad University
Ahar Branch, IRAN
j-jabbari@iau-ahar.ac.ir

Mehdi Nozad Bonab
Department of Computer Engineering
Islamic Azad University
Marand Branch, IRAN
M.Nozad@gmail.com

Siavash Khorsandi
Department of Computer Engineering
Amir Kabir University of Technology
Tehran, IRAN
Khorsand@cic.aut.ac.ir

***Abstract* -Over the recent years, one of the most important problems in wireless sensor network is to develop a routing protocol that has energy efficiency. Since the power of the sensor nodes is limited, conserving energy and network life is a critical issue in wireless sensor network. In this paper, first we propose an ELCH (Extending Lifetime of Cluster Head) routing protocol that has self-configuration and hierarchal routing properties. It reforms the existing routing protocols in several aspects and constructs clusters on the basis of radio radius and the number of cluster members. In this method, the clusters in the network are equally distributed. We also suggest a novel clustering algorithm for sensor networks, which lets sensors vote for their neighbors in order to elect suitable cluster heads.**

Key Words: Wireless Sensor Network, Routing, Clustering

I. INTRODUCTION

Limited battery power impedes the arrangement of wireless sensor networks. In order to decrease energy consumption, techniques of energy-efficient data dissemination are required. According to [1], there are three major data dissemination methods: centric, local and external storage. In centric or local storage, data are kept within the network and queries are forwarded to the nodes that store the requested data. In this paper, we will study the external storage, in which data require to be stored in a fixed sink outside the network.

The lifetime of a sensor network can be defined as the duration from the deployment of the network to the time when the first or the last sensor runs out of energy. One of the energy-efficient techniques to extend the lifetime of a sensor network is clustering [2, 3]. To extend the sensor lifetime, it is often coupled with the data fusion [4]. Each cluster selects one node as the cluster head. The data gathered from the sensors are forwarded to the cluster head first, and then to the sink. The cluster heads can fuse the data from the sensors to minimize the amount of the data to be forwarded to the sink. Clusters can be organized hierarchically when the network size increases.

Here we are going to develop an ELCH routing protocol. It is a clustering-based protocol which is designed to minimize the energy dissipation in wireless sensor networks. This new algorithm has the capability of combining the load balancing, topology and energy information. Moreover, on contrary to the traditional energy-efficient clustering approaches, it can generate fewer clusters and a longer network lifetime. There are not any assumptions about sensor location and network topology in this protocol, and it is fully distributed and energy-efficient.

The rest of the paper is organized as follows. In Section II, some previous works on cluster-based routing protocols in wireless sensor networks are briefly reviewed. In Section III, the proposed architecture together with the methods and algorithm is described in detail. Section IV illustrates experimental results and discusses the system performance. Finally, in section V, we conclude this paper and suggest future work.

II. RELATED WORKS

First, Low Energy Adaptive Clustering Hierarchy (hereinafter referred to as LEACH) [5] is a clustering-based protocol that uses randomized rotation of the cluster-heads to distribute the energy load evenly among the sensor nodes in a network. Once the clusters are built, the cluster heads broadcast TDMA schedules which provide the order of transmission for members on the cluster. Each node has its own time slot. It transmits data to the cluster head within its exclusive time slot. When the last node in the schedule has transmitted its data, the cluster head will be selected randomly in the next round. To improve the scalability and balance the energy usage of the network among all the nodes, it makes use of localized coordination.

Improvements to LEACH are proposed in [6, 7]. TEEN (Threshold Sensitive Energy Efficient Sensor Network) protocol is founded on LEACH. The former has two more restrictions [3]. First, as soon as the absolute value of the sensed attribute exceeds a Hard Threshold (HT), the node that senses this value must switch on its transmitter and report it. Secondly, when the change in the value of the sensed attribute is greater than a Soft Threshold (ST), it stimulates the node to switch on its transmitter and report the sensed data. A node will report data only when the sensed value is beyond the HT or the change in the value is greater than the ST.

PEGASIS (Power Efficient Gathering in Sensor Information Systems) is a chain-based power efficient protocol constructed on the basis of LEACH [7]. It assumes that each node must know the location information about all other nodes at first. PEGASIS begins with the farthest node from the sink. The chain can be easily built by using a greedy algorithm. The chain leader aggregates the data and forwards them to the sink. To create a balance in the overhead engaged in the

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communication between the chain leader and the sink, each node in the chain takes turn to be the leader.

To lengthen the network lifetime by distributing energy consumption, HEED (Hybrid Energy-Efficient Distributed Clustering) has been proposed in [8]. HEED is a standalone distributed clustering approach in which each node takes two factors into account: remaining energy and communication cost before deciding to join one cluster or the other. In HEED, a cluster head, once elected, is kept for a fixed number of iterations. This is in contrast to some other approaches in which the cluster heads are elected anew in every step. This is to reduce the unnecessary high setup cost associated with the cluster head selection process.

III. THE PROPOSED PROTOCOL

In order to solve the foregoing problems, we propose a new clustering algorithm for sensor networks. This new approach lets sensors vote for their neighbors to elect suitable cluster heads. We utilize hybrid protocol that combines the cluster architecture with multi-hop routing for the reduction of the transmission energy.

Multi-hop routing is adopted in many WSN and ad hoc wireless networks. This approach lets a node wanting to transmit the data to a destination find one or multiple intermediate nodes. The data packets from the source node are relayed among the intermediate nodes until it reaches the destination [9]. The main advantage of this approach is to reduce the transmission energy consumption.

In our protocol, after clusters have been organized, the cluster heads can form a multi-hop routing backbone. For the communication within a cluster, every member node forwards the data to the cluster head directly. While for the communication between the cluster heads and the sink, a multi-hop routing is adopted to decrease the transmission energy and to minimize the difference of energy consumption among all the nodes. Our protocol uses “Minimum Transmission Energy” (MTE) routing [10] as the routing algorithm.

To develop our protocol, we make the same assumptions as for LEACH about the network model as follows. First, every node in the network shares the same infrastructure and is homogenous. Besides, the energy of every node is limited. Secondly, all nodes in the network have enough power to communicate directly with any node in the network including the sink. In other words, all nodes can employ power control to vary their transmission power and range. At the same time, each node has enough processing power to support different protocols and to signal processing tasks. These assumptions have been made possible due to the availability of many advanced radio frequency devices and low power computing devices. Finally, we suppose that those nodes nearby have highly correlated data that are redundant for the sink. The following section describes our protocol in detail.

This section describes an operation of the proposed system especially in the clustering architecture, power-aware cluster-head selection method and cost-based multi-hop routing algorithm. The basic operation of the sensor networks is divided to rounds [11]. In the proposed system, each round comprises a setup phase and a steady-state phase.

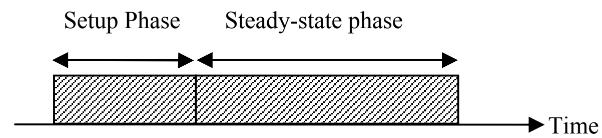

Figure 1. Round of sensor network operation

A. Setup Phase

In this phase, each node makes use of the proposed methods and algorithm to perform the following: 1) cluster formation, 2) cluster-head selection. The process of the setup phase is shown in Fig. 2.

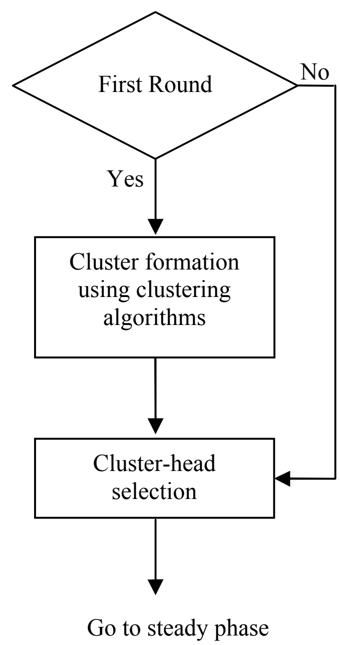

Figure 2. Setup phase process

Cluster formation– The heuristics behind the sensor voting is that the importance of a sensor should be reflected from all its neighbors instead of being done from its local properties alone. Each sensor calculates this suitability that one of its neighbors becomes its cluster head and casts a vote for that neighbor [12].

At the same time, sensors gather votes from their neighbors and calculate the total votes received. The more votes a sensor accumulates, the more importance it obtains in the whole network. During the clustering phase, sensors compete with one another in terms of the total votes each has received. Because sensors are location-unaware, topology and residual energy become the two primary factors in electing the cluster heads. A sensor uses the following rules to calculate the vote for each of its neighbors:

R1) The sum of the votes a node gives to all its neighbors is 1.0.

R2) The neighbor whose proportion of residual energy to distance from the node is greater should gain more vote than the neighbor whose proportion of residual energy to distance is less.

Since the total vote that a sensor holds is 1.0, rule R1 has the following implications: If a sensor has more neighbors, each neighbor receives a smaller vote for there are many candidate cluster heads for this node. Because each neighbor gives some vote to a sensor, sensors with more neighbors tend to receive more votes. Thus cluster heads are likely to be those high-degree nodes. Rule R2 attempts to balance the workload among all the sensors. It is based on the heuristic that cluster heads should be selected from nodes with proportion of residual energy to distance from the node is greater must gain more vote than the neighbor whose proportion of residual energy to distance is less. According to the rules R1 and R2, the following strategy is used to share a sensor's vote among its neighbors. For a sensor v_i, the vote it casts for another sensor v_j is:

$$v(v_i, v_j) = \begin{cases} \dfrac{\left(\dfrac{e_j}{d_{ij}}\right)}{\sum_{d_{ik} \le R} \dfrac{e_k}{d_{ik}}} & d_{ij} \le R \\ 0 & d_{ij} > R \end{cases} \tag{1}$$

The total vote of sensor v_i is the sum of the votes from all its neighbors.

$$vote(v_i) = \sum_{d_{ij} \le R} v(v_i, v_j) \tag{2}$$

Then, in the second step, each sensor selects one of its neighbors with the most votes as the cluster head and then sends a message CHS (Cluster Head Select) to it. If the node receiving the message CHS is not a member on any cluster, its probability of selection increases, otherwise it decreases. In the proposed algorithm, the following points, too, should be taken into consideration;

1) If a node does not have a neighbor, it declares itself as the head.
2) If a node receives a message CHS from one of its neighbors and is not already another cluster member, it will declare itself as the cluster head, but if it is a member of another cluster or has been already selected as the head, it ignores the received message CHS.
3) If the node A selects the node B as the head, and does not receive any reply for the message CHS (due to failure or lack of energy), the probability of selecting the node B as the head deceases.

B. *Steady-state phase*

This phase consists of three steps; creation of clusters, forwarding to the head, and forwarding to the sink. Since we have distributed our cluster heads evenly in the previous phase, now it is time to create the clusters. Each head can take as its members the sensors that are in the radius less than the radio radius. Then it can schedule the time slot TDMA for each cluster member in each round.

In this phase, every node will switch on the receiver in the same manner as in LEACH. Then, the cluster-head will broadcast an advertisement containing the TDMA time slot information. Each cluster member will know its respective time slot. Thus, the cluster member will keep the transceiver off during its time slot. It transmits the sensing data to the cluster-head during its time slot. In addition, it transmits the value of its remaining power. The cluster-head maintains a table which records the node with maximum power at current round. After it has forwarded the data to the sink, it selects the node with maximum remaining power as the cluster-head for the next round.

Forwarding to cluster head - Once the clusters are created and the TDMA schedule is fixed, the data transmission can start. It is assumed that the nodes always have data to transmit, and they send their sensed data and energy to the cluster-head during the allocated time slot. Depending on the signal strength of the cluster-head advertisements, the cluster nodes adjust their transmission energy dynamically. In this phase, only the cluster-head always turns on the transceiver. The cluster members only turn on the receiver during its allocated time slot.

Forwarding to sink - In our protocol, if there is a head to which the node A wants to send a packet, it will calculate the function D(X) of all other heads as hereunder:

$$D(x) = d_{A-x}^2 + d_{x-\sin k}^2 \tag{3}$$

Then the minimum of these will be picked and compared to the square of the distance from the head node A to the sink. Only if

$$Min(D(x)) \le d_{A-\sin k}^2 \tag{4}$$

The node that makes the function minimal (we name the node B) will be selected as intermediate node. Otherwise the node A will still transmit to the sink directly. When the packet arrives at node B, the above algorithm will be repeated to decide whether the node B should select an intermediate node or transmit to the sink directly. This process will be iterated till the packet reaches the sink [13].

IV. EXPERIMENTAL RESULTS

Metrics of "Energy dissipation in nodes"," Number of live nodes "and" the number of packets received by the sink "are considered to evaluate the suggested algorithm. Theories and parameters used in simulations are as follows:

- Simulation is done in an area of 100 x100 m^2.
- Sensor nodes are supposed static during the simulation process.
- The primal energy of each node is considered 3.0J.
- The sense cost of any event for each sensor node is supposed 0.001J.
- The sense radius for each sensor node is supposed 20m.
- The sense delay for each sensor node is supposed 0.1 second.
- The sending radius of aggregated data by each cluster head to the other cluster heads is supposed 100m.
- Each data size equals 36 bytes.
- The network topology is generated by using random uniform distribution [14].

As it is seen in the Fig. 3, at the beginning because of sufficient energy in the sensors the rate of sensor dissipation in both protocols is almost the same until the 200th second. But considering the fact that the rate of energy consumption has a direct relationship with receiving and forwarding distance, LEACH does not observe the distribution of the heads in the environment under consideration, and the cluster heads forward their data direct to the sink, this distance increases in the passage of time and dissipation of the sensors, and the cluster heads which are far from the sink lose their energy soon.

However, since ELCH forwards the data hierarchically, it decreases the gradient of sensor dissipation compared to LEACH. Of course, it should be noted that the sensors get lost with a high gradient in the final steps when the number of the sensors in the environment exceeds 15 active sensors.

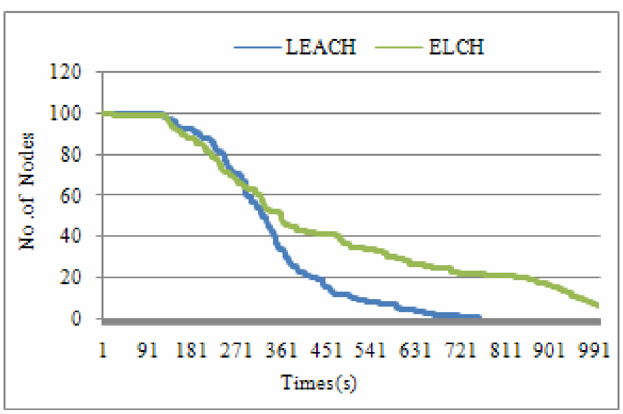

Figure 3. Number of live nodes with LEACH and ELCH protocols

The Fig. 4 shows another expression of the comparison between the lifetimes obtained in a network with 100 nodes for the proposed protocol in terms of the change in the number of each cluster. In this simulation, the primary energy of all the nodes is 3 j. as seen in the figure, the gradient of active sensor dissipation becomes less with an increase in the number of the members of each cluster, but if the number of the members of each cluster in the environment exceeds from a certain amount due to the parameters related to the topology of the network mentioned in the previous section, it will have a negative effect on the network operation for it causes multiple pressure on the heads of each cluster and increase in the energy consumption.

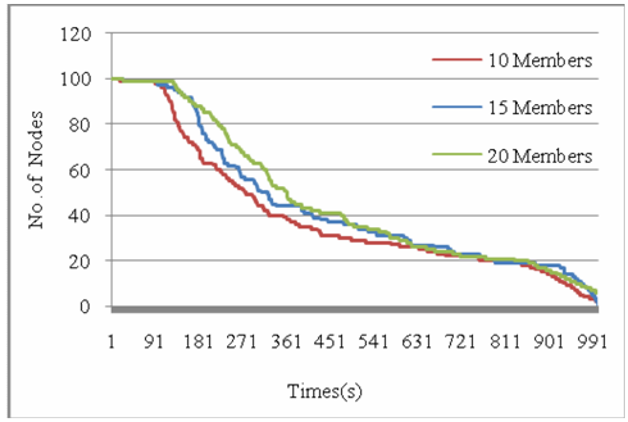

Figure 4. Number of live nodes with different cluster members in ELCH

The Fig. 5 demonstrates the results for the simulation of the energy dissipation for all the nodes. As a result of even distribution of the heads in the environment, the improvement of efficiency of this protocol in high density and the changes of density in the distribution of the heads in different geographical areas, the protocol ELCH balances the consumption of energy in all the nodes. Consequently, the energy dissipation of all the nodes will have the same gradient during simulation. However, the rate of energy consumption, contrary to the proposed protocol, decreases very much at the times when the rate of the remaining energy of all the nodes reaches the quarter of its primary amount because the number of the cluster members is different in the protocol LEACH.

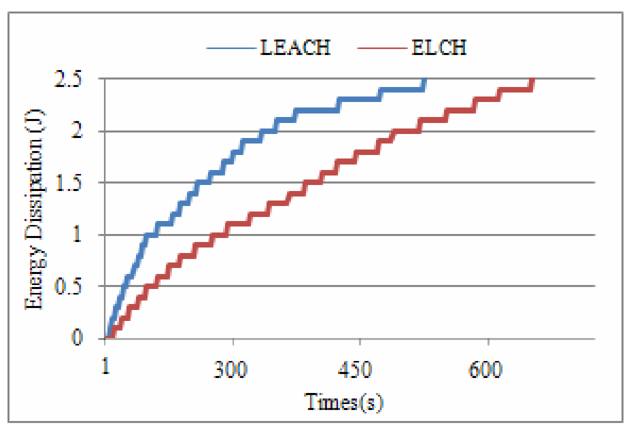

Figure 5. Energy dissipation with LEACH and ELCH protocols

The Fig. 6 compares the LEACH and ELCH algorithms in terms of the number of the packets received by the main node gathering the data (sink) in the four conducted experiments with different parameters (number of members on each cluster, dimensions of simulation environment, number of sensors and primary energy). It is seen that the number of the packets received by the main node gathering data is more in the network using the proposed algorithm for clustering than in the networks using other algorithms. The reason lies in the equilibrium of the energy consumption in the network that uses ELCH for clustering.

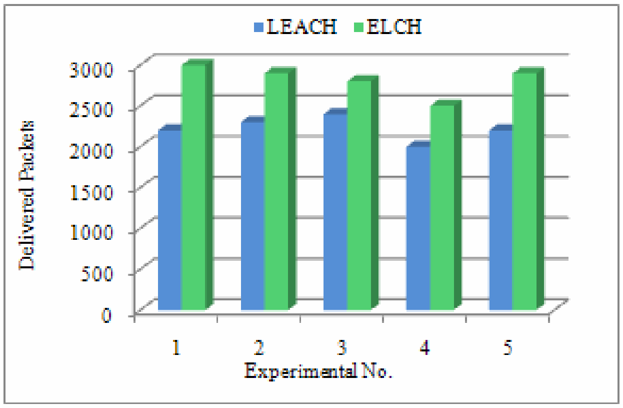

Figure 6. Comparison of LEACH & ELCH protocols in terms of the number of packets received by the sink

V. CONCLUSION AND FUTURE WORK

In this paper, we have presented a novel hybrid network protocol for WSN and compared it to the LEACH protocol. ELCH outdoes LEACH by a more balanced cluster distribution and by reducing the non-uniform cluster topology. The results from our simulations show that our protocol provides better efficiency for energy efficiency and network lifetime.

In the distributed algorithms, since each node decides how to carry out clustering with consideration of a series of local data, it is possible that the set of these local decisions do not ultimately lead to the equal distribution of energy consumption among the heads. This is one of the factors limiting the lifetime of the networks which use this kind of algorithms for routing, whereas in the centralized algorithms the sink gathers all the data required for the routing algorithms from the network surface and determines appropriate route to forward the data with an overall perspective to the whole network structure and limitations of each node; therefore, it causes the energy consumption to be distributed more evenly among the heads compared to other groups.

Thus, one of the future works can be to change the routing phase from the distributed status to the centralized one. Our proposed algorithm improves the reported methods by using even distribution of the heads and balancing the clusters. The proposed algorithms employ the radio domain to create a cluster in a certain environment and improve the head's distance of communications with the main station through a hierarchical tree. We do our best to solve the problem of simultaneous data forwarded by the nodes. Creating thousands of nodes and forwarding data simultaneously is difficult. One of the solutions is to use CDMA instead of TDMA at the level Mac. Another is to recognize optimal parameters. It is important to find optimal parameters such as number of members on one cluster and the radio domain for ELCH.

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