LEACH-1R: Enhancing The LEACH Protocol Using The First Round Clusters

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***Abstract*—Wireless sensor networks (WSNs) gained a lot of attraction two decades ago due to their ease of deployment in many fields such as forests and battle fields. Although these networks resemble ad hoc networks, the routing protocols of the latter were not very amenable to sensor networks because of the energy limit constraint in sensors. The LEACH clustering protocol was proposed to save more energy when aggregating data. A big advantage of LEACH is its capability of performing clustering without the need of a position system to locate sensors. Yet, plenty of research papers showed several weakness of LEACH in terms of unbalanced clustering, non-centrality of cluster-heads, and thus wasting sensors energy. In this paper, we present the LEACH-1R which modifies LEACH by using only the first round of clustering and perform inter-cluster selection of new cluster heads instead of overall re-clustering. Experimental results show higher stability of LEACH-1R in terms of creating clusters. Moreover, LEACH-1R made the network survives for a period almost as twice as LEACH with stable transmission of packets to the base station.**

Wireless sensor network; sensor clustering; cluster heads; LEACH protocol; energy saving; inter-cluster selection.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are considered to be one of the potential emerging computing technologies, edging closer towards widespread feasibility [1]. Cheap and smart sensors networked through wireless communication with the Internet hold remarkable prospects for controlling and monitoring environment, homes, health care, military, and other strategic applications. The original motivation behind the research into WSNs was military application. Examples of military sensor networks include large-scale acoustic ocean surveillance systems for the detection of submarines, self-organized and randomly deployed WSNs for battlefield surveillance and attaching micro sensors to weapons for stockpile surveillance [2]. As the costs for sensor nodes and communication networks have been reduced, many other potential applications including those for civilian purposes have emerged.

Sensor nodes are usually powered by small batteries where replacing or recharging these batteries is often not feasible [3][4]. Therefore, in many cases, the lifetime of a sensor network is over as soon as the battery power in critical node(s) is depleted [5]. Therefore, many protocols were proposed to reduce the energy consumption throughout the whole network and, as a result, extend the network lifetime. Some of these protocols depend on reduction of communication overhead over long paths through using multi-hopping from the source node to the base station [6][7]. Other protocols suggested improvements through routing algorithms [4] [5] [8]. One of the most important algorithms that were suggested in the field of WSNs is the LEACH algorithm [9], which introduced an innovative implementation of clustering, aggregation, and dynamic scheduling. Despite these capabilities of LEACH, it still has a weakness directed toward the selection of the optimal number of CHs.

At each round, a number of sensor nodes is elected to act as cluster heads (CHs). Each non-CH node is associated to a CH thereby forming the clusters. After that, each node senses the environment and measures physical phenomenon of interest (e.g., temperature, pressure, smoke, humidity). Each node then aggregates and transmits its measurements and information to its associated CH. The CH compresses this data in a single signal and transmits it to the BS (sink).

The primary objective of this article is to present a new clustering mechanism based on the LEACH strategy, yet enhancing the lifetime of sensors. We will show that the first rounds in LEACH are the most balanced in terms of CHs selection. Therefore, only the first round will be considered as an initial cluster forming, and then independently select new CHs inside each cluster.

The rest of this paper is organized as follows. In Section 2 we present a general overview of wireless sensor networks (WSNs) and some sensors clustering methods. Our mechanism of enhancing the lifetime of a WSN based on LEACH is introduced in Section 3 with details of the proposed method phases. In Section 4 simulation results are presented along with some interpretation and analysis. Section 5 is the conclusion.

II. RELATED WORK: WIRELESS SENSOR NETWORKS CLUSTERING PROTOCOLS

Power aware routing protocol [10] in wireless networks relies on utilizing routes that have high energy nodes in its path but are longer to reach the base station than the route that have shorter paths and low energy nodes respectively. This is done to minimize the overall energy of the network. In the cluster-based approach, only some of the nodes in the network are allowed to transmit and receive information from the base station, which is located at a large distance from the sensor nodes [11]. The key issue here is that, this allows sensor nodes to sense and transmit the information to the CHs directly, instead of routing it through its immediate neighbors. Also, since communication energy is proportional to the square of the distance, having all nodes to transmit its sensed data individually to the base station, exhausts the energy of each node drastically and hence the life time operation of the network gets significantly reduced. As a consequence it does not serve the purpose with which WSNs are designed for, namely network should be operational for a long period of time.

CHs collect the data sent by each node in that cluster, compressing it and then transmitting the aggregated data to the base station for further processing. Comparative analyses of the performance of the two approaches have been made in [12]. A multi-hop tree based approach is considered inefficient for routing in WSN considering the global distribution of nodes as shown in [13].

A. The LEACH Protocol

LEACH (Low Energy Adaptive Clustering Hierarchy) is a popular and significant communication protocol that helps the nodes to minimize the overall energy dissipation in the network using clustering [11]. It is the first significant protocol for the minimization of the overall energy in this type of network.

LEACH organizes nodes into clusters with one or multiple nodes from each cluster acting as a CH. The aim of the protocol is to randomize the CH election in each round so that the energy among the sensor nodes becomes evenly distributed. In this approach, the base station is assumed to be fixed and all the nodes are assumed to be energy constrained in nature.

The motivation of LEACH came from the MIT's AMPS project - the fact that communication energy between sensor nodes and base station is expensive and thus it is infeasible for the sensor nodes to sense and gather data and send them to the base stations individually in a single hop, which is a high power operation. Moreover, if CH selection is static, the nodes selected as CHs will quickly drain out its limited power and die quickly. Apart from selecting the CH, priorities were given to data aggregation and data fusion methodologies. Data fusion combines different data measurements and then reduces the uncorrelated noise to provide a more accurate signal. The randomized rotation of nodes that is necessary to be CHs, for even distribution of energy consumption over all nodes in the network is the main characteristic of this algorithm.

As shown in Fig. 1, LEACH operation is broken into rounds, having a set-up phase and a steady-state phase. In the beginning of the set-up phase, each node probabilistically decides whether or not to be a CH.

After electing itself as a CH, the node broadcasts an advertisement message announcing its intention to the rest of the nodes, using CSMA-MAC (Carrier Sense Multiple Access-Medium Access Control) protocol [14]; all the CHs broadcast using the same transmit energy. Each non CH node thus receives advertisements from the CHs and selects the cluster to join based on the largest received signal strength of the advertisement. This implies that minimum amount of transmission energy is needed for communication with the selected CH. Nodes inform the CH of the cluster they intend to join, using the CSMA-MAC protocol. Each CH then assigns a TDMA (Time Division Multiple Access) schedule for the nodes in the cluster, for sending sensed data. The TDMA slots are being calculated based on the number of nodes present in the cluster and are then broadcasted back to the cluster nodes.

B. Problem of Cluster-Head Selection

Clustering helps the nodes to minimize the overall energy dissipation in the network by allowing only some nodes to take part in the transmission to the base station. Moreover it also helps to reuse the bandwidth and thus utilizes better resource allocation and improved power control. LEACH (Low Energy Adaptive Clustering Hierarchy) is a popular current approach for CH selection and has formed the basis for many other approaches [3] [1] [5]. Algorithms like LEACH use only the local information in the nodes to select CHs stochastically. But this method of selecting CHs using only local information has its own limitations. Since each node probabilistically decides whether or not to become the CH, there might be cases when two CHs are selected in close vicinity of each other. Moreover, the node selected can be located near the edges of the network, in which the other nodes will expend more energy to transmit data to that CH.

In fact considering only one factor, like energy, is not suitable to elect the CH properly. This is because other conditions like centrality of the nodes with respect to the entire cluster, also gives a measure of the energy dissipation during transmission for all nodes. The more central the node is to a cluster, the more is the energy efficiency for other nodes to transmit through that selected node. The concentration of the nodes in a given region also affects in some way for proper CH election. It is more reasonable to select a CH in a region, where the node concentration is high.

C. Problem of Clusterheads Growth

In order to become a CH in LEACH (Fig. 1), each node n_i chooses a random number between 0 and 1. If the number is less than a threshold $T(n_i)$, the node becomes the CH for the current round. The threshold is set at based on the CH probability P, the the current round r, and the set of nodes that have not been CHs in the last $\frac{1}{P}$ rounds (G). Thus, after $\frac{1}{P} - 1$ rounds $T(n_i)$ =1 for all nodes that have not been a CH.

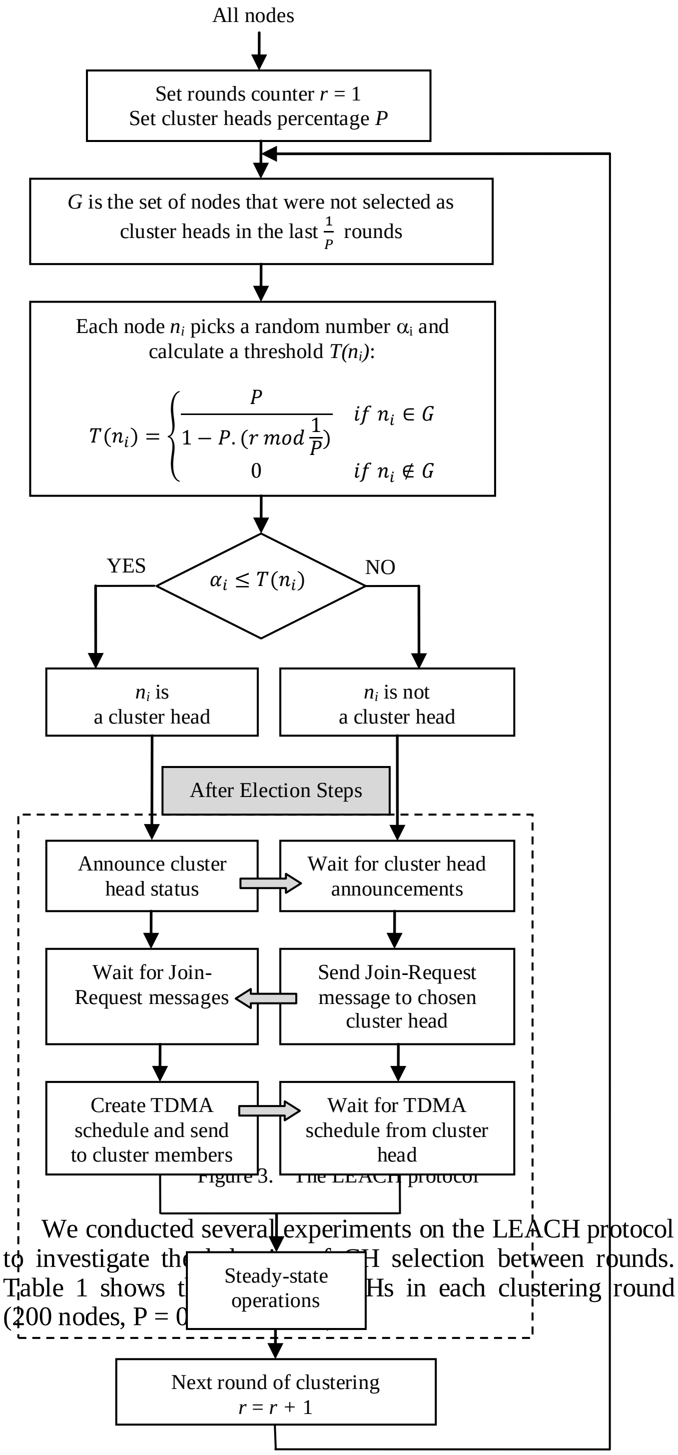


Figure 3. The LEACH protocol

We conducted several experiments on the LEACH protocol to investigate the ... CH selection between rounds. Table 1 shows t... CHs in each clustering round (200 nodes, P = 0...

TABLE I. CLUSTER-HEAD SELECTION THROUGH 90 ROUNDS

Rounds	+0	+10	+20	+30	+40	+50	+60	+70	+80
1	19	0	0	0	0	0	0	0	0
2	23	5	0	0	0	0	0	0	0
3	17	7	0	0	0	0	0	0	0
4	14	2	2	0	0	0	0	0	0
5	25	9	5	1	0	0	0	0	0
6	17	19	9	2	0	0	0	0	0
7	21	31	12	9	2	1	1	0	0
8	16	24	25	17	6	4	1	0	0
9	25	40	46	35	20	8	4	2	0
10	23	63	101	136	172	187	192	194	196

Table 1 shows that the CH percentage P (10%) was more or less respected in the first 10 rounds (first $\frac{1}{P}$ rounds). Since LEACH bans any CH node to be selected in the next $\frac{1}{P}$ rounds, and since all class0 rounds (rounds r where $r \bmod \frac{1}{P} = 0$) accepts any node not selected in the last $\frac{1}{P}$ rounds, the protocol unfortunately forces the nodes to be selected only in class0 rounds. Table 1 shows clearly the class0 rounds (rounds 10, 20, …, 90) attracts more and more CHs until it drains all the nodes making them CHs in late rounds (round 90).

III. OUR APPROACH: ONE ROUND LEACH (LEACH-1R)

In order to achieve our goal of enhancing the WSNs clustering, we need to perform more control of the clustering process, i.e., detecting CHs and their members. In fact, such operation is based on two phases. In the first phase (Fig. 2 (a)), CHs are selected upon the first round of LEACH mechanism. In fact, we can use any of the first $\frac{1}{P}$ rounds since the percentage P is more or less respected. In the second phase (Fig. 2 (b), the clusters are preserved and a new CH is selected only if the current one ran out of energy, i.e., the battery level beyond certain threshold). In this case, a new CH is selected among the cluster members only taking in consideration the strength of the last received signal.

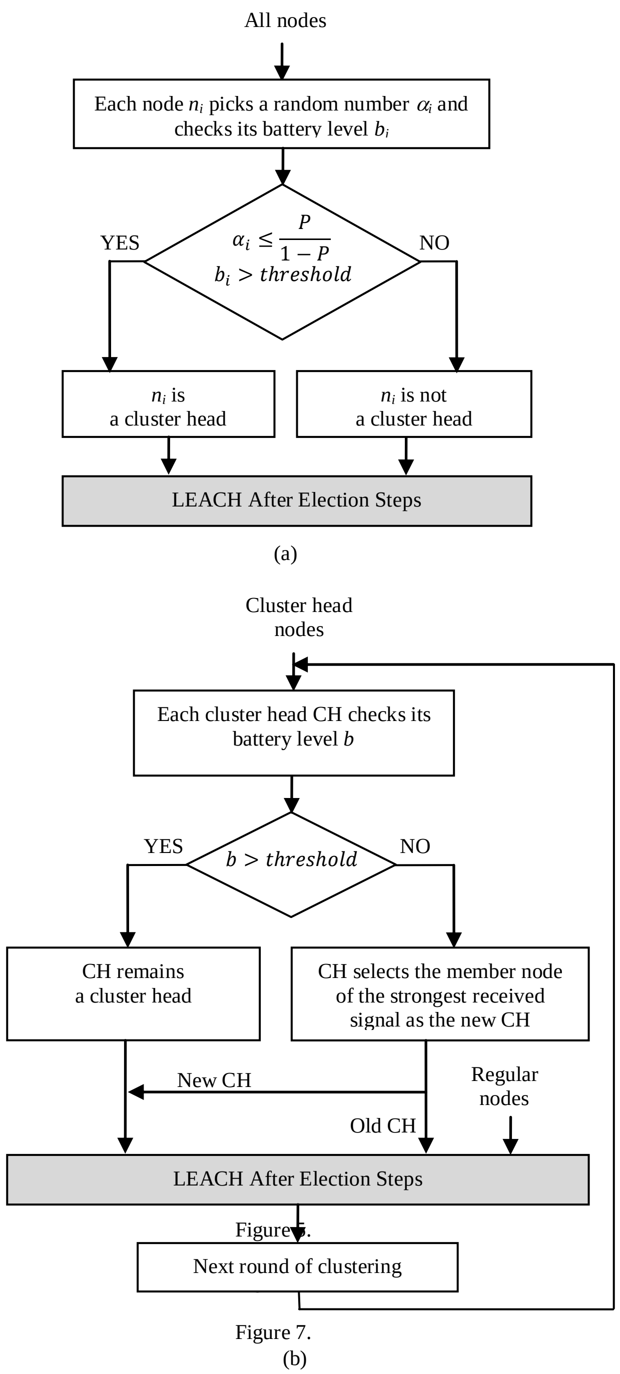


Figure 8. The LEACH-1R protocol: (a) first clustering round (b) other rounds

IV. SIMULATIONS AND RESULTS

Through several experiments, we analyzed the performance of LEACH and LEACH-1R via conducted simulations using MATLAB. Since energy conservation is the primary objective of our work, performance metrics such as network lifetime, energy consumed per round, and the residual energy level of sensor nodes are of particular interest.

A. Network Configuration

In our analysis, we use the same radio model as in [3]. In order to transmit k bits through a distance d the required transmission dissipated energy E_{Tx} and reception dissipation energy E_{Rx} are obtained as follows:

$$E_{Tx}(k,d) = \begin{cases} E_{elec} * k + E_{fs} * k * d^2 & d \leq d_0 \\ E_{elec} * k + E_{mp} * k * d^4 & d > d_0 \end{cases} \quad (1)$$

$$E_{Rx}(k,d) = E_{elec} * k \quad (2)$$

Where:

E_{elec}: per bit energy dissipations for transmission and reception.

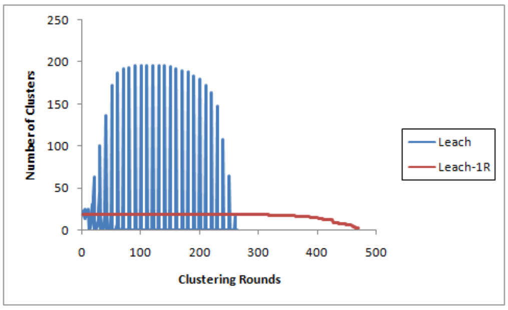
E_{fs}: the fading space energy required by the transmission amplifier to maintain an acceptable signal-to-noise ratio in order to transfer data messages reliably when the distance is below certain threshold distance d_0.

E_{mp}: the multi path energy required by the transmission amplifier to maintain an acceptable signal-to-noise ratio in order to transfer data messages reliably when the distance exceeds the d_0 threshold.

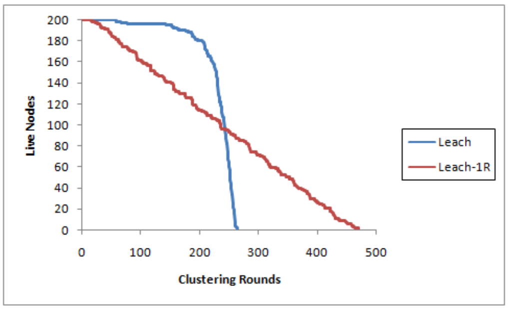
In our simulation, we used a network operation model as shown in Table 2. The reference network consists of 200 nodes randomly distributed over an area of 100x100 meters with an initial energy of 0.1 Joule. The base station is located at the coordinate 50, 50.

TABLE II. SIMULATION PARAMETERS

Parameters	Values
Zone Height	100 meters
Zone Width	100 meters
Number of Sensors	200 nodes
Base Station Position	50, 50
Cluster Head Percentage (P)	0.1
Initial Energy (E_0)	0.1 Joule
Transmission Energy (E_{elec})	50 nJoule/bit
Propagation Energy (fading space E_{fs})	10 pJoule/bit/m^2
Propagation Energy (multi path E_{mp})	0.0013 pJoule/bit/m^4
Data Aggregation Energy (E_{da})	5 pJoule/bit/signal
Threshold distance (d_0)	10 meters
Packet Size	500 bytes
Packets per Round	1



(a)



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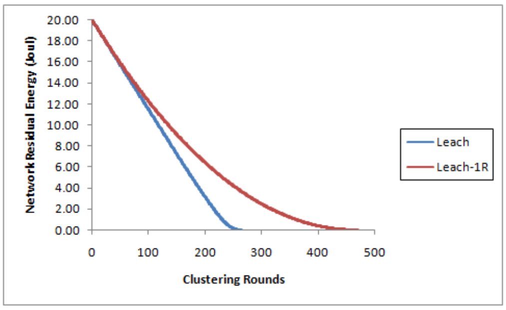

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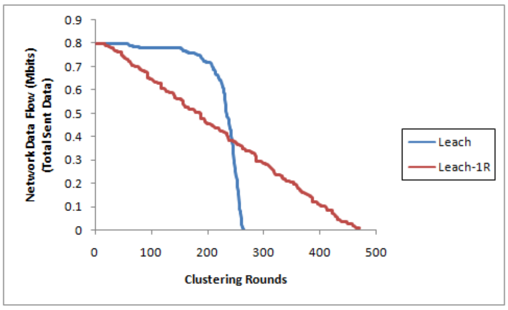

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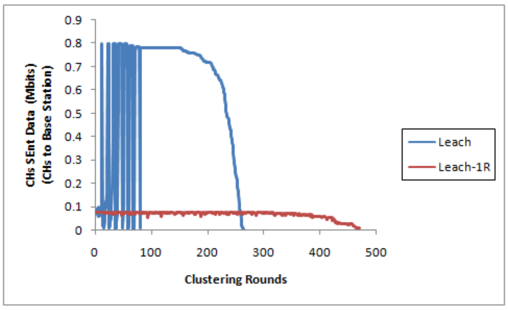

(e)

Figure 3. Experimentation Results

B. Results and Analysis

Fig. 3(a) shows the number of clusters through clustering rounds. It is clearly seen that LEACH-1R was very stable since it maintains a steady level of 19 clusters and then decreases slowly when nodes ran out of energy. Whereas, LEACH quickly jumped between low and high numbers of clusters wasting lot of energy in the steady operation phase.

Fig. 3(b) shows the number of live nodes through clustering rounds. Although LEACH kept almost all nodes alive in the first 100 rounds, a free fall took place between rounds 200 and 274. On the other hand, LEACH-1R maintained a gradual decrease of live nodes.

Fig. 3 (c) shows the total residual energy of the sensors. In fact, both LEACH and LEACH-1R showed a gradual decrease of energy, yet with LEACH-1R the network survived until round 470, i.e., almost as twice as LEACH.

Fig. 3 (d) shows the entire data flow of the network, i.e., data sent from sensors to CHs and from CHs to base station. LEACH showed a high data flow in the network in the first rounds before nodes ran out. On the contrary, LEACH-1R succeeded to maintained a proportional data flow vis-à-vis the current live nodes.

Fig. 3 (e) shows the aggregated data sent to the base station. The figure show a high oscillation in LEACH before it reaches the state where all nodes are CHs. On the other hand, LEACH-1R maintained a fixed amount of data during most of the network lifetime.

V. CONCLUSION

In this paper, we presented a modified version of the sensor network clustering protocol LEACH. The idea was to use the first round of LEACH as a basis for clustering instead of re-clustering, aiming to achieve a better clustering stability and thus saving network energy.

Simulation results were presented to demonstrate the performance of the LEACH-1R over LEACH and its effects on energy conservation and network lifetime. We used residual energy and live node parameters per round to evaluate the behavior of LEACH-1R and LEACH. Simulation experiments were conducted using many different values of initial energy and number of nodes. Our experiments showed that LEACH-1R achieves significant energy savings and enhances network lifetime compared to LEACH protocol. Moreover, LEACH-1R showed a better distribution of clusters formation over different clustering rounds.

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