Paper

Residual Energy-Aware Clustering Transformation for LEACH Protocol

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Abstract—Energy is one of the crucial performance parameters in wireless sensor networks (WSNs). Enhancement of network lifetime is an important consideration as well. Low energy-aware clustering hierarchy (LEACH) is one of the protocols proposed for WSNs. In this paper, a residual energy-aware clustering transformation protocol for LEACH (REACT-LEACH), enhancing performance of LEACH by introducing a clustering mechanism, is proposed. The proposed cluster head (CH) rotation and cluster reformation processes are more effective in REACT-LEACH, as residual energy is considered to be one of the metrics. Performance of REACT-LEACH is validated based on simulations.

Keywords—clusters formation, cluster head, residual energy, wireless sensor network.

1. Introduction

Wireless sensor networks (WSNs) have been attracting special interest from the research community in recent years due to their applicability in almost all fields of research. As the nodes of WSNs are battery-powered, effective utilization of energy available in these networks is a primary goal that needs to be achieved in order to ensure long network lifetime. Since frequent recharging or replacement of batteries is infeasible in some WSN applications, energy efficiency has to be assured through proper protocol design [1], [2]. Routing is a process of establishing a path from the source node to the sink. Optimal route selection depends also on the placement of nodes within WSNs. If the nodes are deployed densely, the chance of establishing alternative paths reaching the destination is higher. Thus, better energy efficiency is assured. On the contrary, if the nodes are deployed sparsely, the number of alternate paths leading to the destination will be lower, which limits the options of selecting the most energy efficient path. It also needs to be borne in mind that nodes located close to the base station (BS) are usually generally overloaded compared with other nodes in the network [3].

Cluster-based protocols have proved to offer better energy efficiency. However, cluster reformation process drains batteries. The scenario is even less favorable when the nodes are mobile, as this means that frequent topology changes are encountered. Most protocols consider reforming all clusters whenever the residual energy of any of the cluster heads (CHs) falls below the threshold value. In this paper, the REACT-LEACH protocol is proposed, relying on rotating the CH within the cluster, without actually modifying the existing cluster. The reformation of the cluster is performed only when the nodes are out of the communication range.

The paper is organized as follows. Section 2 presents the literature review. Section 3 describes the LEACH protocol. Section 4 gives an insight into the proposed REACT-LEACH protocol. Section 5 presents the results and an analysis thereof, while Section 6 concludes the paper.

2. Related Work

To overcome problems with energy, different routing protocols have been proposed by researchers [4]. For example, paper [1] proposes an energy efficient direction-based PDORP routing protocol for WSNs, where the fixed cooperative-based clustering approach is used. This protocol is designed for fixed WSNs. A comparison with LEACH is made and the protocol proves to behave well in homogeneous distributed clustering. Selection of the CH is an issue of key importance in the clustering algorithm.

The authors of [5] present a survey concerned with routing protocols for wireless sensor networks. They showcase, inter alia, a delay aware routing protocol. In this case, sensor nodes are homogeneous and static in nature with very limited mobility. This protocol is designed to manage neighboring nodes. Each node maintains a forwarding table to select an efficient path for transmitting data between the node and the BS. If the node is within BS range, data is transferred directly. Else, multi-hop communication takes place.

In article [6], the position responsive routing protocol (PRRP) is presented, showcasing a novel approach to CH selection. Here, the nodes are distributed in the form of a grid – and approach that is required in such applications as disaster management, forest fire surveillance systems, etc. Energy consumption is directly proportional to the communication distance. Each processing round consists of four phases.

In the energy-aware routing protocol [7], energy optimization is performed by relying on hybrid algorithms, i.e. the dynamic source routing (DSR) protocol is used and is found to be more suitable in terms of low energy density. The goal is to identify dead nodes and choose a different path suitable for the transmission.

Article [8] introduces LEACH, an application-specific protocol architecture for wireless micro-sensor networks. The mathematical formulas of all the probabilities that are considered for the process of cluster formation and CH selection in the LEACH protocol are clearly presented in this paper.

3. LEACH Protocol

The LEACH protocol aims to form clusters in a network based on such parameters as the level of the radio signal received, the number of times the node has been a CH, and the average network energy level. In fact, LEACH incorporates an algorithm which is distributed and each node decides, autonomously, whether to become a CH or not depending on a random value. This value is a probability and covers many parameters, such as distance of the node from BS, the number of times the node has been a CH, residual energy, etc. This randomly chosen value is compared with a defined threshold. If the chosen value is below the threshold, then the node becomes a CH. Figure 1 shows communication between the nodes and BS during the cluster formation process.

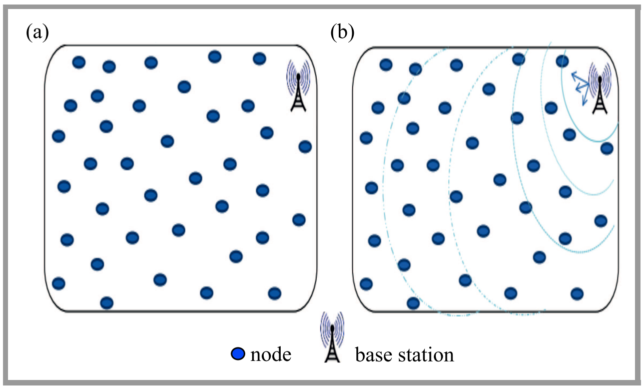

Fig. 1. Distribution of nodes (a) and nodes communicating with BS for CH selection process (b).

Once the CHs are formed, they broadcast "hello" messages. The CH nodes may receive hello messages from more than one CH. If such messages are received, they decide to join the appropriate cluster based on their distance from the respective CH. This process is as shown in Fig. 2. The algorithm runs multiple times, and different nodes assume the role of CHs in each round. The threshold value is calculated in each round using the following formula [9]:

$$T_n = \frac{p}{1 - P \cdot \left(r \bmod \frac{1}{p}\right)}, \qquad (1)$$

where T_n is the threshold value for n rounds, P is the percentage of CHs in the network, r is the current round number, and G stands for the set of nodes that were not acting as CHs in the $(\frac{1}{p})$ preceding rounds.

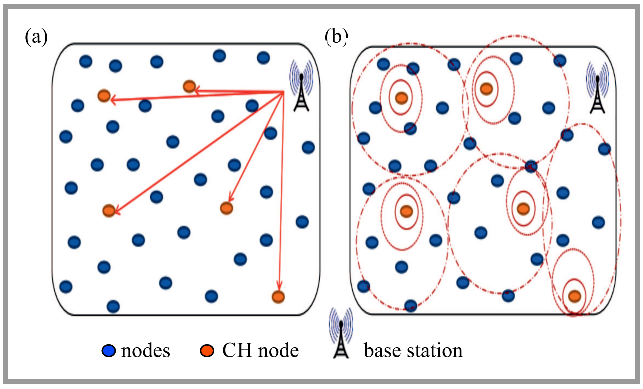

Fig. 2. CH selection (a) and advertisement from a CH to nearby nodes to form a cluster (b).

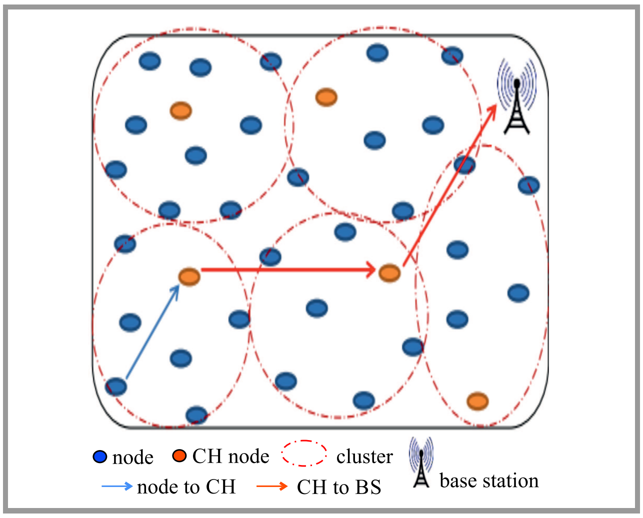

Fig. 3. Communication between nodes and BS through CH.

Data sent from any node to BS passes through the CHs. Cluster members convey the information to the respective CHs, and the CHs then communicate with the BS. The process is shown in Fig. 3, where the control flow is indicated. Various improvements to LEACH protocol have been proposed by researchers, making it more suitable for specific applications [10]. The following aspects may be addressed to ensure further performance enhancements:

- a node that is located farther away from the CH dies faster when compared to a node located close by,
- CH selection is not dependent on the residual energy and is a random process,

- energy losses are incurred during the reformation of clusters and CHs, in each round,
- there is chance of having a maximum number of CHs concentrated in one part of the network, which leads to some nodes not having any CHs in their vicinity,
- the routing table must be updated for each round,
- selection of an efficient path to the BS from every CH should be performed in each round.

Based on those potential areas of development, a decent number of variants of the LEACH protocol has been proposed in the literature [11]. In most of them, the criterion for the rotation of CHs was addressed better, with the residual energy of nodes taken into consideration [12], [13].

4. Residual Energy-Aware Clustering Transformation for LEACH

As discussed in Section 3, CH reformation taking place in LEACH is incorporated in each round. This process requires a lot of control packet exchanges and, thus, is energy-intensive. The proposed REACT-LEACH approach may be a good solution to overcome this obstacle. REACT-LEACH also operates in rounds with the initial round being exactly the same as in LEACH [14]. The initial cluster formation and CH selection procedures are depicted in Figs. 1–3. During the first round, REACT- LEACH is similar to the LEACH protocol, but later on the new algorithm depends purely on the residual energy of the current CHs for their reselection and for the cluster reformation process.

In REACT-LEACH, the process of CH reselection and cluster reformation depends on residual energy and distance. Once CHs have been selected, clusters are set based on the distance between the nodes and CH. Next, the nodes within the cluster transfer data to the respective CHs the CHs transfer the same to the BS – meaning that the process is similar to that relied upon in LEACH. The CH reselection and cluster reformation process is only performed if:

1. residual energy of the current CH falls below the threshold value,
2. the CH has moved far away from the within its cluster,
3. the nodes have moved far away from their CH.

In scenario 1, the CH collects residual energy data from all its cluster members [15]. The node with the maximum residual energy level is selected to be the new CH. The newly appointed CH reforms the cluster based on its communication range. The new CH broadcasts an advertisement packet within its transmission range.

In scenario 2, due to mobility-related considerations, there may be a chance that the CH moves away from the cluster members. When the CH moves away from any nodes, then the distance ones attempt to connect to their nearby clusters by sending a request message to the respective CHs. This process occurs in each round, thus no node is left out within the network.

During the selection of a new CH within the cluster, the current CH should collect residual energy data from all cluster nodes. This process is shown in Fig. 4. The control flow is indicated by arrows.

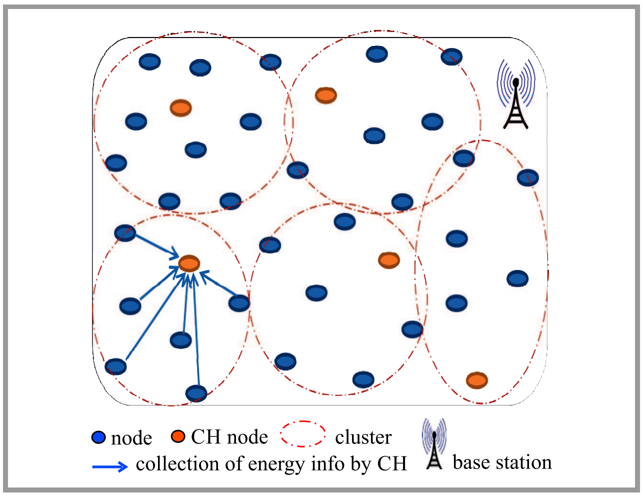

Fig. 4. Residual energy information flow from nodes to CH for new CH selection.

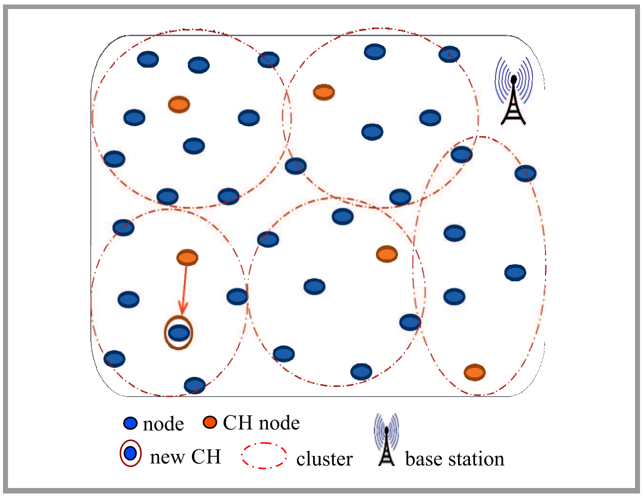

Fig. 5. New CH selection in REACT-LEACH.

The new CH is selected based on the highest residual energy level amongst the nodes within a given cluster. Then, the cluster will be reformed, with the location of the new CH taken into consideration, depending on the distance between cluster nodes. During this CH reselection process, only the nodes within the current clusters may become a CH. Nodes that are within the communication range of the new CH form a new cluster [16]. Any node that is left out during the reformation of clusters may have to join the nearest CH. This process is depicted in Fig. 5.

In scenario 3, similarly to scenario 2, mobility may lead to a node moving away from its cluster. The node that is left out of the cluster tries to communicate with the nearest CH and joins the respective cluster. Figure 6 shows a detailed flow of the REACT-LEACH protocol.

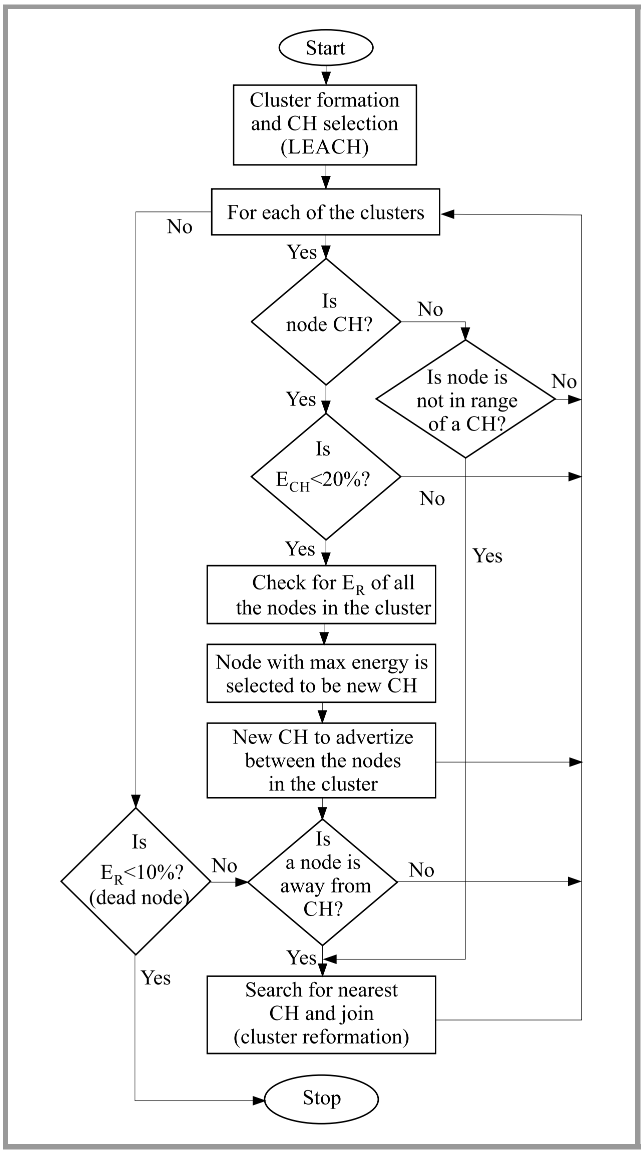

Fig. 6. Flow chart of REACT-LEACH.

5. Simulation Results and Analysis

Performance of the proposed REACT-LEACH approach is compared with the traditional LEACH protocol based on key performance parameters. Table 1 shows the parameters have been taken and the average values are considered to verify considered while validating performance using the NS-3 software simulator.

In this paper, performance of REACT-LEACH and LEACH protocols is compared through simulations. 5 trails were taken and the average values are considered to verify overall network performance levels.

Table 1
Parameters used in simulations

Simulation parameters	Specifications
Simulation environment	NS-3
Number of nodes	70
Antenna type	Omnidirectional
Network area	400 × 400 m
Deployment of nodes	Random
Simulation rounds	2000 rounds
Initial energy of nodes	0.5 J
Mobility pattern	Random

The comparison shown in Fig. 7 proves that the REACT-LEACH protocol is characterized by a constant number of CHs during the entire simulation cycle [17], [18]. Despite the fact that CHs change depending on residual energy levels, the total number of CHs remains constant. Once the number of CHs is selected by the random procedure in LEACH, it is maintained for all subsequent operations.

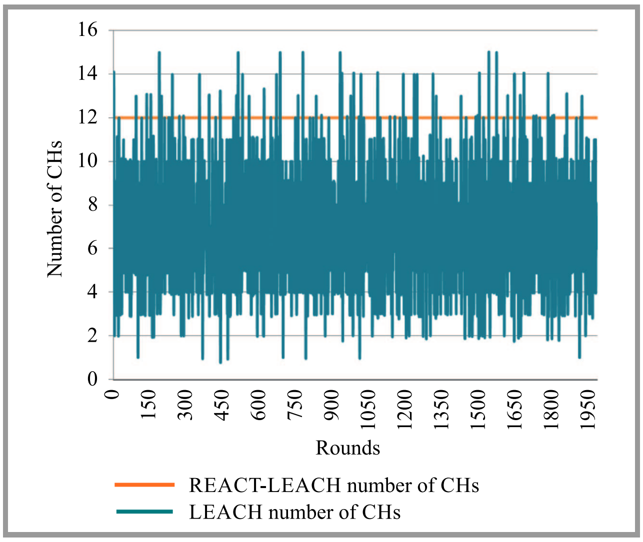

Fig. 7. Comparison of number of CHs that are selected in each round.

Table 2 compares performance of the proposed REACT-LEACH approach with the traditional LEACH protocol in terms of the average energy level at each node and the total energy within the network.

The average energy level of each node, after individual operation rounds, may be observed in Fig. 8. The REACT-LEACH approach seems to be more energy-efficient when compared to the LEACH protocol. The drainage of energy experienced during cluster formation in each round in LEACH is reduced in REACT-LEACH, because cluster reformation takes place only when there is a need. After completion of the simulation, the average percentage of residual energy in the network is found to equal 90% of the initial value in REACT-LEACH, whereas in LEACH it amounts to 28% only.

Table 2
Comparison of LEACH and REACT-LEACH

Round	REACT-LEACH				LEACH			
	Avg energy [J]	Total energy [J]	Number of CHs	Percent of CHs	Avg energy [J]	Total energy [J]	Number of CHs	Percent of CHs
1	0.999663	34.9882			0.999666	34.9883	13	0.19
200	0.989061	34.6171			0.928034	32.4812	4	0.06
400	0.978459	34.2461			0.856415	29.9745	7	0.10
600	0.967857	33.875			0.784272	27.4495	5	0.07
800	0.957255	33.5039	12	0.26	0.712611	24.9414	8	0.11
1000	0.946653	33.1329			0.641585	22.4555	8	0.11
1200	0.936051	32.7618			0.570115	19.954	6	0.09
1400	0.925449	32.3907			0.497864	17.4252	10	0.14
1600	0.914847	32.0196			0.426424	14.9248	6	0.09
1800	0.904028	31.641			0.354799	12.418	3	0.04
1999	0.893322	31.2663			0.283827	9.93396	6	0.09

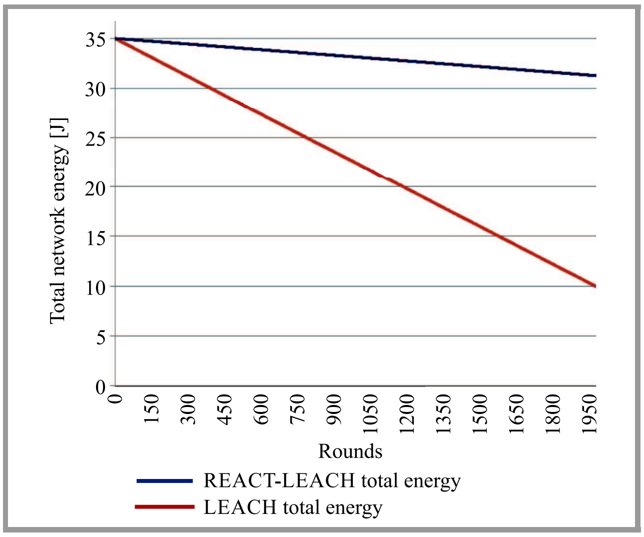

Fig. 8. Comparison of node energy levels [%].

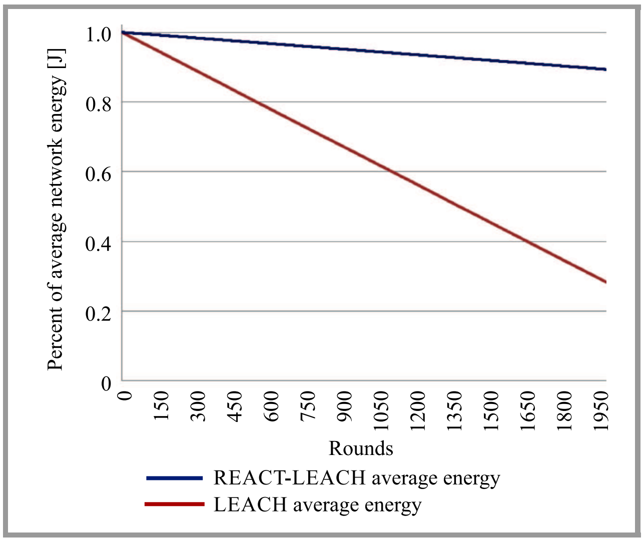

Fig. 9. Comparison of total energy of the network.

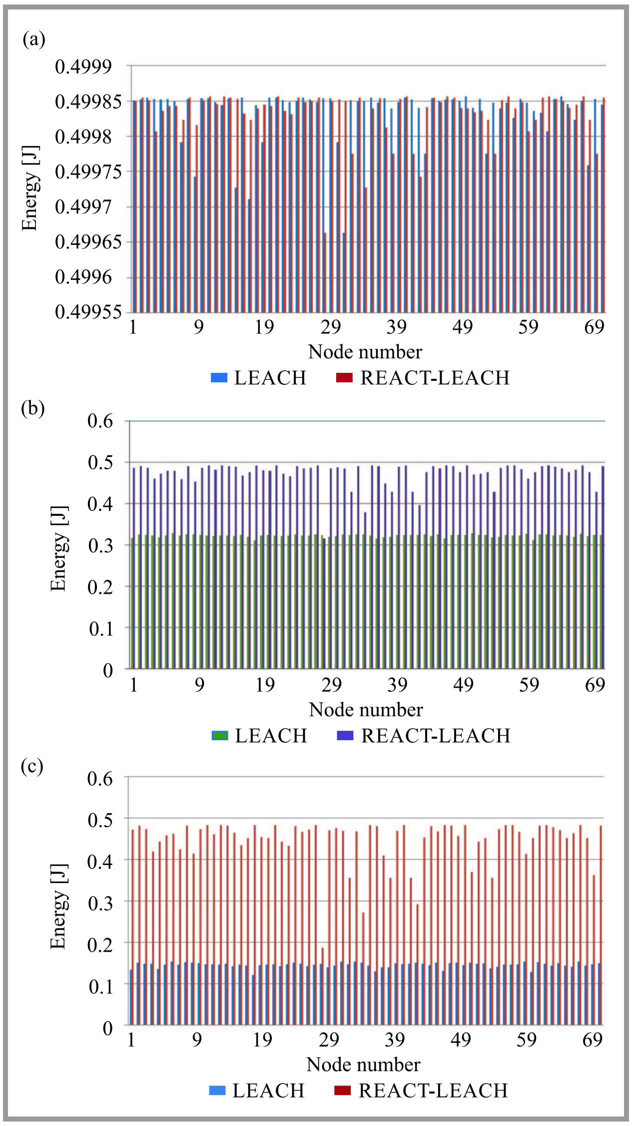

Fig. 10. Residual energy of each nodes after: (a) one round, (b) 1000 rounds, and (c) 2000 rounds.

The total energy consumed by the network (Fig. 9) is directly dependent on the nodes' energy and, thus, the total energy drain of the network is comparable to the graph shown in Fig. 8. Energy consumption in reduced significantly in REACT-LEACH.
Figure 10 shows the residual energy level of each node after different operation rounds. It is proved that the REACT-LEACH approach assures a better energy balance between all nodes, as each of the nodes serves as a CH at some point of time. The REACT-LEACH protocol ensures also that higher residual energy levels are maintained in all nodes, and thus leads to an enhancement in network lifetime.

6. Conclusion

The REACT-LEACH protocol offers better energy efficiency when compared with the well-known LEACH approach. The average residual energy at each node in REACT-LEACH is around 90% after 2000 rounds of simulation, versus 28% in the case of LEACH. This is mainly because of the fact that multiple cluster formation and CH selection processes have been completely eliminated in REACT-LEACH. In the proposed protocol, control-related communication required in cluster formation and CH selection processes occurs only when there is a need, instead of taking place in each round. Validation is performed based on simulations, with low mobility of the nodes considered.

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