A multi-hop routing protocol for an energy-efficient in wireless sensor network

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ABSTRACT

The low-energy adaptive clustering hierarchy (LEACH) protocol has been developed to be implemented in wireless sensor networks (WSNs) systems such as healthcare and military systems. LEACH protocol depends on clustering the employed sensors and electing one cluster head (CH) for each cluster. The CH nodes are changed periodically to evenly distribute the energy load among sensors. Updating the CH node requires electing different CH and re-clustering sensors. This process consumes sensors' energy due to sending and receiving many broadcast and unicast messages thus reduces the network lifetime, which is regarded as a significant issue in LEACH. This research develops a new approach based on modifying the LEACH protocol to minimize the need of updating the cluster head. The proposal aims to extend the WSN's lifetime by maintaining the sensor nodes' energy. The suggested approach has been evaluated and shown remarkable efficiency in comparison with basic LEACH protocol and not-clustered protocol in terms of extending network lifetime and reducing the required sent messages in the network reflected by 15%, and, in addition, reducing the need to reformatting the clusters frequently and saving network resources.

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1. INTRODUCTION

The advances in technologies, wireless communications, and wireless sensor networks (WSNs) facilitate the implementation of various applications in many sectors for instance military sensing, healthcare organizations, industry, traffic surveillance, target tracking, underwater acoustic sensor systems, and environment monitoring. WSNs and their technologies have attracted the attention of researchers due to the multiplicity and diversity of their application areas. The essential motivation for WSN development was military applications, especially battlefield surveillance [1], [2]. Additionally, WSN facilitates the development of healthcare systems that affects people's lives directly. Generally, WSNs include low-cost and small devices (sensors) that have limited capabilities of processing, sensing, and storing and they communicate wirelessly [1]. WSN consists of a group of wireless sensor nodes and a sink node named the base station (BS). Wireless sensor nodes are responsible for sensing, collecting data, and sending it to the base BS directly or indirectly, where this process is named data aggregation. The base station analyses the received data and eliminates redundancies. Then, BS transmits the analyzed data to a specified connected device, which may be located in a far area for decision-making. This process would result in a high communication overhead, that sensor nodes may be unable to tolerate [3].

Wireless sensor nodes suffer from extensive limitations for instance low memory, limited computational ability, and security issues. Limited power is a serious problem in sensor nodes, which directly affects network lifespan. In addition, application requirements influence energy consumption. Further, sensor nodes are sometimes used in hostile areas where recharging their batteries or changing them cannot be possible because it is inaccessible [4]. Thus, batteries play a significant role in WSN as it is controlling the network lifetime. In wireless networks, routing protocols with efficient energy consumption are vital because the process of data transmission consumes most of the energy. Many studies considered this issue and proposed many routing protocols with energy-efficient designs for WSNs. Some researchers introduced different approaches aiming to reduce energy consumption, where these approaches may implement in any layer for example physical layer [5], [6]. Routing protocols based on clusters got the researchers' attention because they consisted of two phases: the first is named the setup phase and the second is named the phase of steady state. The processes of the setup phase include dividing the WSN into groups of nodes called clusters and electing nodes in each cluster to be CH. The operations in the steady state phase include sensing and transmitting the sensed data by all node members in the cluster (except the CH nodes) to CH. The low-energy adaptive clustering hierarchy (LEACH) is a superior routing protocol in WSN, which has facilitated employing of WSN in various applications [7]. Figure 1 describes the LEACH protocol architecture. The sensor node is represented in circle shapes, squares are cluster-head sensors, and the light lines show the wireless connection between the nodes of BS and the CH.

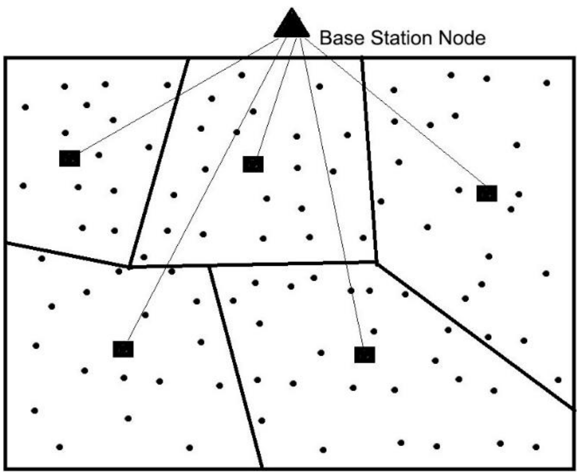

Figure 1. The architecture of LEACH protocol

LEACH protocol combined two energy-efficient concepts, which are media access and cluster-based routing. Although the LEACH protocol minimized energy consumption in sensor nodes and reduced the size of the routing table, this protocol still suffers from some limitations [8], [9]. For example, the process of becoming a cluster head relies on a random number between the range of 0 and 1 that is generated by sensor nodes. In addition, does not take the node's residual energy into consideration when selecting the CH. Thus, there are no restrictions on becoming cluster heads. However, the sensor energy efficiency is influenced by the number of times of becoming CH. Further, the distance that separates the CH and BS node affects the consumed energy to transmit a message. Therefore, consumed energy is increased when the distance that separates the CH and BS nodes is increased. Moreover, many broadcasting messages are sent in the cluster setup phase, which is repeated in each round (when required). Resulting in consuming more energy in clusters setup when electing new clusters head nodes [7], [8].

This research investigates the energy-consuming issues in WSNs. In addition. it proposes a new approach to routing protocol in WSN that depends on LEACH protocol and aims to increase the life span of WSN. The new proposal takes into consideration the node residual energy to become CH. It requires that the node contains a proper source of residual energy for instance solar energy to elect itself as CH. This approach guarantees to elect of CH nodes that have the best level of energy in WSN, thus reducing the demand to update the CH and prolonging the life of WSN, where the need for cluster reformatting in the setup phase will decrease, and this maintains the energy of all nodes in WSN.

This paper is arranged as follows. Recent related works are detailed in section 2. The network model of energy analysis is discussed in section 3. Section 4 declares the LEACH algorithm in detail. Losing energy in the LEACH algorithm is described in section 5. Section 6 introduces the proposed approach in detail. Results are explained and analyzed in section 7. At last, the conclusion is declared in the section.

2. RELATED WORK

Many studies and research have been proposed in this field aiming to improve the performance of WSN. Khan and Awan [10] developed a hybrid LEACH clustering algorithm based on implementing round phases for each cycle. Rather than implementing two stages as in the basic LEACH. The developed approach aims to increase network lifespan by saving the sensor's energy.

Jagan *et al.* [11] suggested a clustering mechanism to be implemented in LEACH that depends on the electrostatic discharge algorithm. It aims to establish the shortest routes between sensors and cluster heads. The suggested algorithm of electrostatic discharge extended network lifetime by saving sensors energy.

Radhika and Sivakumar [12] addressed issues of basic LEACH in WSNs, for instance, robust randomness and best local in the path enhancement. This research aims to enhance the LEACH protocol by developing an optimally combined weighting and improving the algorithm of ant colony optimization. Cheng *et al.* [13] proposed the genetic algorithm (GA)-LEACH routing protocol that aims to improve the process of CH selection in traditional LEACH. The routing protocol of GA-LEACH is based on both the micro genetic algorithm and the LEACH protocol. The proposed approach reduces the energy consumption of the network. The MATLAB tool is implemented to simulate the proposal and the results show an improvement in the network lifetime.

In [14], an enhanced energy-saving protocol named (IEE-LEACH) was suggested based on modifying the routing protocol in LEACH. It takes into consideration the available nodes' energy and network average energy. IEE-LEACH aims to specify the best selection of CH numbers, where the nodes inside the range of BS are forbidden from engaging the cluster that guarantees to save the WSN power. The experiments of the proposal were implemented using MATLAB 2014a.b.

Hosen and Cho [15] integrated the LEACH protocol with improvement on the threshold value obtained from the equation of selecting cluster heads. An algorithm is developed to choose the nearest CH by specifying the shortest path among the sensor node trees. The application of MATLAB is used to simulate the suggested protocol. The results revealed a reduction in dead sensor nodes and enhanced relatively the consumed energy by the sensor nodes.

Mostafaei [16] developed an algorithm that is based on distributed learning automata. This proposal concept is depending on selecting a proper node subset from the network. To extend the life cycle of the sensor node, each node was supervised by one or more active nodes to accomplish the global goal of the network, where each node knows that it is protected.

Darabkh [17] presented a modification on threshold calculation that is used in classical LEACH protocol. The proposed method was agreed fairly with the implemented approach in LEACH. A novel formula of threshold power is suggested, which aims to extend the life of the first node and bypass data loss. The VB.Net 4.5 class library *.dll* files are used to implement the simulation.

Mostafaei and Obaidat [18] proposed a new algorithm named greedy partial coverage (GPC). The GPC algorithm aims to maintain the connectivity of selected nodes based on using neighbor nodes and achieve the required coverage rate by using the overlap between nodes. This results in prolonging the life of the network.

Rao *et al.* [19] developed an algorithm for selecting cluster heads in LEACH protocol, which is depending on particle swarm optimization. In addition, proposing particle coding and fitness function to minimize the energy consumption in the optimization of particle swarm. The C programming was used to test the proposed algorithm.

Al-Baz and El-Sayed [20] developed node ranked–LEACH protocol, which aims to extend the life cycle of the network. In the proposal, the process of selecting the CH depended on both costs of the path and the link number that separated between nodes. In [21], a new modification to the LEACH protocol was introduced which is based on affinity propagation (AP). The proposal offers distributed control by fixing the issues of classic LEACH by facilitating functionalities of the network and minimizing the cost of sensor hardware.

Elshrkawey *et al*. [8] introduced an approach based on the LEACH protocol that aims to minimize energy consumption during network communications by increasing the power balancing among the implemented sensors in clusters. The suggested method is depended on the task of CH selection. In addition, a modification on the schedule of the time division multiple access (TDMA) is implemented to enhance the performance. MATLAB 2015 is used to simulate the proposal. The results show a little improvement, for example, in round 30, the number of dead nodes in the proposed approach is 46 nodes, while in LEACH, it is 60 nodes.

Kumar *et al.* [22] proposed a method based on modifying EACH that aims to load balancing in the clusters to extend network lifetime and throughput. MATLAB is used to simulate this proposal. The results show that the performance of the proposal is the same as the LEACH protocol when the numbers of rounds are small, whereas in round 1,600 the number of dead nodes in the proposal is less than in the LEACH protocol.

The aforementioned studies have introduced many investigations on the LEACH protocol to address its issues. Most of them present an optimization of the LEACH protocol from one perspective only. LEACH protocol suffers from many issues such as energy consumption, data volume, and network coverage. Cheng *et al*. [13] and Mostafaei and Obaidat [18] presented an optimization to the LEACH protocol by developing new approaches that consider minimizing energy consumption only. Mostafaei and Obaidat [16] and Sohn *et al*. [21] focused on optimizing the choice of CH node's location only, while disregarding many other issues of LEACH protocol, for instance, the coverage of the network.

This research is aiming amends and improves the protocol of LEACH from many perspectives such as minimizing the number of messages required to be sent, reducing reformatting the clusters frequently, and extending the network lifetime. Taking into consideration many aspects for instance the advances in a sensor node, recent technologies in providing energy (e.g., solar energy), and method of selecting cluster head. Experiments results reveal that the novel proposed protocol can effectively maintain the nodes' energy, decreasing the need of reformatting the clusters, and prolonging the lifetime of WSNs. Further, minimizing the required send messages, which results in saving network resources.

3. NETWORK MODEL OF ENERGY ANALYSIS

WSN is composed of many sensor nodes, which have some common features such as small size, and cheap price. The sensor nodes are employed to fully cover some physical phenomena via intercommunication among them. Many network operations are influenced by how the node is deployed in WSNs for instance routing, security, and energy [23]. The node deployment method mainly impacts the WSN lifetime. Sensor nodes located in the range of BS nodes consume energy more than other sensors. This is attributed to their role of forwarding the received packets to the BS node. The sensor nodes are deployed in the target field as required, where each sensor node is specified by its own unique ID that determines its location and its energy. The sensor node has the ability to approach directly to the base station node if the distance separated between them can be covered by the signal. In general, sensor nodes have different amounts of initial energy. The node is dead if it consumes its battery energy where the battery is not rechargeable. Figure 2 shows the model of radio energy [24].

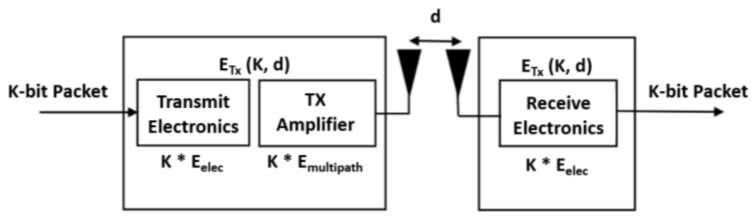

Figure 2. The radio energy model

The routing protocols in WSN use two types of models for energy consumption, which are the models of free space and multipath fading. Free space model required amplification energy εfsd^2 where εfs is the amplification energy in a free space and d represents the distance separated sender and the receiver. Multipath fading model εmpd^4 where εmp is the amplification energy. The distance between the receiver and transmitter affects both models. The way to calculate the required energy to transmit the k-packet for a distance d is represented in (1). The simple form is represented in (1) while the general form is represented in (2).

$$E_{TX}\ (k,d) = E_{TX-elec}(k) + E_{TX-amp}\ (k,d) \quad (1)$$

$$E_{TX}\ (k,d) = \begin{cases} \mathrm{K} * \mathrm{Eelec} + \mathrm{k} * \varepsilon\mathrm{fs} * d^2, & \mathrm{d} < \mathrm{d0} \\ \mathrm{K} * \mathrm{Eelec} + \mathrm{k} * \varepsilon\mathrm{mp} * d^4, & \mathrm{d} \geq \mathrm{d0} \end{cases} \quad (2)$$

$$E_{RX}\ (k) = E_{RX-elec}(k) = k * E_{elec} \tag{3}$$

where
E_{TX} is the required and used energy to send the k-packet,
E_{elec} is electronic energy that counts on the filtering, modulation of the digital coding, and spreading of the signal,
E_{RX} the required and used energy to receive a packet,
d_0 is equal to the square root of the dividing E_{DA} free space model by the multipath fading model, and
E_{DA} is the consumed energy in aggregation [25].

Specifying the ideal number of cluster heads in WSN depends on many conditions. Assuming the number of used sensor nodes is equal to N, and C represents the number of clusters that divided the network, there are N/C average numbers of sensor nodes in each cluster. Thus, consumed energy in the CH node in a single frame can be represented as explained in (4). In the case of non-cluster head nodes, the required energy consumption that is consumed in sending the k-packet to the CH is represented in (5). The average distance between BS and CH nodes is represented in d_{toBS}.

$$E_{CH} = kE_{elec}N/C + KE_{DA}N/C + K\ \varepsilon_{mp}d^4{}_{toBS} \tag{4}$$

$$E_{non-CH=}kE_{elec} + K\varepsilon_{fs}d^2{}_{toCH} \tag{5}$$

4. LEACH ALGORITHM

LEACH operations consist of a number of rounds, and each round includes two phases. The first phase is named set-up, in which the clusters are created and formatted. The second phase named steady-state, in which data are gathered and transmitted to the BS. Usually, the steady-state phase takes time more than the set-up phase to reduce costs. Some of the used sensor nodes are elected based on specific conditions to be cluster heads in WSN. When the sensor nodes are located to cover a particular area, the operation of electing CH is initiated at the commencement of each round process. The process of choosing CH among the sensors is a dominant process and includes four phases.

a. Advertisement phase: Initially, each node takes the decision of being a CH or not for the current round depending on the proposed percentage of cluster heads. This network percentage is specified a priori based on the times number that the node acted as CH. Being CH node decision is taken by the node n based on selecting an arbitrary number within the range of 0 and 1. For the current round, the node beings a cluster head if the chosen number is less than threshold T(n). The threshold is calculated as (6),

$$T\ (n) = \begin{cases} \frac{P}{1-P*r\ mod\frac{1}{p}} & if\ n\ \in G \\ 0 & otherwise \end{cases} \tag{6}$$

where P is the desired percentage of cluster heads in the current round (e. g., P=0.05), r represents the current round, and G is nodes set that were not cluster-heads in the last 1/P rounds. In the current round, each node that has been elected itself as cluster-head sent broadcasting messages to advertise itself to the rest of the nodes. Cluster-head nodes use the carrier-sense multiple access (CSMA) as a media access control (MAC) protocol in the advertisement phase. All cluster heads transmit their advertisement using the same transmit energy. During this phase, hearing all cluster-head node advertisements requires the non-cluster-head nodes to maintain their receivers on. At the end of this phase, each non-cluster-head node can know to which cluster it will belong for this round. The decision of selecting the appropriate cluster is depending on the strength of the received advertisement.

b. Cluster setup phase: notifying the cluster-head node about its members in that cluster. This requires each non-cluster-head node to send messages to the cluster-head node. Each node sends this information again to the CH using the CSMA MAC protocol. All CH nodes require to maintain their receivers during this stage.

c. Schedule creation phase: In this phase, each CH node knows the nodes that have the desire to engage in the cluster. The CH node makes a time division multiple access (TDMA) schedule to inform each node of its time slot for transmitting, where the scheduling process is depending on the number of joined nodes in that cluster. The cluster-head node broadcasts the schedule to the member nodes of the cluster.

d. Data transmission phase: In this phase, each node sends its data during its time slot to the CH. The transmission energy is chosen depending on the received strength of the CH announcement, usually, it uses a minimal amount. The non-CH nodes commence listening only in their time slot, to decrease dissipated power in these nodes, whereas, receiving data from the node members of the cluster requires the CH node maintaining its receiver. The cluster head node implements signal processing tasks to compact the received data into one signal after receiving all the data from the sensor nodes in the cluster. The resulting signal is transmitted to the BS, and it requires high-energy transmission because the base station is usually far away [24]. Figure 3 shows the TDMA schedule for the LEACH procedure and round sequences.

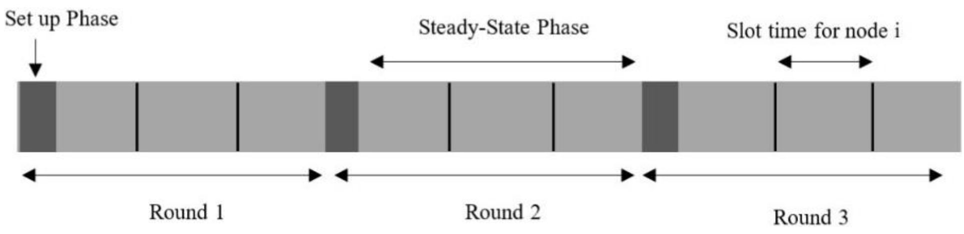

Figure 3. The TDMA schedule of LEACH

5. LOSING ENERGY IN LEACH ALGORITHM

LEACH algorithm is based on the threshold value and allows nodes that have not acted as CHs in the last $\frac{1}{P}$ rounds (G) from electing to be a cluster-head node. This does not guarantee an appropriate method in electing the node with the largest available energy. Thus, the network is unstable because some nodes will dissipate their energy earlier while other nodes maintain their energy for a longer period. One of the main causes of losing energy earlier in a node is being a CH node. In addition, setting the clustering process, which includes the phases of (advertisement, cluster setup, and schedule creation) consume the energy of nodes [24], [26], [27].

6. PROPOSED APPROACH

The proposed method depends on modifying the LEACH algorithm. It develops a new version of LEACH based on electing CH nodes that own better power resources than other nodes in the network. The elected CH nodes must be equipped with good sources of energy such as a resource of solar energy to guarantee their ability to serve as CH for a long time. Where, the need for re-setup of the clusters frequently will decrease, since CH nodes will always have good energy levels. Figure 4 shows the cluster distribution in the proposed approach.

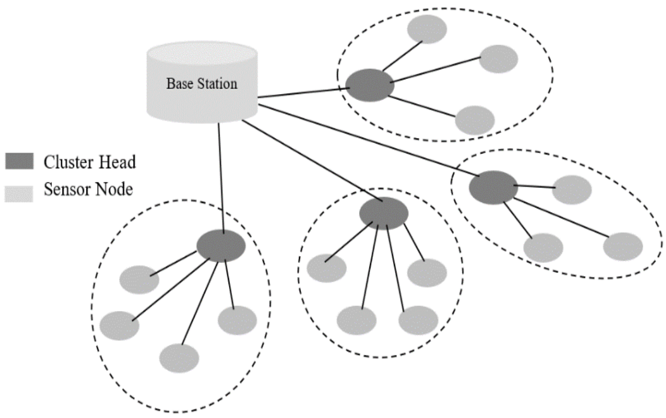

Figure 4. The cluster distribution

The procedure of the proposal can be presented as the following: i) distribute all the nodes including sensors and CHs to the required geographical area; ii) cluster-head nodes are chosen depending on their available power, where they must be equipped with a good source of energy for example solar energy; iii) cluster-head nodes send broadcasting messages to advertise themself to all nodes in the network; iv) each non-CH node sends a message to the cluster-head node to notify the cluster-head about its member nodes;

v) the CH node innovates a TDMA schedule and transmits it to all sensor nodes in the cluster to inform each node when it can transmit; and vi) start data transition where each node transmits its data within its assigned time slot to the CH node. Then, the CH node receives the data sent by the sensors within the cluster and then sends them to the BS node. Note that steps 1 to 5 are performed once time only at the initialization of using sensors.

7. RESULTS

Simulator NS2 has been used to implement the proposal. Table 1 describes the applied metrics, which were employed in the simulation. Three models have been simulated for comparison and validation purposes: first is the non-cluster protocol, second is the LEACH protocol and third is the proposed protocol.

Table 1. The simulation metrics

No.	Parameters	Value
1.	No. of nodes	50
2.	Network Grid	(0, 0)×(100, 100)
3.	Initial energy	0.5 J
4.	Tx and Rx energy for each node	50×10–9
5.	Node Distribution	Random
6.	No. of rounds	1,000
7.	Number of clusters (k)	5 (5% of N)
8.	Data packet size	500 bytes
9.	Packet header size	25 bytes

Fifty sensor nodes (including cluster-head nodes) were distributed randomly in the suggested network. The implemented nodes are distributed in five clusters. Figure 5 explains the dead nodes' number. It declares that the number of dead nodes is increased with the progress of network performance in not-cluster and LEACH protocols. In the not-cluster protocol, the dead sensors occur in round 400, while in the LEACH protocol dead nodes occur in round 600. In the proposal protocol, there are no dead nodes until round 900. The proposed protocol outperformed the other two protocols since it extends the steady phase until round 900. Thus, the network lifetime will increase. Figure 6 represents the number of sent packets in three applied protocols.

The obtained results reveal that the not-cluster protocol requires transmitting the largest number of packets than the other two protocols. The higher number of messages sent, the higher consumption of nodes' energy, which leads to the death of more nodes. In contrast, the proposal transmits the lowest number of packets. From round 250, the not-cluster protocol sent packets less than LEACH and suggested protocol. This is attributed to the number of dead nodes in the non-cluster protocol, which is larger than the other two protocols. Dead nodes have no energy to send single-packed. The proposal extends the life of the network more than the LEACH protocol and minimizes the required number of sent packets by 15% less than the LEACH protocol.

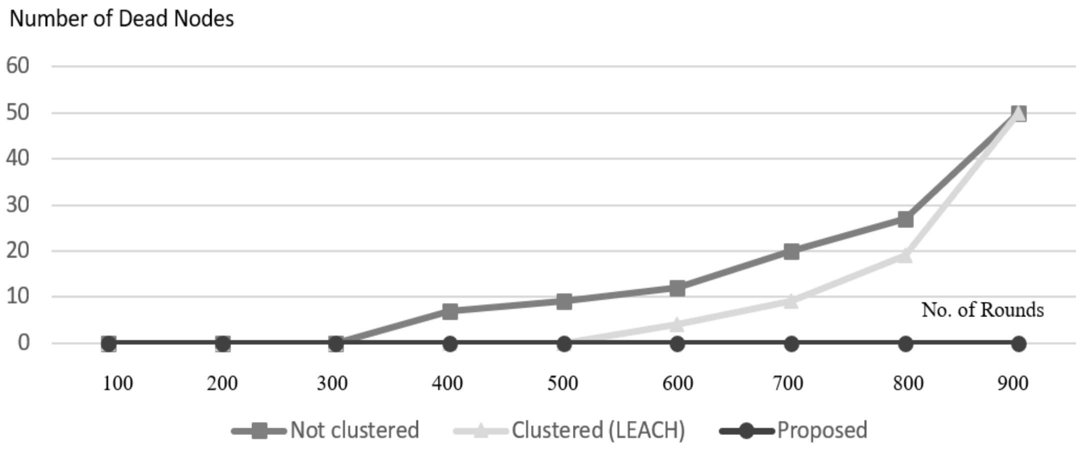

Figure 5. The dead nodes number

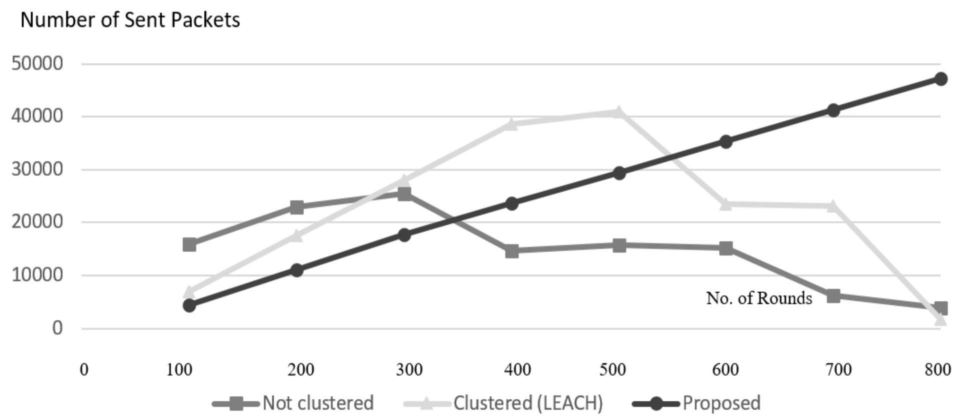

Figure 6. The number of sent packets

8. CONCLUSION

This research presents an effective approach to enhance the efficacy of the LEACH protocol. It proposes a new method that aims to extend the lifetime of WSNs. The proposal is based on using cluster head nodes equipped with a good or continuous source of energy, which is solar energy. Equipping the sensor nodes with solar energy has been applied in many systems and applications, so it can be used to achieve the proposal's aim. Thus, updating the cluster-head process is performed at a lower rate than the basic LEACH protocol. This saves the energy of other nodes (not cluster-head nodes), which will use their energy for sensing and sending its sensed data to CH nodes only upon system requirements. The proposal minimized the need of performing the cluster setup phase, reduced the transmitted messages, and increased the lifetime of the network. The suggested system has been performed using an NS2 simulator, where the results reveal its effectiveness in saving the network resources in terms of minimizing the sent messages. As the process of reformatting clusters is required less frequently than the LEACH protocol. In addition, to prolong the network lifetime, for validation purposes, the proposal has been compared to the basic LEACH protocol and not-clustered protocol, where all of them have been implemented in the same environment. The experiments of implementing the proposed approach clarified its ability to preserve the nodes' energy, reduce the requirement of clusters re-format, extend the WSNs lifetime, and reduce the number of required transmitted messages, which resulted in saving the network resources. The results revealed the superiority of the proposal over basic LEACH protocol and not-clustered protocol in terms of extending the lifetime of WSNs and saving network resources.

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