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An enhanced energy-efficient routing protocol for wireless sensor network

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ABSTRACT

Recent few years, Wireless Sensor Network (WSN) has been an increasingly important technology that has been applied in almost all domains, even in complex environments where human activity is impossible. In WSN, various factors are impacted energy consumption, such as communication protocols, packet data transmission, and limited battery. So, the lifespan of the WSNs is limited. In this context, energy efficiency is the factor most attracted by many researchers. In this paper, we proposed a new improved LEACH routing protocol. This proposed protocol based on the current energy to select cluster-heads, and it uses a root cluster-head with more current energy and low distance to the sink to gather all data, then sends it to the sink. The simulation results in MATLAB confirmed that the proposed algorithm performed better than the conventional LEACH protocol, and increased the network lifetime in WSN.

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1. INTRODUCTION

In the last few years, WSN recognizes an increased interest through its use in different domains such as military, medical, environment, etc. [1, 2]. The WSN consists of a large number of low power micro-sensor nodes deployed in a large space with at least one BS [3]. Every micro-sensor monitors physical or environmental conditions such as pressure, temperature, humidity, etc. [4] then dispatch the collected data back to the BS. In WSN, the positions of the nodes are not predetermined, which allows an autonomous organization of the network [5, 6]. As shown in Figure 1 WSN includes sensor nodes distributed randomly, a BS receives all data that was collected from the environment, and the user that gathered data through the internet.

Each sensor node in the network has four units: sensing, treatment, wireless transmission and power unit (generally are batteries) [7] as presented in Figure 2. One of the most important units is the power unit. Sensor nodes in such an environment are energy-constrained since the batteries can not be recharged or replaced [3]. Consequently, designing an energy-aware protocol got an interest to prolong the network lifetime [8]. Thus, energy consumption is the major important factor in most applications where all sensor nodes are constrained with energy which related to the lifetime of the network. The restricted power of nodes needs the design of a protocol of communication that conserves energy [9]. The restricted power of nodes needs the design of a protocol of communication that conserves energy [9]. In this way, many kinds of research are focused on routing protocols, which is one of the most technologies in WSNs.

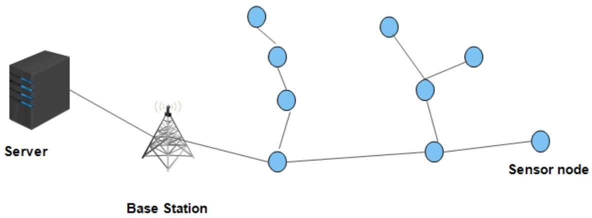


Figure 1. WSN architecture

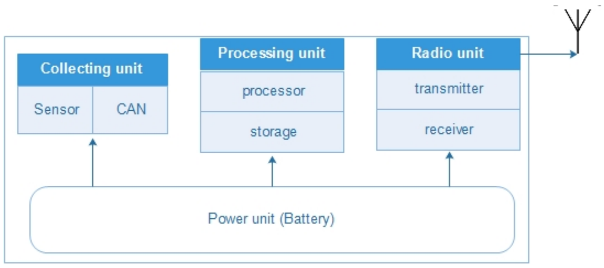


Figure 2. Sensor node units in WSN

In the literature, many routing protocols have designed to arrange the transmission of data from nodes to the sink [10], and most of them are based on the hierarchical clustering mechanism [11]. The Low Energy Adaptive Clustering Hierarchical (LEACH) protocol [12] is the famous and the popular hierarchical clustering routing protocol, which will be described in the next section [13]. In order to prolong the network lifetime and reduce energy consumption in LEACH, various protocol are proposed, such as DMR [14], MH-LEACH [15], MHT-LEACH[16], O-LEACH [17], etc. In this work, we are based on the LEACH protocol to develop a new enhanced LEACH protocol, which improves the energy consumption in WSNs. The present paper aims to propose energy-efficiency, stability, residual energy, distance, and the multi-hop technique based clustering routing protocol. This protocol uses these metrics to minimize the energy consumption in the network and extend the network lifespan in WSNs.

The remaining of the paper is orderly as follows: Section 2 presents the LEACH protocol. The proposed protocol will be described in section 3. Section 4 covers results and analysis. Finally, the last section concludes the paper.

2. LEACH (LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY)

LEACH [12] is the most popular and the most famous clustering hierarchical protocol designed for an energy economy of the network [18]. It uses the clustering technique which divides the network into clusters, and through clustering mechanism, the nodes organize themselves into a hierarchical organization. Every round in the LEACH algorithm consists of two main phases: set-up phase and steady phase[19].

In the first phase, CHs are elected and clusters are formed. At the beginning of each round, every sensor node produces a random value between 0 and 1 [20]. If this value is lower than the probability function T(n) defined in the equation (1), this node selected as CH. Even if, it becomes a normal node [21].

$$T(n) = \begin{cases} \frac{P}{1-P*(r\ mod(1/P))}, n \in G \\ 0 \qquad\qquad \text{else} \end{cases} \tag{1}$$

Where p concerned the percentage of the number of clusters in the network. r is the current epoch, and G is a group of nodes that have not been selected as CHs in epoch r.

Afterward, the CHs are selected, they diffuse information to the network. Therefore, each normal node chooses its CH belongs depending on the strength of the received signal. In the second phase, when clusters are configured and each node knows its time slot in TDMA. The normal nodes transmit their collected data to their CHs by their time slots in the TDMA schedule. The TDMA schedule is used to adjust the channel of internal access in every cluster and reduce the interference between clusters [22]. Therefore, each CH aggregates and compresses the received data from its members with its own. Thus, the cluster's information is routed directly in a single hop to the BS through the CHs.

2.1. Radio energy consumption model

In each node, the transmitter consumes E_{Tx} defined in the equation (2) to transfer n bits remote receiver di meters. There are two different radio models: (1) the free space (fs) that it is adopted when the distance between the transmitter and the receiver is less than the threshold distance di_0; (2) the multi-path (mp) which it is used when the distance is greater than di_0. Then, the receiver consumes E_{Rx} described in the (4) to receive n bit of packet.

$$E_{Tx}(n, di) = \begin{cases} n.E_{elec} + n.\epsilon_{fs}.di^2, & di < di_0 \\ n.E_{elec} + n.\epsilon_{mp}.di^4, & di >= di_0 \end{cases} \tag{2}$$

$$di_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \tag{3}$$

$$E_{Rx}(n) = n * E_{elec} \tag{4}$$

Where the energy consumption of the transmitter or the receiver is introduced by E_{elec}, ϵ_{fs} and ϵ_{mp} present the energy consumption factor of amplification in the free space and the multi-path respectively.

LEACH is designed to decrease energy consumption. It has some advantages, such as every node can equally divide the charge imposed at CHs to a certain extent because any sensor node that was selected as a CH in some epoch can not be reselected as a CH yet [23]. Besides, the exploitation of the TDMA avoids the collision between CHs. Nonetheless, it has some disadvantages as it affects the single-hop while CHs communicate directly to the sink. Furthermore, for long-distance betwixt CH and the BS can produce more energy consumption that makes LEACH not apt for large networks. Moreover, the random selection of CHs leads to not giving all nodes the possibility to become CHs. Thereby, if a node with less current energy is elected as CH would die rapidly, which affects the network life cycle.

3. THE PROPOSED PROTOCOL

In this document, our contribution is an enhanced LEACH algorithm. The overall purpose of the proposed protocol is selecting CH according to the residual energy of nodes to avoid the participation of nodes with less energy as CH. To prevent that all CHs communicate with the BS, it picks out a CH with the greatest residual energy and the smallest distance to the sink as a parent CH. Then, it uses the multi-hop between CHs to reach the parent CH as we can see in Figure 3. The multi-hop technique is used to improve the transmission distance betwixt CHs and the sink. It includes two principal phases as mentioned below. Set-up phase where we form clusters and we select CH of each cluster. The steady phase that contains three sub-phases.

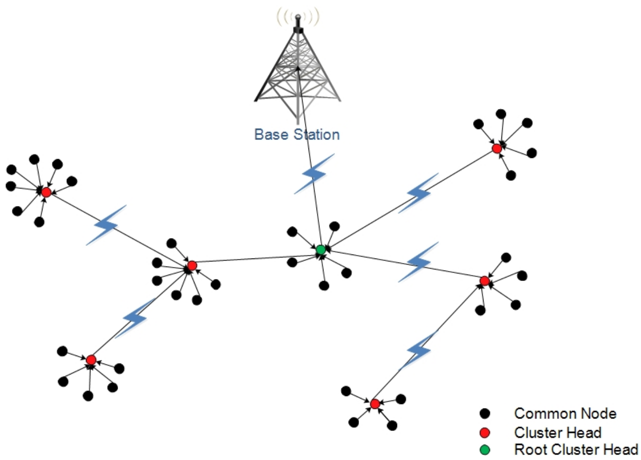


Figure 3. The proposed protocol architecture

3.1. Set-up phase

The random selection of CHs in LEACH leads to not giving all nodes the opportunity to become CHs, also it results in the energy imbalance of sensor nodes. To guarantee the energy balance in the network, the proposed algorithm selects CH according to the current energy. In every epoch, each node computes its current energy applying the (5). This node can participate in the CH role if its current energy is superior to the average current energy.

$$E_{cur} = E_{init} - E_{con} \tag{5}$$

Where E_{con}= E_{Tx} + E_{Rx}
E_{Tx} and E_{Rx} are defined respectively in equation (2) and (4) in section 2.1., and E_{init} is the initial energy provides to the nodes at the beginning.
Thus, based on [12, 24, 25] we defined a new threshold function as shown in (6).

$$Th(n) = \begin{cases} \frac{PE}{1-P_r*(t\ \%(1/Pr))}, n \in C & ,Where \quad \text{PE = Pr} * \frac{E_{cur}}{E_{init}} \\ 0 \quad \text{else} \end{cases} \tag{6}$$

Where the percentage of the number of CHs in the network is presented by P_r, t introduces the number of the current turn, C presents the collections of the nodes that have not yet been CH in the last 1/P_r turns. E_{init} represents the initial energy provides the nodes at the beginning whereas E_{cur} shows the current energy of nodes at the t turn.

After the first condition, each node takes a random value between 0 and 1. This node will be elected as a CH at the current turn if this value is inferior to the threshold function Th. On the other hand, it becomes a normal node. Afterward, CHs broadcast information to the network. Each normal node determines its CH belongs according to the strength of the received signal from CH.

3.2. Steady phase

3.2.1. TDMA (time divisionmultiple access) schedules

TDMA schedule is created by every CH after cluster configuration according to the distance and the total number of nodes in each cluster [25, 26]. Each normal node has a TDMA time slot for sending its data to its CH.

3.2.2. Root cluster head selection

In this phase, the proposed algorithm selects the root CH that has residual energy more than the average residual energy of CHs and its distance to the sink is less than the average distance between CHs and the sink, where are depicted in (7) and (8) respectively.

$$E_{average} = \frac{\sum_{i=1}^{CH} E_{cur}(i)}{CH} \tag{7}$$

$$d_{average} = \frac{\sum_{j=1}^{CH} d_(j)}{CH} \tag{8}$$

E_{cur} offers the residual energy of CH at the current turn when d indicates the distance between every CH and the sink.

3.2.3. Data transmission

When all components in the network know their roles in the previous phases, the normal nodes starting to gather data from the environment then transfer it to their CHs corresponding. Afterward, each CH communique with the closest CH to reach the root CH applying the multi-hop technique. After receiving information of all CHs, the root CH aggregates them with its own then sends them directly in a single hop to the sink as shown in Figure 3.

4. RESULT AND ANALYSIS

In this section, we use simulation to analyze and emulate the performance of the proposed approach. Simulations are performed in the Matlab 2016b platform. The simulation parameters of our proposed model are mentioned in Table 1. We deployed randomly 200 nodes in area 200 *200 m^2, the sink was placed at position (100,250).

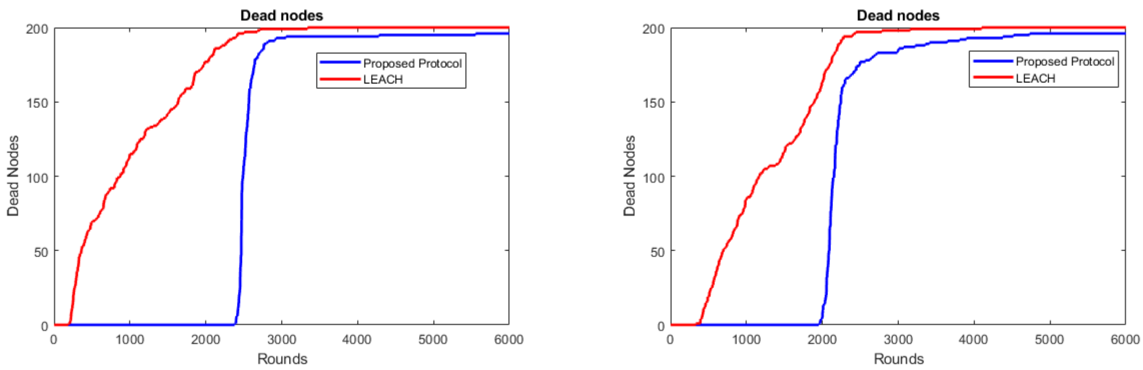
Table 1. Parameters value

Parameter	Symbol	Value
Total number of nodes	N	200
Total number of sinks	S	1
Area	M*N	200 * 200 m^2
Initial energy	E_{init}	1 Joule
The sink location	(x,y)	(100, 250)
The deployment of nodes	deployment	random
Energy consumed in the Radio module to transmit or receive the signal	$E_{Tx} = E_{Rx}$	50 nJ/bit
Energy consumed by the amplifier to transmit at a short distance	ϵ_{fs}	10 pJ/bit/m^2
Energy consumed by the amplifier to transmit at a longer distance	ϵ_{mp}	0.0013 pJ/bit/m^4
Data aggregation energy	EDA	5 nJ/bit
Packet size	n	500 bytes
Number of rounds	r	6000

The main purpose of the proposed algorithm is to extend the network lifetime by selecting CHs according to the current energy and choosing a root CH. In the beginning, all nodes have the same initial energy E_{init} =1 Joule. Each sensor node transmits a 4000 bits data packet per round to its cluster head. The percentage of the total number of CHs in the network is 5%, while the simulation is repeated with 10% and 20% both for the proposed algorithm and LEACH.

The simulation result that shows the relative performance of discussed protocols with parameter values of Table 1, and P_r=20% are presented in Figure 4 (a). It provides dead nodes depending on rounds. Figure 4 (b) compares the behavior of both LEACH and the proposed protocol for P_r=10%. Figure 5 illustrates the diagram of comparative analysis of both discussed protocols for P_r=5%, while FND presents the First Die Node, and HND indicates the Half Node Die. Figure 6 (a), Figure 6 (b), and Figure 7 illustrate the total current energy of nodes in the network for 20%, 10%, and 5% respectively.

The obtained results from the tree cases exhibit the effectiveness of our method for optimizing the energy consumption in WSNs. Thereby, it indicates that the proposed algorithm has performed better than the original LEACH protocol in all cases by balancing the total energy consumption, increasing the stability period and extending the network lifetime.



(a) (b)

Figure 4. Dead nodes in LEACH and the proposed protocol for 20% and 10%, (a) Dead nodes for 20%, and (b) Dead nodes for 10%

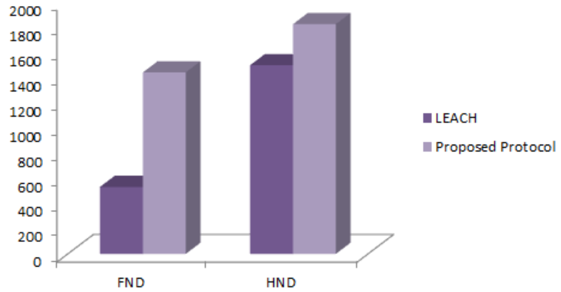
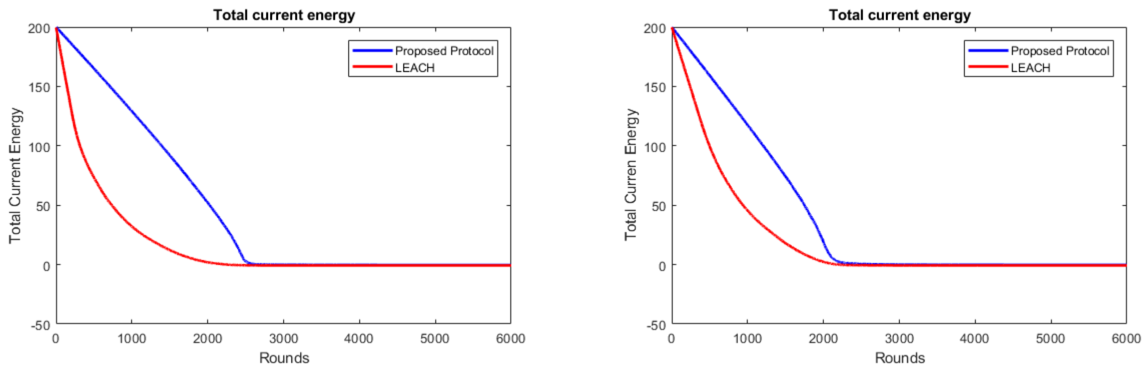


Figure 5. Dead nodes in LEACH and the proposed protocol for 5%



(a) (b)

Figure 6. Total current energy in LEACH and the proposed protocol, (a) Total current energy for 20%, and (b) Total current energy for 10%

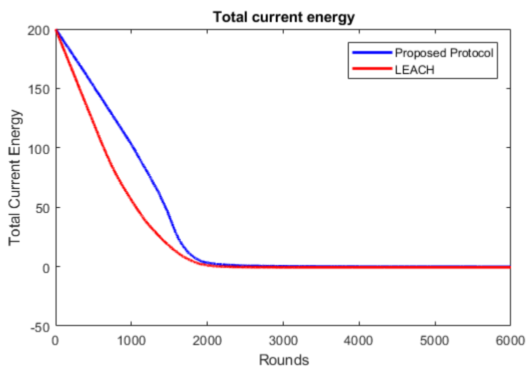


Figure 7. Total current energy in LEACH and the proposed protocol for 5%

5. CONCLUSION

Presently, the major challenge faced for routing protocol in WSN is making an energy-efficient design. To solve this problem, it must make the sensor node working for a long period with less consumption of energy. The sending data and reception present generally the major energy consumption in the network. To meet this challenge several clustering routing protocols have been developed. This paper proposed a new approach for hierarchical clustering routing protocol in WSN with energy-saving by the hierarchical and clustering method. The first purpose of the enhanced protocol is balancing the energy consumption of nodes. The second purpose is prolonging the network lifetime and improving the stability period through: (1) taking into account the current energy in CH selection, (2) consideration of current energy and the distance to the sink to pick a leader CH that send aggregated data to the sink after receiving all collected data. The present study was designed to evaluate the proposed protocol performance against the original LEACH algorithm.

Simulation results in MATLAB confirmed that the proposed algorithm enhances the stability period. Hence, it extends the network lifespan more than the original LEACH protocol owing to the number of dead nodes and the total current energy of the network. Thus, it indicates also that the proposed algorithm achieves better results than the conventional LEACH protocol in all discussed cases.
As future research, it is destined to implement other QoS (Quality of Service).

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