IBRE-LEACH: Improving the Performance of the BRE-LEACH for Wireless Sensor Networks

Ikram Daanoune1 · Abdennaceur Baghdad1

Accepted: 29 May 2022 / Published online: 21 June 2022
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2022

Abstract
Wireless sensor networks are extensively used in different fields, including severe and harsh environments such as battlegrounds, volcanic areas, healthcare, and so on. The major constraint of WSNs is the limited power supply, which impacts the lifecycle of the entire network. Clustering is a performing method used in WSNs to optimize power consumption and extend the lifetime of WSNs. LEACH is considered the first classical clustering protocol used in WSNs to optimize energy consumption. Many protocols have been developed to enhance the conventional LEACH protocol. BRE-LEACH (Balanced Residual Energy LEACH) is one of them. It is used to enhance the performance of the LEACH protocol. In this paper, we propose a new improved BRE-LEACH protocol called IBRE-LEACH (Improved Balanced Residual Energy LEACH), which improves the performance of the BRE-LEACH approach. The IBRE-LEACH combines clustering and multi-hop techniques. It selects CHs according to the residual energy and limits the maximum number of nodes in each cluster to balance the energy consumption. Thus, IBRE-LEACH allows the Abandoned Nodes to send their data to the BS. Furthermore, it routes the gathered data using CHs, ANs, and a root node, which is a node with maximum residual energy and minimum distance to the BS. The simulation results in MATLAB show that the IBRE-LEACH protocol increases the throughput, optimizes energy consumption, extends network lifetime, and ameliorates stability by 81.99%, 94.33%, and 91.47% compared to BRE-LEACH, LEACH-C, and LEACH, respectively.

Keywords WSN · Efficient routing protocol · LEACH · Network lifetime · Abandoned nodes

1 Introduction

Recently, wireless sensor networks (WSNs) have attracted the attention of scientific researchers as they became widely applicable in several applications, especially in severe and sensible spaces where human operations are difficult or impossible [1, 2], such as

Ikram Daanoune
daa.ikram@gmail.com

1 Faculty of Sciences and Techniques, Hassan II University of Casablanca, BP 146, 20650 Mohammedia, Morocco
in forest fire detection, military activities, seismic areas, medicine, and so forth. WSN includes a large number of sensor nodes, which are randomly distributed in a special area to monitor and collect diverse types of environmental information [3]. Sensor nodes in the WSN can monitor an area, communicate with neighboring devices, and execute calculations on the gathered data [4]. The function of each sensor node in the WSN is to collect sensing data from the monitored geographical location and forward it to the Base Station (BS) and then to the user via the internet [5, 6], as mentioned in Fig. 1.

Generally, sensor nodes have a basic hardware capability equipped with at least one sensor, processor, storage, a radio transceiver, and a small battery [7, 8]. These tiny sensor nodes are typically energy-constrained. Therefore, the critical constraint in WSNs is energy owing to the tiny size of the batteries. Thus, the main research issue in WSNs is improving the energy efficiency by implementing various techniques [9]. Routing is the most attractive technique proposed by researchers to enhance energy performance in WSNs [10]. A routing protocol is required to establish a route between the transmitter and the receiver devices, which optimizes the energy consumption in WSNs [11]. Clustering is a beneficial technique in WSNs, which can enhance lifetime and scalability by decreasing power consumption and balancing energy distribution in the network [12]. The LEACH protocol is one of the most popular hierarchical clustering protocols that are applied to reduce energy consumption in WSNs. The operation of the LEACH protocol includes two main phases: the set-up phase where clusters are formed, and the data transfer phase [13]. In the first state, the LEACH algorithm groups the network into groups (clusters), each composed of cluster members and a CH (Cluster-Head). Each cluster member collects data from the supervising area and sends it to its CH. Thus, the BS receives the data aggregated by the CH [14]. However, the LEACH approach has many problems, such as random selection of CHs without considering energy, the number of cluster members is not the same in all clusters, which leads to energy imbalance. Furthermore, the LEACH approach uses a single hop between devices to achieve the BS. In this context, several improved LEACH protocols are proposed to enhance the lifetime and decrease the energy consumption of LEACH [15]. BRE-LEACH is one of them, which has improved the performance of LEACH, it is presented and evaluated in [16].

In this paper, we propose a new approach to enhance the performance of the BRE-LEACH approach. In the proposed IBRE-LEACH (Improved Balanced Residual Energy LEACH) protocol, the threshold function for selecting CHs includes the ratio of residual energy to the initial energy of each node. Therefore, the percentage of a low-energy node becoming a CH is highly excluded. Thus, instead of the random number of nodes in each cluster in BRE-LEACH, IBRE-LEACH defines a maximum number that should not be exceeded in the clusters to balance the energy load of CHs in the network. In IBRE-LEACH, nodes that cannot join any cluster can forward their data to the BS unlike in BRE-LEACH. Thus, in BRE-LEACH, all CHs send their data to the root even CHs that are
closer to the BS than the root. Also, in BRE-LEACH, the next hop may not be in the same direction as the BS, which requires more energy. In the IBRE-LEACH protocol, each CH (or AN) generates its routing table to choose the optimal path to reach the BS through intermediate nodes (CHs, ANs, or the root), or directly to the BS.

The document is organized as follows: Sect. 2 gives an overview of the related work. Section 3 provides a brief detail of the BRE-LEACH protocol. Section 4 described the proposed IBRE-LEACH protocol. The simulation results are analyzed and presented in Sect. 5. A comparative analysis of the proposed protocol with BRE-LEACH, LEACH-C, and the conventional LEACH algorithm is given in Sect. 6. At the end of the paper, a conclusion is given in Sect. 7.

2 Related Work

Clustering is a beneficial routing technique for WSNs, which can enhance lifetime and scalability by decreasing power consumption and balancing energy distribution in the network. Heinzelman [17] proposed an efficient clustering routing algorithm, called LEACH (Low Energy Adaptive Clustering Hierarchy). It provides a clustering mechanism for wireless sensor networks. The LEACH protocol aims to decrease energy consumption in WSNs by providing the clustering technique. The sensor nodes organize themselves into clusters and designate one of them as the leader (CH) [18]. LEACH is a hierarchical routing protocol that ensures that the node cannot regularly participate in the CH election by using a random probability function to choose the CHs defined in the Eq. 1 [17].

\[
T_{LEACH} = \begin{cases} 
\frac{P_r}{1-P_r \times (r \times (1/P_r))}, & n \in G \\
0, & \text{otherwise} 
\end{cases}
\]

Here, \(p_r\) and \(r\) introduce the probability of CHs in the full network and the current round, respectively. \(G\) presents the collection of nodes that have not become the leader in the previous \(1/p\) rounds.

The LEACH approach uses the round concept. Each round consists of two phases: (1) the set-up phase, and (2) the regular-state phase. The first phase consists of three sub-phases: advertisement, schedule creation, and cluster formation. On the other hand, the second phase concerns data transmission.

In the first phase, every sensor node decides whether to become a leader or a common node. At the start of each round, each node chooses an arbitrary number between zero and one. The node will be considered as a CH in the current round if the chosen number is less than the threshold function described in the Eq. (1). On the other hand, it becomes a common node. In the advertisement step, the CHs announce the network nodes by their status. Then, the common nodes designate their corresponding CH depending on the strength of the received signals.

In the second phase, each CH aggregates data from its cluster members and then sends it directly to the sink as shown in Fig. 2.

The LEACH protocol has the following advantages:

– The hierarchical LEACH protocol has the benefit of easy implementation and can efficiently balance network loads [19].
– It has increased the lifetime of the WSN by reducing and distributing energy consumption within the network compared to direct communication.
– It provides a random rotation of the CH between nodes.

Unfortunately, the LEACH approach has many shortcomings, including:

– Every CH sends aggregated data to the sink immediately, regardless of the remaining energy and the distance to the base station. Therefore, for distant CHs, more energy will be consumed, and if the CH’s remaining energy was low, it will die early. When a CH dies, the cluster becomes useless because the data collected by the cluster members will never reach the sink.
– It does not operate in a larger network environment.
– Random selection of CH. Therefore, it is important to note that the remaining energy was not taken into consideration in the CH selection and cluster formation [13].
– The number of nodes in each cluster is not the same, resulting in an imbalance of energy consumption because a cluster with more members consumes more energy to aggregate, process, and transmit data.
– Data from nodes that cannot join any cluster does not reach the BS.

Considering the drawbacks of the LEACH approach, many LEACH-based cluster routing protocols have been proposed in many kinds of research to improve the lifetime of WSNs. These LEACH protocol variants are classified into three categories, as described in [15], protocols that enhance CH selection, protocols that improve data transmission techniques, and protocols that ameliorate both phases of LEACH.

Low Energy Adaptive Clustering Hierarchy-Centralized (LEACH-C) is one of these variant of the LEACH protocol, it was suggested by Heinzelman et al. in [20]. LEACH-C is a centralized clustering protocol based on LEACH, which improves the traditional LEACH approach. Unlike the self-organization of nodes into clusters in LEACH, in LEACH-C the BS responsible for cluster formation [21]. Thus, in LEACH, CHs are randomly elected by the sensor nodes, while in LEACH-C, they are randomly chosen by the sink based on their residual energy level and location. Identical to LEACH, the LEACH-C protocol has two phases: the set-up phase and the steady-state phase [22].
At the beginning of each round in the set-up phase, each sensor node in the network sends some information to the sink (its remaining energy and its location). Furthermore, the BS based on this information to select the CHs and form the clusters. Nodes with energy less than the average will not be considered as CHs in the current round. Once, the CHs are selected and the clusters are established, the steady-state phase takes place, which is similar to that of the LEACH approach. Generally, the LEACH-C protocol provides an improved distribution for CHs compared to LEACH. Thereby, it enhances the network lifetime. Nonetheless, the LEACH-C protocol has some drawbacks, such as it is not applicable for large networks, and the communication between all sensor nodes and the BS, regardless of the distance, can impact the energy consumption.

Authors in [23] proposed an enhanced version of LEACH, called MH-LEACH (Multi-Hop LEACH). The MH-LEACH protocol aims to choose the optimal path of each CH to reach the BS using multi-hop communication with intermediate CHs. Consequently, every CH forwards its data to the closest CH and so forth until the BS. The set-up phase in the MH-LEACH protocol stays the same as that of the LEACH. The MH-LEACH algorithm uses the multi-hop technique between CHs to optimize energy by decreasing long-distance communications.

MHT-LEACH (Multi-Hop Technique LEACH [24] is a LEACH-based protocol, which has increased the network lifetime compared to the original LEACH protocol. The MHT-LEACH protocol proposes a new method to forward data from CHs to the sink. This new technique is used to divide the network into two levels depending on the distance. The MHT-LEACH functions in three phases. The first one concerns the selection of the CHs in the network, which is similar to the set-up phase of the traditional LEACH protocol. In the second phase, the CHs are divided into two groups (external and internal) based on the distance. Finally, the third phase concerns data transmission. Every CH gathers its data with its cluster members’ data. Thereby, the CHs of the external level send their packets to the CHs of the internal level by using the routing tables, and then the CHs of the internal group forward their data directly to the BS in a single hop.

In another way, authors in [25] have proposed Cell-LEACH to improve network coverage in WSNs by dividing the network into cells. Every cell selects a node to be the cell-head within the cell. Therefore, each cluster consists of seven cells, normal nodes, and a CH. The main objective of the cell-LEACH protocol is to decrease the communication cost between the CH and its cluster members by electing cell-heads in each cell.

3 Overview of BRE-LEACH (Balanced Residual Energy LEACH)

The BRE-LEACH approach has enhanced the stability and the life-cycle of WSNs compared to the classical LEACH algorithm [16]. Unlike LEACH, the BRE-LEACH algorithm provides four phases, (1) the cluster setup phase; (2) the TDMA scheduling phase; (3) the root CH selection phase; and (4) the data transmission phase.

Since the CH aggregates all cluster members’ data, it needs more energy than normal nodes. Therefore, it is necessary to choose CHs based on the remaining energy. In this context, BRE-LEACH chooses CHs based on the remaining power to avoid nodes with less energy participating in CH selection, unlike LEACH which elects CHs randomly.

Once the clusters are formed, BRE-LEACH chooses the CH with the most remaining power and the smallest distance to the sink as the root. This root collects the data from the other CHs, aggregates it, and then forwards it to the sink. Although nodes choose their CHs...
based on the signal strength received from the CHs, in both BRE-LEACH and LEACH, some nodes cannot join any cluster. Therefore, the data of these nodes cannot reach the sink. Besides, in the BRE-LEACH, CHs that contain over-membered nodes may expire their power earlier than others because of the unequal number of nodes in the clusters. Furthermore, in the BRE-LEACH algorithm, the root CH aggregates all the data from the CHs and forwards it to the sink, nevertheless, CHs that are placed near to the sink rather than the root may consume more energy by sending data to the root rather than to the base station.

4 The Proposed Protocol

In this work, we proposed a new energy-efficient protocol, which aims to optimize energy consumption, extend network stability, increase network lifetime and improve throughput. The proposed approach is an improved BRE-LEACH clustering protocol, which has rounds and each round has phases, just like LEACH and BRE-LEACH. Instead of the LEACH algorithm that has two phases, the proposed protocol has four phases for each round, as described below.

4.1 First Phase

To avoid low energy nodes being scheduled to become CHs and to save energy, the proposed approach suggests selecting CHs based on the residual energy of the nodes. According to the workflow of LEACH and its improved protocols, at the beginning of each round, each node chooses a random number \( R_n \) \((0 < R_n < 1)\). This node becomes a CH in the current turn if the value of \( R_n \) is inferior to the threshold function defined in the Eq. (2) as proposed in our previous work [16], which is examined as a modification of the Eq. (1). On the other hand, it becomes a Normal Node (NN).

\[
T_p(n) = \begin{cases} 
\frac{P}{1-P^*(r \mod (1/P))} \cdot \frac{E_{\text{remaining}}}{E_{\text{initial}}} & n \in G \\
0 & \text{otherwise}
\end{cases}
\]  

(2)

where \( E_{\text{remaining}} \) is the remaining energy of the nodes at the \( r \)th iteration, and \( E_{\text{initial}} \) denotes the initial energy of the nodes.

To conserve and balance the energy in the network, the proposed approach serves to limit the number of NNs in each cluster not to exceed \( N_{cl} = N/CH \). This number depends on the total number of alive nodes and the number of CHs.

Once CHs are selected, each one creates a TDMA (Time-Division Multiple Access) scheduled to receive data from the cluster members in their time slots. Then, they broadcast an announcement message to the network, which includes the ID and the coordinates of each CH.

When the NNs receive these messages, they create a table of distances to the CHs. To choose the CH to belong to, the NN sends a JOIN-demand to the CH that has the lowest distance in its table and less than the threshold distance \( l_0 \) defined in the Eq. (9). If this CH still has a free time slot in the TDMA schedule and the number of nodes in its cluster is less than \( N_{cl} \), this CH will be the corresponding CH. On the other side, the NN sends a second JOIN-demand to the next CH that has the lowest distance in its table and lower than the threshold distance, and so forth. The IBRE-LEACH approach suggests that the distance...
between NNs and their CHs should be less than the threshold $l_0$ to avoid multipath propagation, which consumes more than the free space as defined in Sect. 4.5.

The distance between two devices is calculated using the Euclidean distance based on the coordinates $(X, Y)$ as shown in the Eq. (3).

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$$  \hspace{1cm} (3)

Furthermore, the proposed solution fixes the number of nodes in each cluster to balance the residual energy of CHs in the network.

Once clusters are formed, NNs that cannot join any cluster will be neglected. These nodes are called Abandoned Nodes (ANs). In this paper, these abandoned nodes can route their data to the BS like NNs and CHs.

### 4.2 Second Phase

Once the ANs are fixed and the clusters are established, all ANs announce themselves to CHs via an announcement message. This message includes the ID and the coordinates of the AN. Then, the proposed protocol chooses a root node. This root will be a CH or AN that has remaining energy greater than or equal to the average current energy of all CHs and ANs ($E_{\text{ave}}$) defined in Eq. (4), and the distance to the BS is less than or equal to the average distance of all CHs and ANs from the BS ($d_{\text{ave}}$) as defined in Eq. (5).

$$E_{\text{ave}} = \frac{E_{\text{aver}}(\text{CH}) + E_{\text{aver}}(\text{AN})}{2}$$  \hspace{1cm} (4)

$$d_{\text{avetoBS}} = \frac{d_{\text{avetoBS}}(\text{CH}) + d_{\text{avetoBS}}(\text{AN})}{2}$$  \hspace{1cm} (5)

Where $E_{\text{aver}}(\text{AN})$ and $d_{\text{avetoBS}}(\text{AN})$ indicate the average residual energy and the average distance to the BS of all the ANs defined in Eqs. (6) and (7), respectively. The same holds for $E_{\text{aver}}(\text{CH})$ and $d_{\text{avetoBS}}(\text{CH})$, which present the average residual energy and the average distance to the BS of all CHs, respectively.

$$E_{\text{aver}}(\text{AN}) = \frac{\sum_{i=1}^{u} E_{\text{res}}(i)}{AN}$$  \hspace{1cm} (6)

$$d_{\text{avetoBS}}(\text{AN}) = \frac{\sum_{j=1}^{u} d_{\text{to-BS}}(j)}{AN}$$  \hspace{1cm} (7)

The root node aggregates its data with the received data from other CHs and ANs, and then sends it directly to the BS. Its main objective is to minimize the overload on the base station and to avoid CHs and ANs with little energy and far from the base station do not communicate directly with it, which consumes a lot of energy.

### 4.3 Third Phase

In this phase, every CH generates its routing table which consists of distances to all CHs, ANs, the root, and the BS. The same applies to the ANs. From this routing table, each CH
and AN recognizes its next hop. Thus, with our approach, all ANs can route their information to the BS, as can the CHs and NNs.

### 4.4 Fourth Phase

In this phase (communication phase), each CH (or AN) can choose its optimal path to route its data to the BS according to its routing table, which includes the distance to all CHs, ANs, the root, and the BS.

Figure 3 illustrates the architecture of the proposed protocol.

This figure describes how our proposed approach works. Each CH (or AN) generates its routing table which contains distances to other CHs, ANs, the root and the BS. Then, it orders these distances from the closest to the farthest. After that, the proposed solution suggests certain conditions to choose the most optimal route for each CH and AN to reach the BS. Let’s take the example of CH1 whose closest distance is with CH2, then the root, the BS, etc. The proposed approach compares $d_{CH1toBS}$ (the distance of the first element of the routing table with the BS) and $d_{CH1toAN}$ (distance between CH1 and the BS). In this case, $d_{CH1toBS}$ is less than $d_{CH2toBS}$. So, CH2 will not be the next hop of CH1. Then, it moves to the next element in its routing table. Similarly, when it compares the $d_{RoottoBS}$ (the distance between the root and the BS) with $d_{CH1toBS}$, it finds that $d_{CH1toBS}$ is lower than the $d_{RoottoBS}$ and the third element in its routing table is the base station. Therefore, CH1 chooses to send directly to the BS because it is the optimal route.

Furthermore, there are three cases to route data to the BS, as follows:
Case 1: The CH (or AN) transmits its data directly to the BS when its distance to the BS is the most optimal. In this case, when the distance to the BS \( d_{CH-BS} \) is less than the threshold distance \( l_0 \), then the transmission energy will be a function of the distance at power 2. Otherwise, it will be a function of the distance at power 4 as shown in the algorithm below (algorithm 1).

**Algorithm 1 Case 1: Transmission directly to the BS**

**Require:** This algorithm is valid for CHs and ANs
- \( d_{CH-BS} \): The distance from CH to the BS
- \( d_{CH-ND} \): The distance from CH to the Next Destination (CH or AN)
- \( d_{CH-root} \): The distance from CH to the root

begin
1: if \( d_{CH-BS} < d_{CH-root} \) then
2:     if \( d_{CH-BS} < d_{CH-ND} \) then
3:         The CH sends its data directly to the BS
         Transmission energy:
4:             if \( d_{CH-BS} < l_0 \) then
5:                 The transmission energy is in terms of the distance squared
                 \( E_{Tx} = m\epsilon_{elec} + m\epsilon_{fx}d_{CH-BS}^{2} \)
6:             else
7:                 The transmission energy is in terms of the distance to the power four
                 \( E_{Tx} = m\epsilon_{elec} + m\epsilon_{mp}d_{CH-BS}^{4} \)
8:         end if
9:     end if
10: end if

Case 2:
The CH (or AN) transmits its data to the root when the distance to the root is the optimal path. In this case, when the distance to the root \( d_{CH-root} \) is less than the threshold distance \( l_0 \), then the transmission energy will be a function of the distance to the power 2. Otherwise, it will be a function of the distance to power 4 as described in the algorithm below (algorithm 2).
Case 3:

The CH (or AN) transmits its data to the next destination (either CH or AN) when the distance is less than the distance to the root and the distance to the BS. In this case, when the distance to the BS ($d_{CH-BS}$) is less than the threshold distance $l_0$, then the transmission energy will be a function of the distance to the power 2. Otherwise, it will be a function of the distance to power 4 as described in the algorithm below (algorithm 3).

Algorithm 2 Case 1: Transmission to the root

Require: This algorithm is valid for CHs and ANs
\[
d_{CH-BS} \text{: The distance from CH to the BS}
\]
\[
d_{CH-ND} \text{: The distance from CH to the Next Destination (CH or AN)}
\]
\[
d_{CH-root} \text{: The distance from CH to the root}
\]

begin
1: if $d_{CH-root} < d_{CH-BS}$ then
2: \quad if $d_{CH-root} < d_{CH-ND}$ then
3: \quad \quad The CH sends its data to the root
4: \quad \quad Transmission energy:
5: \quad \quad \quad $E_{Tx} = m \cdot E_{elec} + m \cdot \epsilon_f \cdot d_{CH-root}^2$
6: \quad else
7: \quad \quad The transmission energy is in terms of the distance to the power four
8: \quad \quad $E_{Tx} = m \cdot E_{elec} + m \cdot \epsilon_{mp} \cdot d_{CH-root}^4$
9: \quad end if
10: end if

Algorithm 3 Case 1: Transmission to the next destination (CH or AN)

Require: This algorithm is valid for CHs and ANs
\[
d_{CH-BS} \text{: The distance from CH to the BS}
\]
\[
d_{CH-ND} \text{: The distance from CH to the Next Destination (CH or AN)}
\]
\[
d_{CH-root} \text{: The distance from CH to the root}
\]

begin
1: if $d_{CH-ND} < d_{CH-BS}$ then
2: \quad if $d_{CH-ND} < d_{CH-root}$ then
3: \quad \quad The CH sends its data to the next destination (either CH or AN)
4: \quad \quad Transmission energy:
5: \quad \quad \quad $E_{Tx} = m \cdot E_{elec} + m \cdot \epsilon_f \cdot d_{CH-ND}^2$
6: \quad else
7: \quad \quad The transmission energy is in terms of the distance to the power four
8: \quad \quad $E_{Tx} = m \cdot E_{elec} + m \cdot \epsilon_{mp} \cdot d_{CH-ND}^4$
9: \quad end if
10: end if

If the next destination is a CH or AN and not the BS or the root, the same procedure is repeated until all CHs and ANs reach the root or the BS. The next hop for each CH and AN will be in the direction of the BS to avoid the next-hop being further from the BS.
4.5 Radio Energy Model

The radio hardware model is presented in Fig. 4, where the transmitter consists of the transmission electronic circuit and the amplifier, then the receiver consists of the reception electronic circuit. Either the transmitter or the receiver consumes energy to perform their operations as shown in the equations below. The transmission power consumption design takes into account a free space channel in terms of $l^2$ and the multipath channel in terms of $l^4$.

For a message of $m$ bits to travel a distance $l$ to attain the receiver, the transmitter consumes the following energy:

$$E_{Tx}(m, l) = \begin{cases} 
m * E_{elec} + m * \epsilon_{fs} * l^2, & l < l_0 \\
m * E_{elec} + m * \epsilon_{mp} * l^4, & l \geq l_0
\end{cases}$$

(8)

$$l_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}$$

(9)

At the reception level, the power consumed is expressed by $E_{RX}$ in the Eq. (10).

$$E_{RX}(m) = m * E_{elec}$$

(10)

Where $E_{elec}$ denotes the energy consumption to transmit (or receive) the signal. $\epsilon_{fs}$ and $\epsilon_{mp}$ present the transmission capacity, and $l$ is the distance from the source node to the destination node.

The proposed approach optimizes the energy consumption of the nodes by using free-space propagation as much as possible to avoid the high consumption dissipated in multipath propagation. It forms clusters by distances between the CH and its members that do not exceed the threshold distance $l_0$.

5 Simulation Results

In this section, we are going to use simulation to analyze our proposed protocol. We use MATLAB as a simulator to evaluate our protocol’s performances against BRE-LEACH, LEACH-C, and LEACH protocols.
5.1 Simulation Setup

To simulate the performance of the proposed IBRE-LEACH clustering protocol, the used parameters are indicated in the Table 1. We consider 100 homogeneous nodes, randomly distributed in a square area of $300 \times 300 \, \text{m}^2$. One BS, with a variable location. We used $1 \, \text{J}$ as the initial energy of the nodes. We consider that all nodes and the BS are stationary and not mobile.

We evaluated the performance of the IBRE-LEACH approach in terms of several metrics: network stability, network lifetime, throughput, and energy consumption of the entire network.

To conclude the impact of the BS position in the network on these metrics, three scenarios are discussed. The first one represents the BS position at the center of the network. The second one is where the BS position is at the edge of the network. The third scenario shows the situation where the BS is placed far from the network.

5.2 Analyse of Results

5.2.1 First Scenario

In the first scenario, IBRE-LEACH is evaluated in a homogeneous network of 100 nodes, distributed randomly in $300 \times 300 \, \text{m}^2$, the BS coordinates are (150,150). Figure 5 illustrates the network lifetime and the network’s total energy consumption for the first scenario. These results give confidence that the proposed approach provides a better network lifetime than the compared protocols. The stability area (represents the number of rounds where all nodes are alive) is improved using IBRE-LEACH compared to LEACH, LEACH-C, and BRE-LEACH, as can be seen in Fig. 5a.

The second important metric is energy consumption. Figure 5b shows the total residual energy in the entire network for the first scenario. The results of this curve show that the proposed technique consumes less than LEACH and its improved protocols LEACH-C and BRE-LEACH.

The third main metric discussed in this paper is throughput. Figure 6 highlights the number of packets sent to the BS in the IBRE-LEACH, BRE-LEACH, LEACH-C, and

| Table 1 Simulation parameters |  
| Parameter | Value |
| --- | --- |
| Number of nodes | 100 |
| Area | $300 \times 300 \, \text{m}^2$ |
| Initial energy ($E_i$) | $1 \, \text{J}$ |
| BS location (x,y) | Variable |
| $E_{\text{elec}}$ | $50 \, \text{nJ/bit}$ |
| $E_{\text{fs}}$ | $10 \, \text{pJ/bit/m}^2$ |
| $E_{\text{emp}}$ | $0.0013 \, \text{pJ/bit/m}^4$ |
| Data aggregation energy (EDA) | $5 \, \text{nJ/bit}$ |
| Packet size | 4000 bits |
| Number of rounds executed | 4000 |
LEACH. From these results, it is remarkable that the number of packets delivered to the BS has increased with IBRE-LEACH compared to LEACH, LEACH-C, and BRE-LEACH.

### 5.2.2 Second Scenario

In the second scenario, we kept all the parameters of the 1st scenario except that the BS location changes from the center to the edge of the network (BS at (150,300)).

As in the first scenario, we evaluated the performance and validity of the proposed approach based on network stability, network lifetime, throughput, and energy consumption. Figure 7 exhibits the network lifetime and network energy consumption when the BS is placed at coordinates (150,300). Consequently, the IBRE-LEACH protocol performs better than the compared protocols.
The total number of packets reaching the BS is illustrated in Figure 8. Once again, the proposed IBRE-LEACH protocol obtained a large number of packets compared to the other approaches.

5.2.3 Third Scenario

In the third scenario, we located the BS far from the network. Figure 9 presents the network lifetime and total residual energy of the network for the third scenario when the BS is located at coordinates (150,350).

Figure 10 depicts the total number of packets received by the BS when it is placed far from the network.

From these results, it is evident that the proposed approach increases the network lifetime by increasing the stability zone. Furthermore, the IBRE-LEACH protocol consumes less energy than other protocols.
the compared protocols in all cases. Thus, the number of packets that reached the BS is more important with IBRE-LEACH than in the other compared protocols.

6 Results Discussion

Interpreting the obtained results, our proposed IBRE-LEACH approach has achieved significant results in improving the network stability, network lifetime, energy consumption, and throughput compared to the conventional LEACH protocol and its variants LEACH-C and BRE-LEACH. These results are likely related to the advantage of the IBRE-LEACH protocol, which revealed several factors responsible for this improvement. The IBRE-LEACH avoids that nodes with less residual energy be elected as CHs by considering the residual energy. It balances the energy among CHs by determining the maximum number of nodes in each cluster and then avoids the
multipath propagation between the CH and its cluster members. In addition, in the IBRE-LEACH data of abandoned nodes can reach the BS as well as data of CHs and NNs. It uses the multi-hop technique between CHs and ANs to reach the BS. To avoid overloading and direct communication of multiple CHs with the BS whatever the distance and energy, the proposed approach selects a root node with enough residual energy and minimum distance to the BS. This root aggregates the data of the distant CHs and ANs after one or more multi-hops.

Table 2 provides the summary statistics of the results obtained in the simulation section. FND (First Node Die), HND (Half Node Die), and LND (Last Node Die).

As the data in Table 2 show, the IBRE-LEACH improves BRE-LEACH, LEACH-C, and LEACH in all cases. In the first scenario, when the BS is located in the center of the network, IBRE-LEACH improves the stability, presented by FND, and the network lifetime by 33% compared to BRE-LEACH, 80.14% to LEACH-C, and 81.41% to LEACH. In the second scenario, it enhances BRE-LEACH by 72.54%, LEACH-C by 94.33%, and LEACH by 87.16%. Finally, when the BS is located far from the network, the proposed method improves the network lifetime and stability by 81.99%, 91.85%, and 91.47% compared to BRE-LEACH, LEACH-C, and LEACH, respectively. The results suggest that our approach improves the stability and lifetime of the network in all positions of the BS compared to other protocols as we can see also in Figs. 5a, 7a, 9a. Furthermore, our proposed protocol will be suitable for all applications, whether the base station is located in the center of the network, at the terminal, or very far from the network.

In addition, IBRE-LEACH aims to decreases the total energy consumption in the entire network, as we can see in Figs. 5b, 7b and 9b. These results indicate that the IBRE-LEACH protocol consumes less energy than the other discussed approaches. It can also be noticed that even if the BS is located far from the network, it consumes less energy. On the other hand, the other protocols consume more energy when the BS changes its position from the center to the outside of the network.

The throughput of the network is also evaluated (see Figs. 6, 8, and 10). Overall, these results indicate that the total number of packets sent to the BS per round is increased with IBRE-LEACH than with BRE-LEACH, LEACH-C, and LEACH. It seems that these results are due to many factors. ANs’ data can reach the BS unlike in BRE-LEACH. The energy balance between clusters,

| BS position | Protocol   | FND  | HND  | LND  | Network lifetime improvement |
|-------------|------------|------|------|------|----------------------------|
| BS(150,150) | IBRE-LEACH | 1264 | 2204 | >4000| –                          |
|             | BRE-LEACH  | 847  | 1823 | 2195 | 33%                        |
|             | LEACH-C     | 251  | 935  | 3350 | 80.14%                     |
|             | LEACH       | 235  | 610  | 2079 | 81.41%                     |
| BS(150,300) | IBRE-LEACH  | 1129 | 2063 | >4000| –                          |
|             | BRE-LEACH  | 310  | 1210 | 2475 | 72.54%                     |
|             | LEACH-C     | 64   | 612  | 3144 | 94.33%                     |
|             | LEACH       | 145  | 596  | 1603 | 87.16%                     |
| BS(150,350) | IBRE-LEACH  | 1055 | 1916 | >4000| –                          |
|             | BRE-LEACH  | 190  | 767  | 2557 | 81.99%                     |
|             | LEACH-C     | 86   | 232  | 2132 | 91.85%                     |
|             | LEACH       | 90   | 391  | 1401 | 91.47%                     |
the root selection, and the multi-hop between CHs and ANs avoid the rapid death of CHs. As a result, the number of packets received at the BS increased.

In summary, the performance of the WSN will significantly increase using the proposed protocol as all the compared metrics have been improved.

7 Conclusion

WSNs are an innovative technology that in recent years has been widely used for several applications, including military, health, and home automation, etc. The WSN consists of many sensor nodes (from several hundred to several thousand), randomly or uniformly distributed in a specific monitoring area. Nonetheless, the energy constraint has limited the capabilities of WSNs. Indeed, this major constraint has attracted considerable attention from researchers to solve the energy consumption and extend the life cycle of WSNs by using different methods. Routing protocols have a significant role in the design and maintenance of a network to produce efficient communication between source and destination sensor nodes. Clustering is an efficient mechanism for organizing the network with conventional routing techniques, due to its numerous advantages, such as high energy efficiency, latency reduction, etc.

In this paper, an energy-efficient approach is proposed to improve the performance of the BRE-LEACH approach. Our IBRE-LEACH protocol has enhanced the selection of CHs, the cluster formation process, and the data transmission technique. Instead of electing CHs randomly, it selects them in the network based on the remaining energy of the nodes, so that only nodes with enough energy can act as CHs. To avoid energy consumption imbalance and CH overload, the proposed IBRE-LEACH algorithm adopts equal clustering. This means that the number of nodes in each cluster does not exceed a predefined number based on the total number of alive nodes and the desired number of CHs in the network. Nodes that cannot join any cluster have the chance to send their data to the BS using IBRE-LEACH unlike in BRE-LEACH. Hence, the proposed protocol has enhanced the data transfer technique. In BRE-LEACH, all CHs send their data to the root, even those that are close to the BS than the root. Moreover, in BRE-LEACH, the next hop may not be in the same direction as the BS, resulting in higher power consumption. In the IBRE-LEACH protocol, each CH generates its routing table to choose the optimal direction to reach the BS through intermediate nodes (CHs, ANs, or the root), or directly to the BS. The same CH process is used by the ANs.

The simulation results illustrated that the proposed IBRE-LEACH approach achieved better performance compared to BRE-LEACH, LEACH-C and LEACH in terms of stability, network lifetime, throughput, and energy consumption. The proposed technique increased the stability and lifetime of the network by 81.99%, 94.33%, and 91.47% compared to BRE-LEACH, LEACH-C and LEACH, respectively. Furthermore, the IBRE-LEACH decreased the energy consumption of the entire network by electing CHs based on the residual energy, limiting the number of nodes in each cluster, and selecting a root node with enough energy and a minimum distance to the BS. Thus, it also extended the throughput by increasing the number of packets arriving at the BS.

In summary, by setting up simulation results, we concluded that the proposed IBRE-LEACH protocol performs better than BRE-LEACH, LEACH-C, and LEACH in all BS positions by improving the stability, network lifetime, throughput, and energy consumption. Therefore, IBRE-LEACH is very suitable for a large network with all BS locations.
Acknowledgements  The authors would like to express their sincere gratitude for the editors and reviewers for the valuable comments, which is helpful in improving the paper quality.

Funding  The authors have not disclosed any funding.

Data Availability  The data and simulation programs that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest  The authors declare that they have no conflict of interest.

References

1. Fanian, F., & Rafsanjani, M. K. (2019). Cluster-based routing protocols in wireless sensor networks: A survey based on methodology. *Journal of Network and Computer Applications*, 142, 111–142.
2. Daanoune, I., Baghdad, A., & Ballouk, A. (2020). An enhanced energy-efficient routing protocol for wireless sensor network. *International Journal of Electrical and Computer Engineering (UOECE)*, 10(5), 8.
3. Liu, Y., Qiong, W., Zhao, T., Tie, Y., Bai, F., & Jin, M. (2019). An improved energy-efficient routing protocol for wireless sensor networks. *Sensors*, 19, 4579.
4. Zungeru, A. M., Ang, L.-M., & Seng, K. P. (2012). Classical and swarm intelligence based routing protocols for wireless sensor networks: A survey and comparison. *Journal of Network and Computer Applications*, 35(5), 1508–1536.
5. Wenliang, W., Xiong, N., & Chunxue, W. (2017). Improved clustering algorithm based on energy consumption in wireless sensor networks. *IET Networks*, 6, 47–53.
6. Tyagi, S., & Kumar, N. (2013). A systematic review on clustering and routing techniques based upon LEACH protocol for wireless sensor networks. *Journal of Network and Computer Applications*, 36(2), 623–645.
7. Zin, S. M., Anuar, N. B., Khal, M. L. M., & Pathan, A.-S.K. (2014). Routing protocol design for secure WSN Review and open research issues. *Journal of Network and Computer Applications*, 41, 517–530.
8. Rehan, W., Fischer, S., Rehan, M., Mawad, Y., & Saleem, S. (2020). QCM2R: A QoS-aware cross-layered multichannel multisink routing protocol for stream based wireless sensor network. *Journal of Network and Computer Applications*, 156, 102552.
9. Youasf, A., Ahmad, F., Hamid, S., & Khan, F. (2019). Performance comparison of various LEACH protocols in wireless sensor networks. In: *2019 IEEE 15th international colloquium on signal processing & its applications (CSPA)* (pp. 108–113). IEEE.
10. Daanoune, I., Baghdad, A., & Ballouk, A. (2019). A comparative study between ACO-based protocols and PSO-based protocols in WSN. In: *2019 7th mediterranean congress of telecommunications (CMT)* (pp. 1–4).
11. Al Aghbari, Z., Khedr, A. M., Osamy, W., Arif, I., & Agrawal, D. P. (2019). Routing in wireless sensor networks using optimization techniques: A survey. *Wireless Personal Communications*, 111(4), 2407–2434.
12. Huang, J., Zhao, Z., Yuan, Y., & Hong, Y. (2017). Multi-factor and distributed clustering routing protocol in wireless sensor networks. *Wireless Personal Communications*, 95(3), 2127–2142.
13. Moothi, & Thiagarajan, R. (2020). Energy consumption and network connectivity based on Novel-LEACH-POS protocol networks. *Computer Communications*, 149, 90–98.
14. Cai, X., Geng, S., Wu, D., Wang, L., & Wu, Q. (2020). A unified heuristic bat algorithm to optimize the LEACH protocol. *Concurrency and Computation: Practice and Experience*, 32(9), e5619.
15. Daanoune, I., Abdennaceur, B., & Ballouk, A. (2021). A comprehensive survey on LEACH-based clustering routing protocols in Wireless Sensor Networks. *Ad Hoc Networks*, 114, 102409.
16. Daanoune, I., Baghdad, A., & Ballouk, A. (2019). BRE-LEACH: A new approach to extend the lifetime Of WSN. In: *Third Inter. Conference on Intelligent Computing in Data Sciences (ICDS)* (pp. 1–6). IEEE.
17. Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. In: *Proceedings of the 33rd annual hawaii international conference on system sciences* (vol. 1, p. 10). IEEE Comput. Soc.
18. Abu Salem, A. O., & Shudifat, N. (2019). Enhanced LEACH protocol for increasing a lifetime of WSNs. *Personal and Ubiquitous Computing*, 23, 901–907.
19. Mengjia Zeng, X., Huang, B. Z., & Fan, X. (2019). A heterogeneous energy wireless sensor network clustering protocol. *Wireless Communications and Mobile Computing*, 1–11, 2019.
20. Heinzelman, W. B., Chandrakasan, A. P., & Balakrishnan, H. (2002). An application-specific protocol architecture for wireless microsensor networks. *IEEE Transactions on Wireless Communications, 1*(4), 660–670.

21. Ma, Z., Li, G., & Gong, Q. (2016). Improvement on LEACH-C protocol of wireless sensor network (LEACH-CC). *International Journal of Future Generation Communication and Networking, 9*, 183–192.

22. Sivakumar, P., & Radhika, M. (2018). Performance analysis of LEACH-GA over LEACH and LEACH-C in WSN. *Procedia Computer Science, 125*, 248–256.

23. Henrique Brandao Neto, J., Cardoso, A. R., & Celestino Jr, J. (2014). MH-LEACH: A distributed algorithm for multi-hop communication in wireless sensor networks. In: *ICN 2014: The thirteenth international conference on networks* (pp. 55–61).

24. Alnawafa, E, & Marghescu, I. (2016). MHT: Multi-hop technique for the improvement of leach protocol. In: *2016 15th RoEduNet conference: Networking in education and research* (pp. 1–5). IEEE.

25. Yektaparast, A., Nabavi, F. H., & Sarmast, A. (2012). An improvement on LEACH protocol (Cell-LEACH). p. 5.

**Publisher’s Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ikram Daanoune is currently pursuing her Ph.D. degree at Hassan II University, Faculty of Sciences & Techniques (FST), Mohammedia, Morocco. She earned the engineering diploma in electrical & telecommunications at FST Mohammedia, Hassan II University, in 2018. Her areas of interest include wireless sensor networks, ad hoc networks, routing protocols, IoT, and channel coding for wireless communication. She authored many research documents in indexed journals and conferences.

Abdennaceur Baghdad is a university professor at FST Mohammedia, Hassan II University Casablanca-Morocco whether he educates the hyper-frequencies, electronic engineering, antenna, and systems of telecommunication. He obtained his doctorate in Electronics from Lille University France in 1992. He is a member of the EEA & TI laboratory at Hassan II University. He has more than 30 years of teaching experience. The research of BAGHDAD are focused on optical communication, electronic and embedded systems, telecommunication systems and information technology. He oversees and he co-supervises many doctoral theses. He is a member of the organizing committees of several international congresses in the same research area.