IBRE-LEACH: Improving The Performance of The BRE-LEACH For Wireless Sensor Networks

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IBRE-LEACH: Improving the performance of the BRE-LEACH for wireless sensor networks

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Abstract Wireless Sensor Networks (WSNs) are extensively used in different areas and especially in severe and harsh environments such as battlegrounds, volcanic areas, healthcare, and so on. The major constraint in WSNs is the limited power supply, which impacts the life-cycle of the entire network. Clustering is a performing method used in WSN to optimize power consumption and extend the lifetime of WSNs. LEACH is considered as the first classical clustering protocol used in WSN to optimize energy consumption. Many protocols had been developed to enhance the conventional LEACH protocol. BRE-LEACH (Balanced Residual Energy LEACH) is one of them. It serves to enhance the performance of the LEACH protocol. In this paper, we suggest a new improved BRE-LEACH protocol called IBRE-LEACH (Improved Balanced Residual Energy LEACH), which ameliorates the performance of the BRE-LEACH approach. The IBRE-LEACH combines clustering and multi-hop techniques. It elects CHs according to the residual energy, limits the maximum number of nodes in each cluster to balance energy consumption. Thus, IBRE-LEACH gives the Abandoned Nodes (ANs) the chance to send their data to the BS. Furthermore, it routes the gathered data using the 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 exhibit that the IBRE-LEACH increases the throughput, optimizes energy consumption, extends the network lifetime, and ameliorates the stability up to 81.99%, 94.33%, and up to 91.47% compared with BRE-LEACH, LEACH-C, and LEACH, respectively.

Keywords WSN · Efficient Routing Protocol · LEACH · Network Lifetime · Abandoned Nodes

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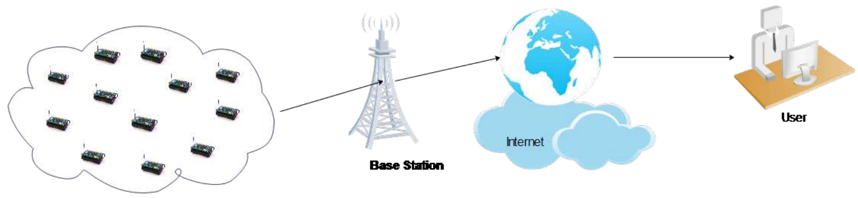


Fig. 1 WSN structure

1 Introduction

Recently, Wireless Sensor Networks (WSNs) caught the attention of scientific researchers for the reason that WSNs become largely applicable in several applications, and particularly in severe and sensible space where human operations are difficult or impossible [1,2], like in forest burning detection, military activities, seismic areas, medical, and so forth. WSN includes an enormous number of sensor nodes, which are aleatory distributed in a special area to monitor and collect diverse kinds of environment information [3]. Sensor nodes in WSN can monitor an area, communicate with neighboring devices, and execute calculations on the gathered data [4]. The function of each sensor node in WSN is to gather sensing data from the monitored geographical location and forward it to the Base Station (BS), then to the final user via the internet [5,6], as mentioned in Figure 1. Generally, sensor nodes have basic hardware capability equipped with at least one sensor, processor, storage, radio transceiver, antenna, and a small battery [7,8]. These tiny sensor nodes are typically restricted in terms of energy. So, the critical constraint in WSNs is the energy owing to the tiny size of batteries. Therefore, the principal research issue in WSN is enhancing energy efficiency by implementing various techniques [9]. Routing is the most attractive technique suggested by researchers to enhance energy performance in WSN. A routing protocol is required to establish a route between the transmitter and the receiver devices, which optimize the energy consumption in WSN [10]. Clustering is a beneficial technique in WSNs, which can enhance the lifetime and scalability through decreasing power consumption and balancing energy distribution in the network [11]. One of the most popular hierarchical clustering protocols that are applied to decrease energy consumption in WSN is LEACH. The operation of the LEACH protocol includes two main phases: the set-up phase where clusters are forming, and the data transfer phase [12]. In the first state, the LEACH algorithm grouped the network into groups (clusters), each one consist of cluster members and a CH. Each cluster member collects data from the supervising area and sends it to its CH. Thus, the BS received the aggregated data by CH [13]. However, the LEACH approach has numerous issues, such as CHs are randomly picked without considering energy, the number of cluster members is not the same in all clusters, which leads to an energy imbalance. Furthermore, the LEACH approach uses a single hop between devices to achieve the BS. In this context, numerous improved LEACH protocols are proposed to enhance the lifetime

and decrease the consumption of power in LEACH [14]. BRE-LEACH is one of them, which has improved the performance of LEACH, it is presented and evaluated in [15].
In this document, we suggest a new approach to enhance the performance of the BRE-LEACH approach. In the proposed IBRE-LEACH protocol, the threshold function for selecting CH includes the ratio between the remaining energy and the initial energy of each node. Therefore, the percentage that a node with low energy becomes a CH is very excluded. Hence, instead of the aleatory number of nodes in each cluster in BRE-LEACH, the IBRE-LEACH defines a maximum number not to be exceeded in clusters to equilibrate the energy load of CHs in the network. In IBRE-LEACH, nodes that can not join any cluster have the chance to forward their data to the BS unlike in BRE-LEACH. Thus, in BRE-LEACH, all CHs send their data to the root even the CHs that are near to the BS as well as to the root. Also, in BRE-LEACH it is possible that the next-hop will 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 pick out the optimal path to reach the BS through intermediate nodes (CHs, ANs, or the root), or directly to the BS.
The document organization is as pursue: Section II gives an overview of the related work. Section III provides a brief detail of the BRE-LEACH protocol. Section IV described the proposed IBRE-LEACH protocol. The simulation results are analyzed and shown in section V. A comparative analysis of the proposed protocol with BRE-LEACH, LEACH-C, and the conventional LEACH algorithm is given in section VI. At the end of the paper, a conclusion is donated in section VII.

2 Related Work

Clustering is a beneficial routing technique in WSNs, which can enhance lifetime and scalability through decreasing power consumption and balancing energy distribution in the network. [16] proposed an effective 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. Sensor nodes organize themselves in clusters and set one of them as a leader (CH) [17]. LEACH is a hierarchical routing protocol that ensures that the node can not participate regularly in the CH election by using a random probability function to choose CHs defined in equation 1[16].

$$T_{LEACH} = \begin{cases} \frac{P_r}{1-P_r*(i\ \%(1/P_r))}, n \in G \\ 0 \qquad\qquad\qquad\qquad \text{otherwise} \end{cases} \tag{1}$$

Here, p_r and i introduce the probability of CHs in the full network and actual iteration, respectively. G presents the collection of nodes that have not become the leader in the previous 1/p rounds.

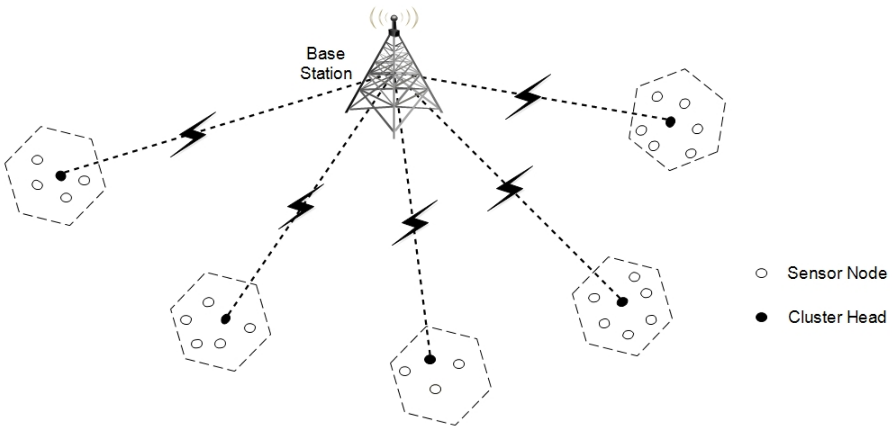


Fig. 2 Clustering in the LEACH protocols.

The LEACH approach uses the round concept. Each round comprises two phases:(1) the set-up phase, (2) the regular-state phase. The first phase consists of three sub-phases: the advertisement, the schedule creation, and the cluster formation. Otherwise, the second phase concerns the data transmission.
In the first phase, every sensor node decides to turn into a leader or as a common node. At the start of each round, every node chooses an arbitrary number amongst zero and one. The node will be considered as a CH in the current round if the chosen number is fewer than the threshold function described in equation (1). On the other hand, it becomes a common node. In the advertisement step, CHs announce network nodes by their status. Then, the common nodes designate their corresponding CH depending on the strength received signals.
In the second phase, each CH aggregates data from its cluster members, then sends its directly to the sink as shown in Fig. 2.

The LEACH protocol has some advantages as follow:

• The hierarchical LEACH protocol has the benefit of easy implementation and can efficiently balance network charges [18].

• It served to raise the lifetime of the WSN by reducing and distributing energy consumption within the network in comparison with direct communication.

• It provides a random rotation of CH between nodes.

Unfortunately, the LEACH approach has numerous shortcomings like

• Every CH sends aggregate data immediately to the sink, not dealing with the remaining energy and the distance between it and the BS. Therefore, for far CHs, energy will be more consumed, and if the remaining energy of the

CH was weak, it will die early. When a CH dies, the cluster will become useless because the data collected by the cluster members will never achieve the sink.

• It is not possible to operate in networks of a larger environment.

• Random selection of CH. So, it is substantial to note that the remaining energy was not taken into consideration in the CH selection and the cluster formation [12].

• The number of nodes in each cluster is not the same, which leads to an imbalance in energy consumption because a cluster with more cluster members consumes more energy in aggregating, processing, and transmitting data.

• Data of nodes that can not join any cluster do not reach the BS.

Given the drawbacks of the LEACH approach, many clustered routing protocols based on LEACH have been proposed in considerable research for ameliorating the lifetime of WSNs. These variants LEACH protocols are classified into three categories as described in [14], protocols that enhance the CH selection, protocols that improved data transmission techniques, and protocols that ameliorated both phases of LEACH.
Low Energy Adaptive Clustering Hierarchy-Centralized (LEACH-C) is one of these variant LEACH protocol, it was suggested by Heinzelman et al. in [19]. LEACH-C is a centralized clustering protocol based on LEACH, which allows improving the traditional LEACH approach. Unlike the self-organization of nodes into clusters in LEACH, in LEACH-Centralized the BS responsible for cluster formation [20]. Thus, in LEACH, CHs are elected randomly by the sensor nodes, while in LEACH-C, they are chosen randomly by the sink according to their residual energy level and their location. Identical to LEACH, the LEACH-C protocol has two phases: the set-up phase and the steady-state phase [21].
At the starting of any round in the set-up phase, every 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 CHs and form clusters. Nodes with energy below the average will not be as CHs in the current iteration. When CHs are chosen and clusters are established, the regular-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 the LEACH. Thereby, it enhances the network lifetime. Nonetheless, the LEACH-C has some shortcomings, such as it is not applicable for wide networks, also the communication between all sensor nodes and the BS whatever the distance can impact the energy consumption.
Authors in [22] 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 by 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 stays the same as that in 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[23] is a LEACH-based protocol, which increased the network lifetime compared to the original LEACH protocol. The MHT-LEACH suggests a new method to forward data of CHs to the sink. This new technique serves 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 CHs in the network, which is similar to the set-up phase of the traditional LEACH. In the second phase, CHs are divided into two groups (external and internal) according to the distance. Finally, the third phase concerns data transmission. Every CH gathers its data with data of cluster members. Thereby, CHs of the external level send their packets to CHs at the internal level by using routing tables, then CHs of the internal group forward their data directly to the BS in a single hop.
In another way, authors in [24] have proposed Cell-LEACH to enhance the network coverage in WSN by dividing the network into cells. Every cell selects a node to be the cell-head within the cell. Therefore, Each cluster is formed by seven cells, normal nodes, and a CH. The main objective of the cell-LEACH protocol is to decreases 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 enhanced the stability and the life-cycle of WSN compared to the classical LEACH algorithm [15]. Unlike LEACH, the BRE-LEACH suggests four phases, (1) cluster setup phase;(2) TDMA scheduling phase; (3) selecting a root CH phase; and (4) Data transmission phase.
Since the CH aggregates all cluster member data, then it needs more power than normal nodes. So, it is necessary to choose the CHs based on the remaining energy. In this context, the BRE-LEACH picks out CHs depending on the remaining power to avoid those nodes with less energy participate in the CH selection contrary to LEACH which elects the CH randomly.
Once clusters are formed, the BRE-LEACH chooses the CH that has more remaining power and less distance to the sink as a root. This root collects data from other CHs, aggregates it, then forwards it to the sink. Although, the fact that nodes choose their CHs depending on the power of the received signal from CHs, in the BRE-LEACH as well as in LEACH, some nodes can not join any cluster. Then, the data of these nodes can not achieve the sink. Besides, in the BRE-LEACH, CHs which contain over-member nodes can expire their power previously than others because of the number of nodes which is not equal in the groups. Furthermore, in the BRE-LEACH algorithm, the root CH groups all CHs data and forwards it to the sink, nonetheless, CHs that placed nearby to the sink rather than the root can consume more energy when sending data to the root instead of to the BS.

4 The proposed protocol

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

4.1 First phase

To avoid that nodes with low energy will be scheduled to become CHs and to save the energy, the proposed approach suggests to select CHs based on the residual energy of nodes. Depending on the working process of LEACH and their improved protocols, at the beginning of each turn, 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 equation (2) as proposed in our previous work [15], which is examined as a modification for equation(1). On the other hand, it becomes a Normal Node (NN).

$$T_p(n) = \begin{cases} \frac{P}{1-P*(i \ mod(1/P))} * \frac{E_{remaining}}{E_{initial}}, n \in G \\ 0 \qquad\qquad\qquad\qquad \text{otherwise} \end{cases} \tag{2}$$

Where $E_{remaining}$ is the remaining energy of nodes at the i^{th} iteration, and $E_{initial}$ represents the beginning energy of nodes.
To save and balance 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 nodes (N) and the number of CHs (CH).
Once CHs are selected, each CH creates a TDMA[1] scheduled to receive data from the cluster members through their time slots. Then, they broadcast an announcement message to the network, which includes the ID and the coordinates of each CH.

When NNs receive these messages, it creates a table of distance to CHs. For choosing the CH belongs, the NN sends a JOIN-demand to the CH which has the lowest distance in its table and less than the threshold distance l_0 defined in equation (9). If this CH still has a free time slot in the TDMA program and the nodes number within its cluster is inferior to N_{cl}, this CH will be the corresponding CH. On the other side, the NN sends a second JOIN-demand to the next CH which has the lowest distance in its table and less 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

[1] Time-Division Multiple Access

to avoid the multipath propagation, which consumes more than the free space as defined in section 4.5.

The distance between two devices is calculated using the Euclidean distance based on the coordinates (X,Y) as shown in the equation below (equation (3)):

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

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 can not join any cluster will be neglected. These nodes named Abandoned Nodes (ANs). In this paper, these abandoned nodes have the chance to route their data to the BS like NNs and CHs.

4.2 Second phase

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

$$E_{ave} = \frac{E_{aver}(CH) + E_{aver}(AN)}{2} \tag{4}$$

$$d_{avetoBS} = \frac{d_{avertoBS}(CH) + d_{avertoBS}(AN)}{2} \tag{5}$$

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

$$E_{aver}(AN) = \frac{\sum_{i=1}^{a} E_{res}(i)}{AN} \tag{6}$$

$$d_{avertoBS}(AN) = \frac{\sum_{j=1}^{a} d_{to-BS}(j)}{AN} \tag{7}$$

The root node aggregates its data with the received data from other CHs and ANs, then sends it directly to the BS. Its main objective is to minimize the overload on the base station and to avoid that 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 for ANs. From this routing table, every CH and AN recognizes its next hop. So, through our approach, all ANs (which are abandoned by other routing protocols) can route their information to the BS, such as CHs .

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 consist of distance to all CHs, ANs, the root, and to the BS.

Figure 3 illustrates the architecture of the proposed protocol.

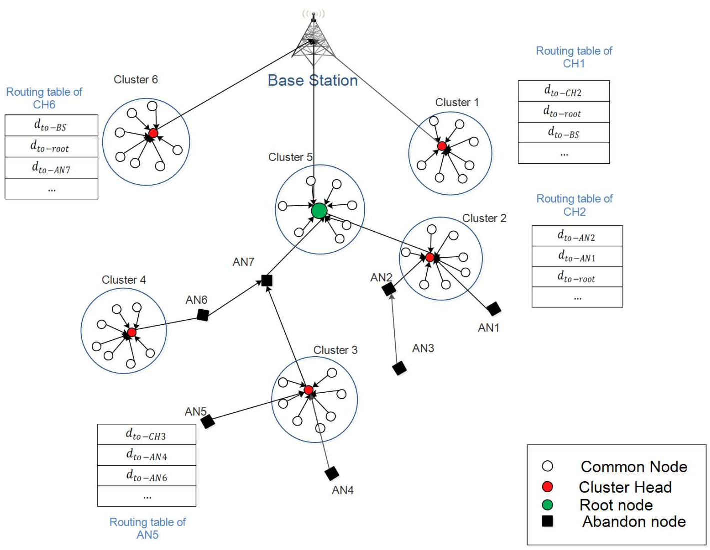


Fig. 3 The proposed protocol architecture.

This figure describes how our proposed approach works. Each CH (or AN) generates it routing table that 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 condition to choose the most optimal route for each CH and AN to reach the BS. Take the example of CH1 whose closest distance is with CH2, after that the root, the BS, etc. The proposed approach compares $d_{CH2toBS}$ (the distance of the first element in routing table with the BS) and $d_{CH1toBS}$ (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 passe to the next element in its routing table. The same, when it compares the $d_{Root-ToBS}$ (the distance of the root with the BS) with $d_{CH1toBS}$, it finds that $d_{CH1toBS}$ is lower than $d_{Root-ToBS}$ and its third element in the routing table is the BS. So, the CH1 choose to send directly to the BS because it will be the optimal route.

Furthermore, there are three cases to route data to the BS as following:

Case 1:
The CH (or the AN) forwards 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
if d_CH-BS < d_CH-root then
    if d_CH-BS < d_CH-ND then
        The CH sends its data directly to the BS
        Transmission energy :
        if d_CH-BS < l_0 then
            The transmission energy is in terms of the distance squared
            E_Tx = m * E_elec + m * ε_fs * d^2_CH-BS
        else
            The transmission energy is in terms of the distance to the power four
            E_Tx = m * E_elec + m * ε_mp * d^4_CH-BS
        end if
    end if
end if
```

Case 2:
The CH (or AN) forwards 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 at power 2. Otherwise, it will be a function of the distance at 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-ND}) 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 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} : *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
if $d_{CH-root} < d_{CH-BS}$ **then**
  if $d_{CH-root} < d_{CH-ND}$ **then**
    The CH sends its data to the root
    Transmission energy :
    if $d_{CH-root} < l_0$ **then**
      The transmission energy is in terms of the distance squared
      $E_{Tx} = m * E_{elec} + m * \epsilon_{fs} * d^2_{CH-root}$
    else
      The transmission energy is in terms of the distance to the power four
      $E_{Tx} = m * E_{elec} + m * \epsilon_{mp} * d^4_{CH-root}$
    end if
  end if
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} : *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
if $d_{CH-ND} < d_{CH-BS}$ **then**
  if $d_{CH-ND} < d_{CH-root}$ **then**
    The CH sends its data to the next destination(either CH or AN)
    Transmission energy :
    if $d_{CH-ND} < l_0$ **then**
      The transmission energy is in terms of the distance squared
      $E_{Tx} = m * E_{elec} + m * \epsilon_{fs} * d^2_{CH-ND}$
    else
      The transmission energy is in terms of the distance to the power four
      $E_{Tx} = m * E_{elec} + m * \epsilon_{mp} * d^4_{CH-ND}$
    end if
  end if
end if

If the next destination is a CH or AN 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 that the next hop will be further from the BS.

4.5 Energy Radio Model

The radio hardware model is presented in Fig. 4, where the transmitter includes the electronic transmission circuit and the amplifier, then the receiver consists of the electronic reception circuit. Either the transmitter or the receiver consumes energy to do their operations as shown in the equations below.

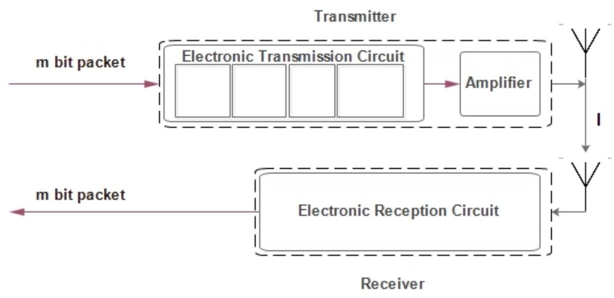


Fig. 4 Radio Model of Energy Consumption.

Transmission power consumption design takes up 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 achieve the receiver, the transmitter consumes the following energy:

$$E_{Tx}(m,l) = \begin{cases} m * E_{elec} + m * \epsilon_{fs} * l^2, & l < l_0 \\ m * E_{elec} + m * \epsilon_{mp} * l^4, & l >= l_0 \end{cases} \quad (8)$$

$$l_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \quad (9)$$

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

$$E_{RX}(m) = m * E_{elec} \quad (10)$$

Where E_{elec} denotes the energy consumption to transmit (or receive) the signal. ϵ_{fs} and ϵ_{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 in order 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.
- It creates routing tables for each CH and AN. Then, it selects for each CH (or AN) the most optimal path in order to consume the least energy at the transmission level.

5 Simulation results

In this part, we are going to use a simulation to analyze our proposed protocol. We use MATLAB as a simulator to evaluate our protocol performances compared to the BRE-LEACH, LEACH-C, and LEACH.

Table 1 Simulation Parameters.

Parameter	Value
Number of nodes	100
Area	300m*300m
Initial energy (E_i)	1J
BS location (x,y)	variable
E_{elec}	50 nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{mp}	0.0013 pJ/bit/m^4
Data aggregation energy (EDA)	5 nJ/bit
Packet size	4000 bits
Number of rounds executed	4000

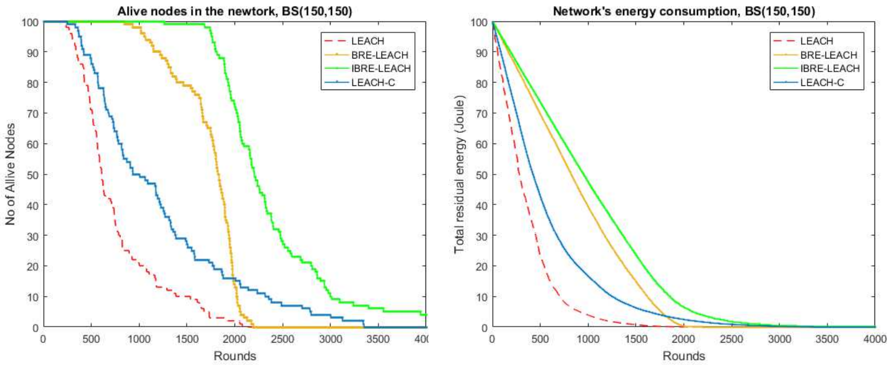
5.1 Simulation setup

To simulate the performance of the clustering proposed protocol IBRE-LEACH, the parameters used are indicated in table 1. We consider 100 homogeneous nodes, scattered randomly within a $300*300m^2$ square area. One BS, which its location is variable. We used 1J as the beginning energy of nodes. We consider that all nodes and the BS are stationary, not mobile.
We evaluated the performances of the IBRE-LEACH approach in terms of many metrics: the stability of the network, the network lifetime, the throughput, and the 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 $300{*}300^2$, 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 we can see in Figure 5 (a).
The second important metric is energy consumption. Figure 5 (b) shows the total residual energy in the entire network for the first scenario. Results from this curve depict that the proposed technique consumes less than LEACH and



(a) Network lifetime, BS(150,150) **(b)** Total energy consumption, BS(150,150)

Fig. 5 Comparison of network lifetime and total energy consumption in IBRE-LEACH, BRE-LEACH, LEACH-C and LEACH protocols for the first scenario.

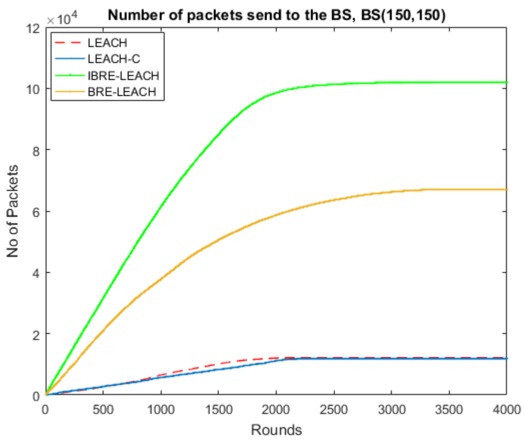
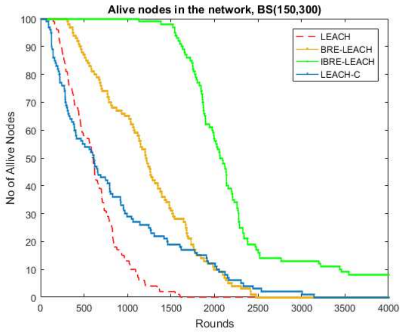
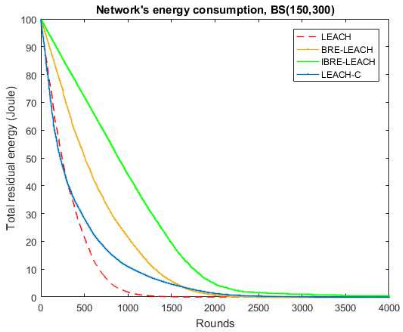


Fig. 6 Throughput of the proposed protocol compared to other protocols

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 LEACH.
From these results, it is remarkable that the number of packets delivered to the BS has extended using IBRE-LEACH in comparison to using LEACH, LEACH-C or BRE-LEACH.



(a) Network lifetime, BS(150,300)



(b) Total energy consumption, BS(150,300)

Fig. 7 Comparison of network lifetime and total energy consumption in IBRE-LEACH, BRE-LEACH, LEACH-C and LEACH protocols for the second scenario.

5.2.2 Second scenario

In the second scenario, we left all the parameters of the 1^{st} scenario except that the BS location changes from the center to the edge of the network(BS at (150,300)).
Like the first scenario, we evaluated the performance and the validity of the proposed approach according to the stability of the network, network lifetime, throughput, and energy consumption.
Figure 7 exhibits the network lifetime and network energy consumption when the BS is placed in the coordinates (150,300). Consequently, the IBRE-LEACH protocol performs better than the compared protocols.
The total number of packets reached to the BS is illustrated in Figure 8. Once more, the proposed IBRE-LEACH protocol has obtained the largest packets in comparison to other approaches.

5.2.3 Third scenario

In the third scenario, we located the BS far from the network.
Like the early scenarios, we evaluated the performance of the proposed approach when the BS placed away from the network.
Figure 9 presents the network lifetime and the total residual energy of the network for the third scenario when the BS is located at the coordinates (150,350).

Figure 10 depicts the total number of packets received by the BS when the BS is placed far from the network.
From these results, it is apparent that the proposed approach increases the network lifetime by increasing the stability zone. Furthermore, the IBRE-LEACH consumes less than the compared protocols in all cases. Thus, the number of packets that reached the BS is more important in IBRE-LEACH than other compared protocols.

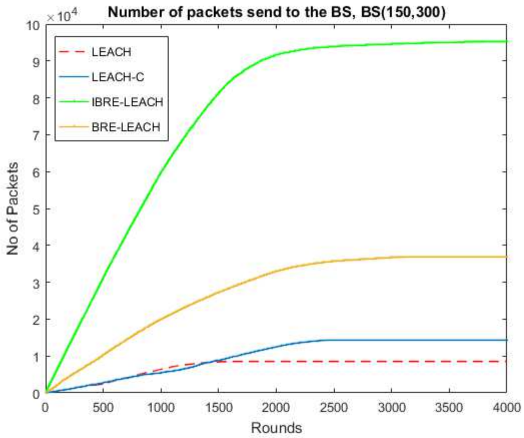
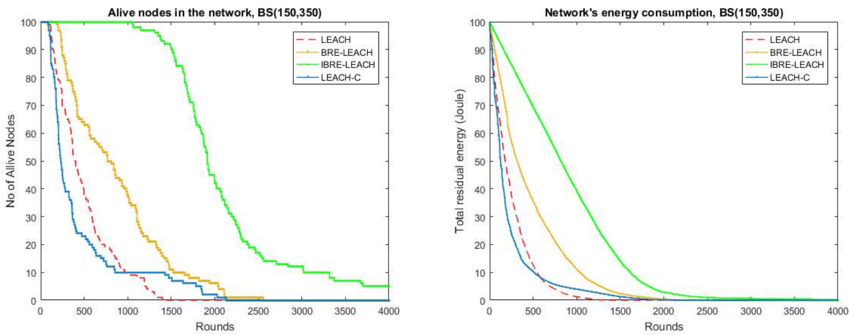


Fig. 8 Throughput of the proposed protocol compared to other protocols, BS(150,300)



(a) Network lifetime, BS(150,350) **(b)** Total energy consumption, BS(150,350)

Fig. 9 Comparison of network lifetime and total energy consumption in IBRE-LEACH, BRE-LEACH, LEACH-C and LEACH protocols for the third scenario.

6 Results discussion

Interpreting the earned results, our proposed approach IBRE-LEACH has been reached significant results in improving the stability of the network, network lifetime, energy consumption, and throughput compared to the classical LEACH protocol and its variant LEACH-C and BRE-LEACH. These results are likely to be related to the benefit of the IBRE-LEACH protocol, which revealed several factors that are responsible for this improvement. The IBRE-LEACH avoids that nodes with less residual energy be elected as a CH by considering the residual energy. It balances the energy between CHs by determining the maximum number of nodes in each cluster, 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

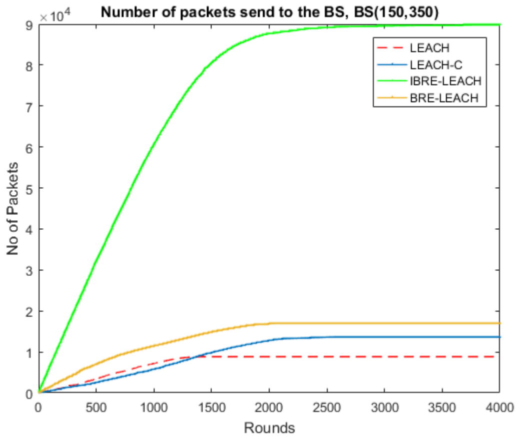


Fig. 10 Throughput of the proposed protocol compared to other protocols, BS(150,350)

data of CHs and NNs. It uses the multi-hop technique between CHs and ANs to reach the BS. In order to avoid overloading and direct communication of several 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 aggregate data from far CHs and ANs after one or more multi-hop.
Table 2 provides the summary statistics for the results obtained in the simulation section. FND (First Node Die), HND (Half Node Die), and LND(Last Node Die).

Table 2 Simulation results

BS position	approach	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%

As can be seen from the data in Table 2, the IBRE-LEACH improves BRE-

LEACH, LEACH-C, and LEACH in all cases. In the first scenario when the BS is located at the center of the network, the IBRE-LEACH improves the stability, which presented by FND, and the network lifetime by 33% compared to the BRE-LEACH, 80.14% to LEACH-C, and by 81.41% to LEACH. In the second scenario, it ameliorates the BRE-LEACH by 72.54%, the LEACH-C by 94.33%, and the LEACH by 87.16%. Finally, when the BS is located far away from the network, the proposed method enhances the network lifetime and the 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 the network lifetime in all position of the BS compared to other protocols as we can see it also in figures 5 (a),7 (a),9 (a). Furthermore, our proposed protocol will be suitable for all applications either positioning the BS in the center of the network, at the terminal or very far from the network.

In addition, the IBRE-LEACH aims to decreases the total energy consumption in the entire network as we can see in Figure 5 (b), 7 (b) and 9 (b). These results indicate that the IBRE-LEACH consumes less energy compared to other discussed approaches. It can also be noticed that even the BS is located far from the network, it consumes less. 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 figure 6, 8, and 10). Overall, these results depict that the total number of packets sent to the BS per round is increased using IBRE-LEACH than BRE-LEACH, LEACH-C and, LEACH. It seems that these results are due to many factors. ANs data can achieve the BS unlike in BRE-LEACH, the energy balance between clusters, the election of the root, and the multi-hop between CHs and ANs avoid the rapid death of CH. Consequently, the number of packets received by the BS increase.

In summary, the performance of the WSN will significantly increase by using the proposed protocol because all compared metrics have been enhanced.

7 Conclusion

WSN is an innovative technology, which becomes recently extensively used for several applications such as in the military, healthcare, home automation, and so on. WSN includes numerous sensor nodes (hundreds up to thousands), which distributed randomly or uniformly into a specific monitoring area. Nonetheless, the energy constraint has restricted the capabilities of WSN. Indeed, this major constraint has gained considerable attention by researchers to solve the power consumption and extend the life cycle of WSNs using different methods. Routing protocols have a significant role in designing and maintaining the passages in the network to produce efficient communication between the 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, and so forth.
In this document, an energy-efficient approach is suggested to ameliorate the performance of the BRE-LEACH approach. Our IBRE-LEACH protocol enhanced the CH selection, the cluster formation process, and the data transmission technique. Instead of electing CHs aleatory, it selects CHs in the network according to the remaining energy of nodes, so just nodes with enough energy can play the role of CH. To avoid an imbalance of energy consumption and overload at CHs, the proposed IBRE-LEACH algorithm adopts equal clustering. That means the number of nodes in each group does not exceed a predefined number depending on the total number of nodes and the desired number of CH in the network. Nodes that can not join any cluster have the chance to send their data to the BS using IBRE-LEACH unlike in BRE-LEACH. Thereby, the proposed protocol enhanced the data transfer technique. In BRE-LEACH, all CHs send their data to the root even the CHs that are close to the BS as well as to the root. Also, in BRE-LEACH it is possible that the next-hop will not be in the same direction as the BS, which will cost more consumption. In the IBRE-LEACH protocol, each CH generates its routing table to choose the optimal direction to achieve the BS through intermediate nodes (CHs, ANs, or the root), or directly to the BS. The same process of CH is used by the ANs.
Our simulation results illustrated that the proposed IBRE-LEACH approach has achieved better performance compared to BRE-LEACH, LEACH-C, and LEACH in terms of stability, network lifetime, throughput, and energy consumption. The suggested technique has extended the stability and the network lifetime up to 81.99%, 94.33%, and up to 91.47% compared with BRE-LEACH, LEACH-C, and LEACH, respectively.
Furthermore, the IBRE-LEACH has decreased the energy consumption of the entire network by electing CHs according to the residual energy, limiting the number of nodes in each group, and selecting a root node with enough energy and minimum distance to the BS. Thus, it has also extended the throughput by increasing the number of packets arriving at the BS.
In summary, by setting up simulation results, we can conclude 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.

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Data Availability Statement

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

Conflict of interest

The authors declare that they have no conflict of interest.

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