

# LBCH: Load Balancing Cluster Head Protocol for Wireless Sensor Networks

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**Abstract.** In recent years, Wireless Sensor Networks (WSNs) received great attention because of their important applications in many areas. Consequently, a need for improving their performance and efficiency, especially in energy awareness, is of a great interest. Therefore, in this paper, we proposed a lifetime improvement fixed clustering energy awareness routing protocol for WSNs named Load Balancing Cluster Head (LBCH) protocol. LBCH mainly aims at reducing the energy consumption in the network and balancing the workload over all nodes within the network. A novel method for selecting initial cluster heads (CHs) is proposed. In addition, the network nodes are evenly distributed into clusters to build balanced size clusters. Finally, a novel scheme is proposed to circulate the role of CHs depending on the energy and location information of each node in each cluster. Multihop technique is used to minimize the communication distance between CHs and the base station (BS) thus saving nodes energy. In order to evaluate the performance of LBCH, a thorough simulation has been conducted and the results are compared with other related protocols (i.e. ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH). The simulations showed that LBCH overcomes other related protocols for both continuous data and event-based data models at different network densities. LBCH achieved an average improvement in the range of 2–172%, 18–145.5%, 10.18–62%, 63–82.5% over the compared protocols in terms of number of alive nodes, first node died (FND), network throughput, and load balancing, respectively.

**Key words:** wireless sensor networks, data aggregation, clustering.

## 1. Introduction

The wireless sensor network (WSN) consists of a large number of small smart devices called sensor nodes distributed randomly in a remote area for monitoring or controlling such area (Sung and Hsiao, 2013; Darabkh *et al.*, 2016). WSNs have many attractive characteristics such as fast deployment, self-organization, low cost, and fault tolerance. Such features make WSNs very favourable for many applications (e.g. military, environmental, etc.) (Barolli *et al.*, 2016; Matrouk and Landfekdt, 2009).

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The sensor node is comprised of a sensing unit, a processing unit, a transmission unit, and a power unit (Darabkh *et al.*, 2019, 2017a). The most crucial aspect of designing issues of software and hardware of WSNs is energy consumption (Ismail *et al.*, 2015; Al-Zubi *et al.*, 2018). This is because the energy source in most WSN applications is a battery and the sensor nodes need energy for various operations; sensing data, processing data, and data communication (Yaseen *et al.*, 2018). Consequently, the transmission and routing protocols that are designed for WSNs must be energy efficient in order to mitigate energy consumption limitation in the network by guaranteeing minimum power communication paths (Vu *et al.*, 2014). Many transmission and routing protocols have been proposed for WSNs (Parwekar, 2014; Awan *et al.*, 2018; Darabkh and Zomot, 2018; Darabkh *et al.*, 2017b). One category of these protocols is known as clustering-based routing protocols. Such protocols have improved the network lifetime and they have proven to be the most energy efficient routing protocols (Darabkh and Alsarareh, 2018).

A cluster based routing protocol is based on network fragmentation principle, where the nodes in a WSN are partitioned into independent groups, which are called clusters (Darabkh *et al.*, 2018; Khalifeh *et al.*, 2017). Each of these clusters has one node working as a leader of the cluster referred to as Cluster Head (CH), while the other nodes are normal nodes referred to as Member Nodes (MNs) (Darabkh *et al.*, 2017c). CH is responsible for collecting sensed data from all MNs, aggregating it, and sending the aggregated data to a base station (BS) (Darabkh *et al.*, 2017d, 2017e). The sensed data is sent by MNs to the CH rather than sending it to the BS directly because sending it directly would drain the batteries of the nodes quickly due to a high power consumption occurrence (Darabkh *et al.*, 2017f).

In this paper, an energy efficient lifetime improvement fixed-clustering based routing protocol for WSNs is proposed and investigated. It is called load balancing cluster head (LBCH) protocol. It focuses on balancing the workload among the nodes evenly and reduces the energy consumption of the network. However, Section 2 presents some of the related works. In Section 3, we introduce the LBCH protocol. In Section 4, we evaluate the LBCH protocol and present the simulation results. In Section 5, we discuss and conclude the paper.

## 2. Related Work

There are a lot of interesting cluster-based routing protocols proposed in the literature. In this section, we introduce closely related protocols (Heinzelman, 2000; Heinzelman *et al.*, 2000; Azim and Islam, 2012; Nam and Min, 2007; Baek *et al.*, 2010; Darabkh and Al-Jdayeh, 2018). In Heinzelman (2000), LEACH-Fixed was proposed. It is the first fixed clustering routing protocol based on LEACH (Heinzelman *et al.*, 2000). Clusters in LEACH-F are constructed initially at the network setup phase and then kept fixed using a centralized cluster formation algorithm. At the end of each round, the role of a CH is rotated among the cluster nodes in a round-robin manner. The steady state phase of LEACH-F is identical to that of the original LEACH. LEACH-F is not scalable since no nodes can be added to the network after construction.

In Azim and Islam (2012), the dynamic round time-based fixed LEACH scheme was proposed. The main reason behind finding this scheme is to mitigate the fixed round time problem in LEACH-F. The round time of the Dynamic Round Time-based Fixed LEACH, is modified based on current energy of MNs, not on their initial energy, and the total energy consumption in the cluster for that round. Hence, by reducing the probability of CHs early death and enhanced network lifetime were achieved. The round time is not the same for all clusters due to the diversity in energy consumption between clusters.

In Nam and Min (2007), the Round-Robin Cluster Header (RRCH) protocol was proposed. It is an energy efficient fixed clustering protocol which balances the energy consumption and achieves high energy efficiency in WSNs due to fixed clustering approach. Initially, the setup phase of the RRCH is performed only once and it is identical to the one of the LEACH where the CHs selection, clusters' construction, and TDMA scheduling are created for cluster member nodes. In the advanced rounds, the selection of CH nodes within the clusters is based on round robin method. The rotation innovation of CHs roles is the responsibility of the initial CHs where a CH role sequence tables for nodes in the clusters are created. The sequence information is broadcasted by the CHs to the MNs combined with TDMA schedules. In the steady state phase, the CHs are modified according to the sequence information of each node based on round robin method. RRCH consumes less energy than LEACH by  $E$ , which is calculated as follows:

$$E = E_{\text{setup}} \times (N_r - 1), \quad (1)$$

where  $N_r$  is the number of rounds,  $E_{\text{setup}}$  is the total energy consumption of the entire sensor node region and it is calculated as follows:

$$E_{\text{setup}} = l \left( N \left( 4E_{\text{elec}} + E_{\text{schedule}} + E_{\text{fs}} \frac{M^2}{2\pi k} \right) + k(E_{\text{mp}}d^4 - 2E_{\text{elec}}) \right), \quad (2)$$

where  $l$  is the data size,  $N$  is the number of nodes in the network,  $E_{\text{elec}}$  is the electronics energy,  $E_{\text{schedule}}$  is the amount of energy consumption due to scheduling in the cluster head node,  $E_{\text{fs}}$  is the amplifier energy (free space model),  $M$  is the length of the region,  $k$  is the number of clusters,  $E_{\text{mp}}$  is the amplifier energy (multipath model), and  $d$  is the distance to the base station.

Self-incentive and semi re-clustering (SISR) protocol was proposed in Baek *et al.* (2010). SISR is a fixed clustering data routing protocol for WSNs. During the setup phase, each node elects itself as a candidate CH with probability  $P$  and then broadcasts an *ADVERTISE-MESSAGE* with the initial radio range  $RR$ . Gradually,  $RR$  is increased until the node receives an *ADVERTISE-MESSAGE* from at least one node. According to the received *ADVERTISE-MESSAGE*, the node checks  $P$  value of nodes; if there is a node with  $P$  value higher than its value, it selects it as an associated CH. Otherwise, a node gives up the competition. The elected CHs broadcast an *INVITE-MESSAGE* with their  $RR$  and wait for a response from normal nodes. While each normal node determines its associated CH, they send a *JOIN-REQ-MESSAGE* to the CHs to inform them about their decisions. After the clusters are constructed, each CH decides its CH sequence based

on the signal strength of *JOIN-REQ-MESSAGE* from normal nodes in its cluster. In the steady state phase, the round length differs between clusters where the number of frames in each round equal to the number of nodes in a cluster. The frames are recognized according to the CH sequences that were sent by initial CHs. At the end of each frame, *HEARTBEAT-MESSAGE* broadcasts by the CHs to their MNs. The nodes that do not respond by *HEARTBEAT-ACK-MESSAGE* are listed as dead nodes. These listed dead nodes are included in a *DEAD-NODES-MESSAGE* that is broadcasted by the CHs to their MNs in order to remove the dead nodes from the sequential schedule. Finally, alive nodes send their *HEARTBEAT-ACK-MESSAGES* that include their incentive values to be CHs.

An Adaptive Clustering Algorithm for Balanced Energy Consumption in WSNs (ACBEC-WSNs) was proposed in Darabkh and Al-Jdayeh (2018). It is an adaptive fixed clustering based solution that has a single setup phase that is executed once at the beginning till the end of the network lifetime and has one long steady state phase. The aggregated data in this scheme are not sent directly from CHs to the BS. Instead, aggregated data go through a multi-hop path from CHs to the BS through nearby nodes called Relay nodes (RNs). The cycle of each RN or CH is not fixed; it depends on the energy consumption level in the cluster. In the setup phase, the initial CHs and RNs are selected, the clusters are constructed, and multi-hop paths are initiated, whereas in the steady state phase, the data is communicated and the roles of CHs and RNs are circulated. The circulation of CH or RN roles between nodes is to balance the load and distribute the energy consumption among them evenly. In CH role switching, the CH will switch its role if the current energy level of CH in cluster  $i$  is smaller than or equal to a certain level. This level is calculated as follows:

$$L_{th} = \alpha \frac{\sum_{n=1}^{N_i} E_n}{N_i}, \quad (3)$$

where  $E_n$  is the residual energy of the node  $n$ ,  $N_i$  is the number of nodes in cluster  $i$ , and  $\alpha$  is a CH switching ratio determined by simulation. The new CH is selected based on a calculated weight for each node. This weight is calculated as follows:

$$CHw(n) = \frac{E_n}{\beta \times d(n, RN_i) + (1 - \beta) \times d_n}, \quad (4)$$

where  $CHw(n)$  is the weight of node  $n$  for the CH nomination,  $d(n, RN_i)$  is the distance between node  $n$  and the relay node of the cluster  $i$ ,  $\beta$  is a constant ratio referred to as the impact ratio which is found by simulation, and  $d_n$  is the average intra-cluster communication distance of node  $n$ , which is calculated as follows:

$$d_n = \frac{\sum_{k=1}^{N_i} d(n, k)}{N_i} \quad n, k \in cluster_i, \quad (5)$$

where  $d(n, k)$  is the distance between node  $n$  and node  $k$ . For the RN, it continues working as an RN until its energy level is falling below a predefined level.

The main difference between our proposed protocol and ACBEC-WSNs is the method of rotating the roles of CH and RN among the nodes in the network. First, ACBEC-WSNs depends on different parameters ( $\alpha$ ,  $\beta$ , and  $\gamma$ ) which are calculated by simulation. This makes such protocol, practically, non-adaptive for any changes in the network features. However, our proposed protocol does not depend in its operation on any parameter that is calculated by simulation. Second, in our proposed protocol, roles of CH and RN are done every certain period called round. This ensures more load balancing among all nodes in the network. However, in ACBEC-WSNs, the CH or RN may not be changed for many rounds.

### 3. The Proposed Protocol

The main goal of our proposed LBCH protocol is to improve the network lifetime through balancing the load among all nodes in the network and minimizing the energy consumption in the network. It ensures the minimization of the transmission distances via a multi-hop communication model through RNs. RNs represent links between the CHs and the BS. They deliver the aggregated data from the CHs instead of forwarding it directly to the BS by the CHs. In the following sections, we present the details of the LBCH protocol.

#### 3.1. Network Model

The network model of the LBCH protocol can be summarized as follows:

- The sensor network consists of a large number of sensor nodes that are randomly distributed over a rectangular area with only one BS.
- The BS is stationary and it is located outside the area of nodes. There is no constraint on its energy or computation resources.
- The sensor nodes are stationary, homogenous, and energy restricted. They cannot be recharged after being deployed.
- Each sensor node has a unique (ID) assigned to it before deploying the network.
- Each sensor node is familiar with its location's coordinates (sensor's localization is out of the scope of this work). Moreover, the nodes can know each other's locations and the BS location via exchanging control messages.
- Links between nodes are symmetric where the power needed to send data from one node to another is the same in both directions.
- Every sensor node has the ability to communicate with the BS and all other nodes in the network.
- To solve the problem of interference between different transmissions, the TDMA scheme is applied for the intra-cluster communications and the code division multiple access (CDMA) scheme is applied for the inter-cluster communications. Note that the BS determines for each cluster its TDMA schedule and the length of the time slot in this schedule. Furthermore, the members of each cluster are assumed to be timely synchronized.

### 3.2. Radio Energy Model

In LBCH protocol, we adopted the radio energy model that has been deployed in Heinzelman (2000), Heinzelman *et al.* (2000), Hong *et al.* (2009), Darabkh and Muqat (2018), Kang and Nguyen (2012). In this model, a simple energy dissipation approach is assumed for transmitting and receiving data bits. In general, for sending  $k$  bits data message over a distance  $d$ , the total energy consumed by the sending node, referred to as  $E_{TX}(k, d)$ , is given as follows:

$$E_{TX}(k, d) = E_{elec}(k) + E_{amp}(k, d), \quad (6)$$

where  $E_{elec}(k)$  is the energy consumed in running the transmitter electronics to transmit  $k$  bits.  $E_{amp}(k, d)$  is the energy consumed for running the power amplifier circuit when transmitting  $k$  bits over distance  $d$ . On the other hand, to receive a message of  $k$  bits, the node will only consume energy to run the receiver electronics. Thus, the amount of consumed energy in the reception process  $E_{RX}(k)$  is given as follows:

$$E_{RX}(k) = kE_{elec}. \quad (7)$$

### 3.3. LBCH Characteristics

LBCH is mainly characterized by the following features that will be discussed later in more details.

#### 1. Fixed-clustering based.

The clusters will be constructed once at the beginning of the network deployment and left unchanged till the rest of the network lifetime. CH and RN will be selected in each cluster at the end of each round according to proposed methods.

#### 2. Position and energy aware.

The position and energy of the nodes are considered in the method of selecting CHs and RNs at the end of each round. Considering these parameters lead to load balancing and prolong the network's lifetime.

#### 3. Multi-hop based.

According to the LBCH protocol, CHs will not be forced to send their aggregated data directly to the BS. Instead, each CH will deliver its data to the associated RN which forwards this data to another RN until it reaches the BS. Each cluster has only one RN assigned to it.

### 3.4. Network Lifetime

According to the LBCH protocol, the network lifetime is divided based on the nature of the fixed-clustering based approaches. It consists of two phases; one relatively short setup phase and one long steady state phase. In the setup phase, the BS constructs the clusters, selects the initial CHs and RNs as well as the multi-hop paths to reach the BS. In the steady

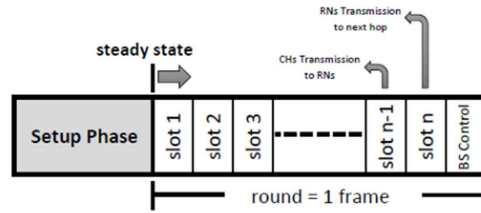


Fig. 1. The network lifetime based on LBCH protocol.

state phase, the data communication process occurred and the roles of the CHs and RNs are rotated between the nodes in each cluster. The steady state phase is divided into fixed time durations called rounds; each round consists of only one frame. This frame is broken into a number of slots equal to the number of nodes in that cluster in addition to one extra slot that is dedicated for the BS to advertise the new RN and CH of each cluster at the next round. Figure 1 depicts the network lifetime of a cluster that consists of  $n$  nodes.

At each round, each node within each cluster will sense and transmit data to its cluster CH during its allocated time slot. The CH will collect data from all nodes within the cluster, aggregate and send it to the associated RN. At slot  $n$ , the RN delivers the received data to the next hop. At the final slot (i.e. BS control), the BS broadcasts a message to inform all nodes, within each cluster, their new CH, RN, and the TDMA schedule of each cluster and each multi-hop path that consists of different RNs from different clusters. Since the round has a fixed duration, the slot time duration is different from one cluster to another, depending on the number of nodes within the cluster. The BS calculates the time slot duration for any cluster as follows:

$$T_{s(j)} = \frac{T_R}{N_j + 1}, \quad (8)$$

where  $T_{s(j)}$  is the slot time duration for cluster  $j$ ,  $N_j$  is the total number of sensor nodes in cluster  $j$ , and  $T_R$  represents the globally-agreed round time duration.  $T_R$  is determined by the BS based on a certain criterion. For example, it could be determined based on the expected number of nodes in one cluster such that the round time is sufficient to send at least one packet from each node in a cluster.

### 3.5. Setup Phase

There is only a single setup phase in the LBCH protocol. In this phase, the initial CHs and RNs are selected, the clusters are constructed, and the primary routes to the BS are established. All these tasks are done by the BS as follows:

- The BS initially broadcasts a HELLO message to all nodes in the network field.
- When the nodes receive the HELLO message, they respond back with ACK messages to the BS to inform about their IDs, their energy levels, and their location coordinates.

- After receiving all ACK messages by the BS, it partitions the network into a number of equal-size-grid-like subfields. Then, it selects the initial CHs and RNs within these subfields. This way guarantees selecting CHs and RNs that are scattered over the network area. We are adopting the model of partitioning the network into subfields that was deployed in Darabkh and Al-Jdayeh (2018). The number of subfields that will partition the network is calculated as follows:

$$C_{\text{fields}}(N, P) = \lceil \text{round}(\sqrt{(P(1-P) \times N)}) \rceil^2, \quad (9)$$

where  $C_{\text{fields}}(N, P)$  represents the number of subfields that will partition the network area that has  $N$  nodes with a pre-defined percentage of CHs of  $P$ . Round represents the round function. To illustrate, if a network has two hundred sensors and  $P = 0.05$ , then  $C_{\text{fields}} = 9$  subfields.

- After calculating the number of subfields, the width and the length of each subfield will be determined as follows:

$$F_L = \frac{Net_L}{\sqrt{C_{\text{fields}}}}, \quad (10)$$

$$F_W = \frac{Net_W}{\sqrt{C_{\text{fields}}}}, \quad (11)$$

where  $F_L$  is the length of each subfield,  $F_W$  is the width of each subfield,  $Net_L$  is the length of the network,  $Net_W$  is the width of the network, and  $C_{\text{fields}}$  is the number of subfields in the network. However, the length and the width of the subfields will not be allowed to exceed the value of  $d_{\text{threshold}}$  to ensure the minimization of intra-cluster communication energy consumption where this threshold can be estimated simply by finding the square root of the ratio between the transmit amplifier energy in free-space and transmit amplifier energy in multi-path fading whereas these values are described in the simulation parameters.

- When the boundaries of each subfield are defined, the BS starts to select the initial RNs; where each cluster has only one RN. Specifically, the sensor node that is the nearest to the BS in each cluster will be elected as initial RN.
- After that, in each cluster, the node that fits the following two conditions together is elected as an initial CH for its cluster.
  - The closest node to the initial RN in that cluster.
  - The node that has the largest amount of residual energy after testing all nodes to be a CH in that cluster for one round.
- Once the initial RNs and CHs are selected, the BS starts creating the clusters by collecting all nodes within a specific CH broadcast range (i.e. the highest value of  $F_L$  and  $F_W$ ).
- Subsequently, the BS specifies the cluster's size, computes the slot time length using equation (15) for each cluster, and creates TDMA schedule for the MNs within each cluster.



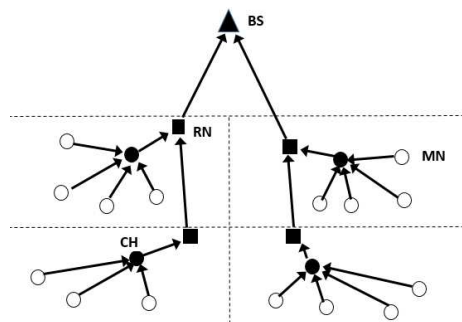


Fig. 2. Data paths in a network using the proposed protocol. Filled circle means cluster head (CH), unfilled circle means member node (MN), filled square means relay node (RN), and filled triangle means base station (BS).

- The BS informs the RNs and CHs about their future roles via individual unicast messages. The unicast messages that are directed to the initial CHs contain information about the slots' time length, the number of its cluster member nodes, cluster MNs IDs, the ID of the associated RN, and the TDMA schedule for the associated MNs.
- The ID of the next hop RN and the ID of the associated CH are attached within the unicast messages that are directed to the initial RNs.
- The next hop RN for the lower layer RN is the nearest RN in the upper layer.
- Finally, the BS announces the created TDMA schedule, location information of all cluster MNs, the CH information, the RN information, and the slot time value to each cluster associated MNs via a broadcast message to each cluster where each cluster communicates with the BS using CDMA.

To illustrate the structure of the network according to the proposed protocol, Fig. 2 illustrates an example of data paths in a network using the proposed protocol LBCH.

### 3.6. Steady-State Phase

At the beginning of this phase, the MNs in all clusters will begin to collect data according to their allocated time slots in TDMA schedules that were announced by the BS in the setup phase. These nodes lose a part of their energy as time passes. The batteries of the CHs and the RNs will deplete faster than that of MNs since the additional responsibilities of the transmission and reception operations carried by these nodes. Because of these, we need a mechanism that balances the energy load among nodes to alleviate faster and uneven consumption of the nodes energy.

#### 3.6.1. RN Role Switching

Relay nodes use a higher degree of communication that is responsible for delivering data from the CHs to the BS. The idea of using RNs minimizes the energy dissipation that occurs due to direct transmission from the CHs to the BS. In the LBCH protocol, we have the following rule for circulating the RN role among the nodes of the network:

- The current RN, in any cluster, continues to work as RN until the end of the round. Then, the BS selects the node with the highest magnitude as a new RN for the next round. The magnitude of each node is calculated as follows:

$$Mag_n = E_n + \frac{1}{d(n, BS)}, \quad (12)$$

where,  $Mag_n$  is the magnitude of node  $n$  to be elected as an RN.  $E_n$  is the energy level of node  $n$ .  $d(n, BS)$  represents the distance between node  $n$  and the BS. The used formula guarantees electing a node with the highest energy and closest to the BS.

- The old RN returns to work as an ordinary node in the cluster.

### 3.6.2. CH Role Switching

At the end of each round, the BS selects new CH for each cluster in the next round as follows:

- At the end of each round, the BS calculates the weight for each node in the cluster as follows:

$$W_n = E_n + \frac{1}{d(n, RN)} + \frac{1}{d_n}, \quad (13)$$

where  $E_n$  is the energy level of node  $n$ ,  $d(n, RN)$  is the distance between node  $n$  and the associated RN of the cluster.  $d_n$  is the average intra-cluster communication distance between node  $n$  and all other nodes in the cluster that is calculated as follows:

$$d_n = \frac{\sum_{k=1}^{N_j} d(n, k)}{N_j}, \quad (14)$$

where  $d(n, k)$  represents the distance between node  $n$  and the  $k$  members of the cluster.  $N_j$  is the total number of nodes in cluster  $j$ .

- After the weight value has been calculated for each node in the cluster, the node with the highest weight is elected as new CH for the next round if and only if this node did not act as CH for  $\alpha$  number of times before.  $\alpha$  represents the number of nodes in the cluster where we select the CH from. In this way, we ensure that all nodes within a cluster work the same number of times as CH. This will equally distribute the load among all nodes.
- Finally, when all nodes within the cluster act as a CH for  $\alpha$  times, the process of selecting CH will be repeated.

## 4. Performance Evaluation

We conduct extensive simulations to evaluate the LBCH protocol and compare its performance with other protocols. The simulations are conducted using MATLAB.

Table 1  
Fixed simulation parameters where other parameters are set according to the used scenario.

Parameter	Value
Data packet size	1024 bits
Control packet size	176 bits
Initial energy	2 J
ETX (energy for transferring one bit)	50 nJ/bit
ERX (energy for receiving one bit)	50 nJ/bit
EDA (energy for data aggregation)	5 nJ/bit
Transmit amplifier energy in free-space	10 PJ/bit/m <sup>2</sup>
Transmit amplifier energy in multi-path	0.0013 PJ/bit/m <sup>4</sup>

#### 4.1. Performance Metrics

We considered four performance metrics:

- **FND:** Stands for First Node Died. This metric represents the round number at which the first node in the network dies.
- **LND:** Stands for Last Node Died. This metric represents the round number at which the last node in the network dies.
- **Network throughput:** this metric represents the total number of received data packets during the simulation time.
- **Balance indicator:** this metric measures the level of balancing in energy dissipation in the network. Its value (in rounds) equals the difference between the values of FND and LND. The best value of Balance Indicator is the lower; when FND and LND values are close to each other.

These metrics are the most known metrics used in the related works because they accurately evaluate the overall performance of any protocol that is proposed to extend the life time of a sensor network. It should be noted that all these metrics are very important and should be studied. For example, we cannot ignore the throughput metric. To clarify, if according to a certain protocol all the nodes do not send any data, then this protocol will achieve the best values for the following metrics: number of alive nodes and the first node died (FND).

#### 4.2. Simulation Parameters

Table 1 presents the simulation parameters used which quite resemble those in closely related works.

#### 4.3. Simulation Results

In our simulations, all nodes always have data packets to send and no idle slots exist. Moreover, we compare the performance of the LBCH protocol with other protocols that have the same assumptions, including: LEACH-F (Heinzelman, 2000), Dynamic Round Time

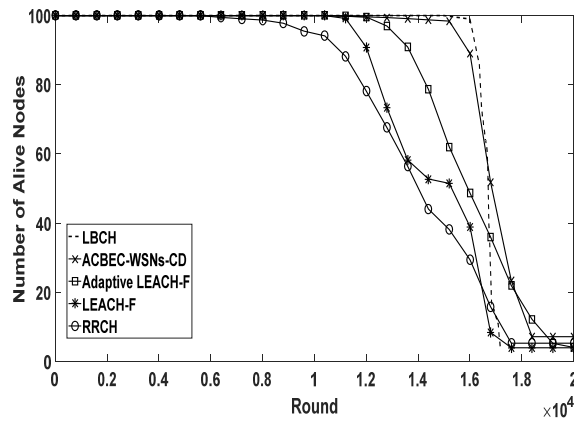


Fig. 3. The number of alive nodes for  $100 \times 100$  m network.

LEACH-F which we refer to as Adaptive LEACH-F (Azim and Islam, 2012), RRCH (Nam and Min, 2007), and an Adaptive Clustering Algorithm for Balanced Energy Consumption in Wireless Sensor Networks-Continuous Data model which we call ACBEC-WSNs-CD (Darabkh and Al-Jdayeh, 2018).

#### 4.3.1. Studying the Number of Alive Nodes in the Network

This study provides us with a comprehensive view of how nodes lose their energy with time and hence the efficiency of the applied protocol. We conduct the simulation of this study under three different network configurations. The first one is  $100 \times 100$  m area with 100 nodes distributed uniformly over it,  $P = 0.05$ , and the position of BS is (50, 125). The second configuration has  $150 \times 150$  m area, 225 nodes,  $P = 0.05$ , and the coordinates of the BS are (75, 150). The third configuration consists of 400 nodes distributed over  $200 \times 200$  m area,  $P = 0.05$ , and the BS is at (100, 175). The number of nodes in each network is chosen to preserve a node density of (0.01 nodes/m<sup>2</sup>). The results of the simulation of these configurations are depicted in Figs. 3, 4, and 5 respectively.

It can be seen from Fig. 3 that LBCH outperforms ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH by about 2%, 15%, 36%, and 57%, respectively. For clarification, 57% improvement represents the average of the improvements calculated over all rounds. Figure 4 shows that LBCH outperforms RRCH, LEACH-F, Adaptive LEACH-F, and ACBEC-WSNs-CD by about 8%, 60%, 109%, and 138%, respectively. Also, Fig. 5 shows that LBCH outperforms ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH by about 7%, 80%, 131%, and 172%, respectively. This is because the LBCH protocol has an ability to overcome the weaknesses of all other works. Based on the LBCH protocol, the network is divided into grid-like subfields to select the initial CHs and RNs. Furthermore, while other protocols employ just round robin, novel methodologies are evolved in the LBCH protocol for rotating the role of CHs and RNs inside each cluster. In the LBCH protocol, the highest energy node and the nearest to the BS node will be elected to handle the role of the new RN in the cluster. Furthermore, the

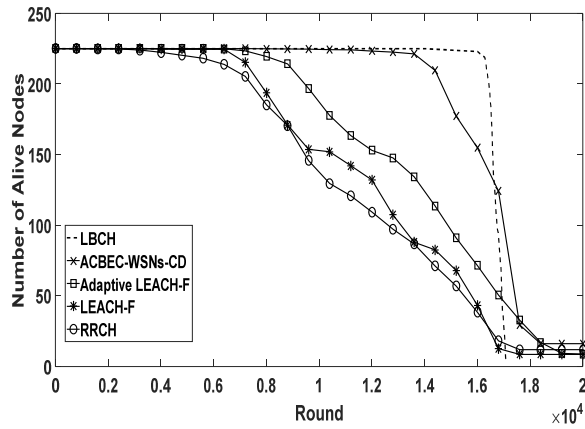


Fig. 4. The number of alive nodes for 150 × 150 m network.

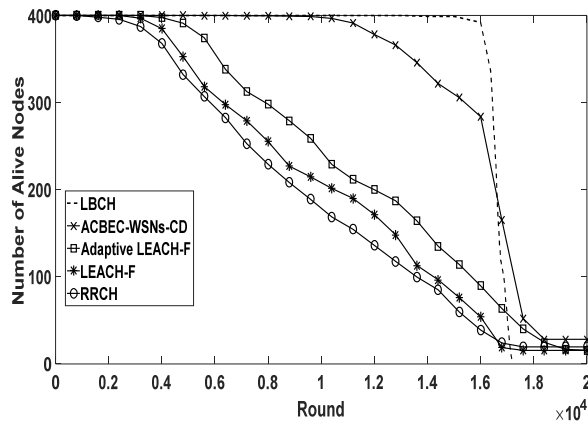


Fig. 5. The number of alive nodes for 200 × 200 m network.

node must achieve three conditions to be selected as new CH; max energy, nearest from the associated RN, and has the minimum average distance to all other nodes in the cluster. In order to balance the load among all nodes within the cluster, each node must be a CH not more than a specific number of times, i.e. a total number of nodes in the cluster. Thus, all these techniques together improve the performance of the LBCH protocol compared to other protocols. Moreover, we can see from Fig. 3, Fig. 4, and Fig. 5, that the speed of nodes death in the compared protocols is slightly affected by the network sizes. In contrast, the nodes death in LBCH protocol is not so much affected by the network size.

#### 4.3.2. Studying FND Performance Metric

We study the FND performance metric for the LBCH protocol and compare it with other related protocols. Note that higher FND means better distribution for energy consumption and better load balancing. Fig. 6 shows the results of this study under the same network configurations considered in Figs. 3, 4, and 5.

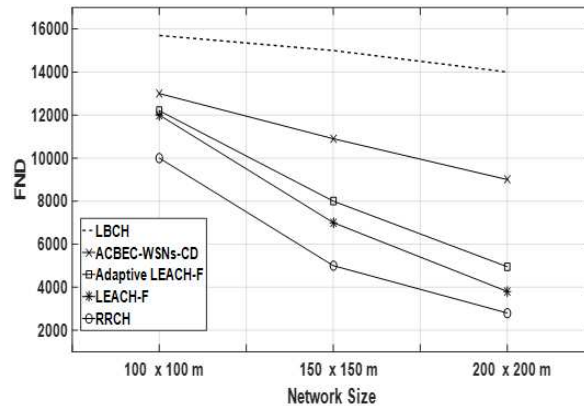


Fig. 6. First node died versus network size.

From Fig. 6, we can see that the LBCH protocol achieves the highest FND compared to other protocols under the considered network configurations. For the network size of  $100 \times 100$  m, the LBCH protocol outperforms ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH by 18%, 26.15%, 28% and 49%, respectively. Whereas, for the network size of  $200 \times 200$  m, LBCH outperforms ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH by 44.7%, 107.4%, 116% and 145.5%, respectively. Another important conclusion that can be excluded from Fig. 6 is that the decreasing rate of FND value with increasing the network size is much smaller in the LBCH protocol compared to other protocols.

#### 4.3.3. Studying the Network Throughput

The throughput factor is used in the network as an indicator of the energy efficiency of the applied protocols in WSNs. We explain the impact of increasing the network size on the throughput metric.

The results in Fig. 7 show the persistent improvement of the LBCH protocol over all compared protocols under different network sizes in terms of network throughput. Specifically, for network size of  $100 \times 100$  m, the LBCH protocol outperforms over ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH by 10.18%, 11.5%, 17.4%, and 30.13%, respectively. For the network size of  $200 \times 200$  m, the throughput gap between the LBCH protocol and ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH is increased to 15%, 39%, 54.6%, and 62%, respectively. We note that, in the case of the LBCH protocol, the growth of network throughput with the size of the network is closer to be exponential, which means more efficient in terms of energy awareness.

#### 4.3.4. Studying the Balance Indicator

The load balancing is one of the important aspects that should be in mind when studying the energy awareness of any proposed solution. A higher load balancing means that the nodes lose their energy in a balanced manner and die in close durations. We use the Balance Indicator metric to measure the load balancing. The difference between FND and

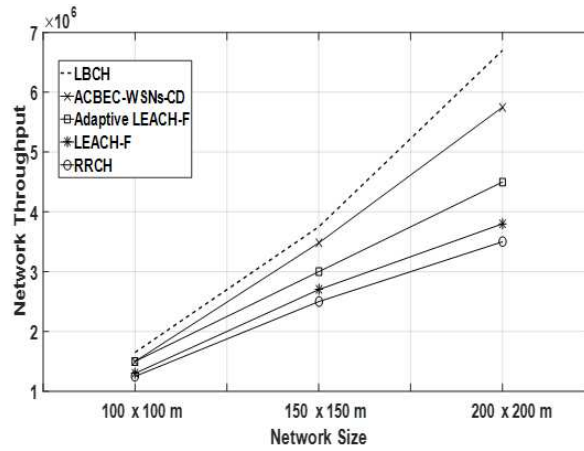


Fig. 7. Network throughput versus network size.

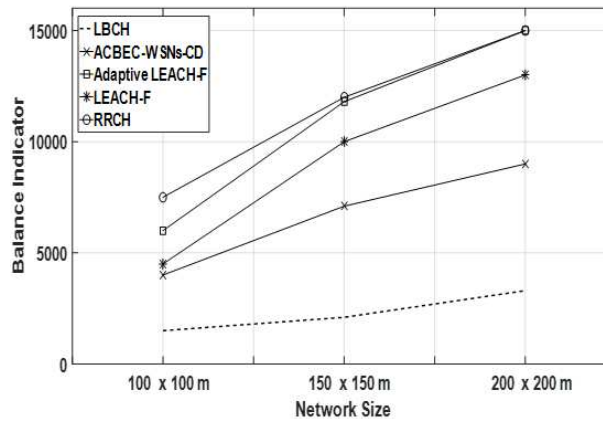


Fig. 8. Balance indicator versus network size.

LND is used as a measure of this metric. Therefore, when the value of the Balance Indicator is smaller, this means more load balancing and vice versa. The simulation results for this study are shown in Fig. 8. From Fig. 8, it can be seen that, for the network area of  $100 \times 100$  m, the LBCH protocol reduced the balance indicator by about 63%, 67%, 75%, and 80% compared with ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH, respectively. For the network area of  $150 \times 150$  m, the LBCH protocol reduced the balance indicator by about 70%, 79%, 82.2%, and 82.5% compared with ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH, respectively. Also, for the network area of  $200 \times 200$  m, the LBCH protocol reduced the balance indicator by about 63%, 75%, 78%, and 78% compared with ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH, respectively.

According to the results shown in Fig. 8, we notice that the LBCH protocol has the minimum balance indicator among all compared protocols at different network sizes. So,

we can conclude that our protocol achieves better load balancing than other related protocols.

## 5. Conclusions and Future Work

In this article, we proposed a lifetime improvement fixed-clustering based routing protocol in WSNs. It is called Load Balancing Cluster Head (LBCH) protocol. The main target of the LBCH protocol is to balance the workload and minimize the energy consumption among all nodes in the network, thereby improving the performance of the network. In particular, LBCH uses a fully centralized control for picking the initial CHs and RNs, constructing the clusters, and switching the role of CHs and RNs. To increase the efficiency and achieve the desired goal, a multi-hop communication is also incorporated within the model. LBCH performance is evaluated by conducting different simulation scenarios; different network densities under continuous data and event-based data models. The simulation results are compared with that of several related protocols (i.e. ACBEC-WSNs-CD, Adaptive LEACH-F, LEACH-F, and RRCH). The results show the superiority in the performance of LBCH over Adaptive LEACH-F, LEACH-F, and RRCH protocols in terms of number of alive nodes, first node died, network throughput, and load balancing. However, the LBCH protocol slightly outperforms ACBEC-WSNs-CD protocol in some scenarios. This is because LBCH and ACBEC-WSNs-CD employ similar procedures for dividing the network into grid-like subfields and for selecting the initial CHs and RNs. However, LBCH applies different conditions; the highest energy node and the nearest node to the BS will be elected as the new RN in the cluster and a node must achieve three conditions to be selected as a new CH which include the maximum energy, the nearest from the associated RN, and has the minimum average distance to all other nodes in the cluster.

For future work, even through the LBCH protocol results in promising performance, there are some areas for improvement. In the current implementation of LBCH, the number of subfields that will partition the network area depends on a pre-defined percentage of CHs (i.e.  $P$ ). This parameter could not be suitable for any distribution or density of nodes and any network size. Therefore, in the future work, we are in the process of proposing a method to adaptively derive this parameter based on the number of nodes, distribution of nodes, and the network size.

## References

- Al-Zubi, R.T., Abedsalam, N., Atieh, A., Darabkh, K.A. (2018). Lifetime-improvement routing protocol for wireless sensor networks. In: *Proceedings of the 15th IEEE Multi-Conference on Systems, Signals, and Devices (SSD'18)*, Hammamet, Tunisia.
- Awan, K.M., Ali, A., Aadil, F., Qureshi, K.N. (2018). Energy efficient cluster based routing algorithm for wireless sensors networks. In: *Proceedings of 2018 International Conference on Advancements in Computational Sciences (ICACS)*, Lahore, Pakistan, pp. 1–7.
- Azim, A., Islam, M.M. (2012). A relay node based hybrid low energy adaptive clustering hierarchy for wireless sensor networks. *International Journal of Energy, Information and Communications*, 3(3), 41–54.



- Baek, J., An, S.K., Fisher, P. (2010). Dynamic cluster header selection and conditional re-clustering for wireless sensor networks. *IEEE Transactions on Consumer Electronics*, 56(4), 2249–2257.
- Barolli, A., Sakamoto, S., Oda, T., Spaho, E., Ikeda, M., Barolli, L. (2016). Performance evaluation of WMN-GA system in node placement in WMNs for different distributions of mesh clients and different selection and mutation operators. *Informatica*, 27(3), 489–502.
- Darabkh, K.A., Al-Jdayeh, L. (2018). A new fixed clustering based algorithm for wireless sensor networks. In: *Proceedings of the 14th International Wireless Communications and Mobile Computing Conference (IWCMC 2018)*, Limassol, Cyprus.
- Darabkh, K.A., Alsarairoh, N.R. (2018). A yet efficient target tracking algorithm in wireless sensor networks. In: *Proceedings of the 15th IEEE Multi-conference on Systems, Signals, and Devices (SSD'18)*, Hammamet, Tunisia.
- Darabkh, K.A., Muqat, R.Z. (2018). An efficient protocol for minimizing long-distance communications over wireless sensor networks. In: *Proceedings of the 15th IEEE Multi-Conference on Systems, Signals, and Devices (SSD'18)*, Hammamet, Tunisia.
- Darabkh, K.A., Zomot, J.N. (2018). An improved cluster head selection algorithm for wireless sensor networks. In: *Proceedings of the 14th International Wireless Communications and Mobile Computing Conference (IWCMC 2018)*, Limassol, Cyprus.
- Darabkh, K.A., Ibeid, H., Jafar, I.F., Al-Zubi, R.T. (2016). A generic buffer occupancy expression for stop-and-wait hybrid automatic repeat request protocol over unstable channels. *Telecommunication Systems*, 63(2), 205–221.
- Darabkh, K.A., Albtoosh, W.Y., Jafar, I.F. (2017a). Improved clustering algorithms for target tracking in wireless sensor networks. *Journal of Supercomputing*, 73(5), 1952–1977.
- Darabkh, K.A., Al-Rawashdeh, W.S., Al-Zubi, R.T., Alnabelsi, S.H. (2017b). A new cluster head replacement protocol for wireless sensor networks. In: *Proceedings of 2017 IEEE European Conference on Electrical Engineering & Computer Science*, Bern, Switzerland.
- Darabkh, K., Al-Maaitah, N., Jafar, I., Khalifeh, A. (2017c). Energy efficient clustering algorithm for wireless sensor networks. In: *Proceedings of 2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET 2017)*, Chennai, India.
- Darabkh, K.A., Al-Maaitah, N.J., Jafar, I.F., Khalifeh, A.F. (2017d). EA-CRP: a novel energy-aware clustering and routing protocol in wireless sensor networks. *Computers and Electrical Engineering*. <https://doi.org/10.1016/j.compeleceng.2017.11.017>.
- Darabkh, K.A., Al-Rawashdeh, W.S., Al-Zubi, R.T., Alnabelsi, S.H. (2017e). C-DTB-CHR: centralized density- and threshold-based cluster head replacement protocols for wireless sensor networks. *Journal of Supercomputing*, 73(12), 5332–5353.
- Darabkh, K.A., Al-Rawashdeh, W.S., Hawa, M., Saifan, R., Khalifeh, A.F. (2017f). A novel clustering protocol for wireless sensor networks. In: *Proceedings of 2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET 2017)*, Chennai, India.
- Darabkh, K.A., Al-Rawashdeh, W.S., Hawa, M., Saifan, R. (2018). MT-CHR: a modified threshold-based cluster head replacement protocol for wireless sensor networks. *Computers and Electrical Engineering*. <https://doi.org/10.1016/j.compeleceng.2018.01.032>
- Darabkh, K.A., El-Yabroudi, M.Z., El-Mousa, A.H. (2019). BPA-CRP: a balanced power-aware clustering and routing protocol for wireless sensor networks. *Ad Hoc Networks*, 82, 155–171.
- Heinzelman, W.B. (2000). Application-specific protocol architectures for wireless networks. *PhD dissertation*, Massachusetts Institute of Technology, USA.
- Heinzelman, W., Chandrakasan, A., Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. In: *Proceedings of the International Conference on System Sciences*, Hawaii, USA, pp. 1567–1576.
- Hong, J., Kook, J., Lee, S., Kwon, D., Yi, S. (2009). T-LEACH: the method of threshold-based cluster head replacement for wireless sensor networks. *Information Systems Frontiers*, 11, 513–521.
- Ismail, S.S., Al Khader, A.I., Darabkh, K.A. (2015). Static clustering for target tracking in wireless sensor networks. *Global Journal on Technology (Selected Paper of COMENG-2014)*, 8, 167–173.
- Kang, S.H., Nguyen, T. (2012). Distance based thresholds for cluster head selection in wireless sensor networks. *IEEE Communications Letters*, 16(9), 1396–1399.
- Khalifeh, A.F., AlQudah, M., Darabkh, K.A. (2017). Optimizing the beacon and superframe orders in IEEE 802.15.4 for real-time notification in wireless sensor networks. In: *Proceedings of 2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET 2017)*, Chennai, India.

- Matrouk, K., Landfekdt, B. (2009), RETT-gen: a globally efficient routing protocol for wireless sensor networks by equalizing sensor energy and avoiding energy holes. *Computer Communications*, 7(3), 514–536.
- Nam, D.-H., Min, H.-K. (2007). An energy-efficient clustering using a round-robin method in a wireless sensor network. In: *Proceedings of the 5th ACIS International Conference on Software Engineering Research, Management & Applications (SERA 2007)*.
- Parwekar, P. (2014). Comparative study of hierarchical based routing protocols: wireless sensor networks. In: Satapathy, S.C., Avadhani, P.S., Udgata, S.K., Lakshminarayana, S. (Eds.), *ICT and Critical Infrastructure: Proceedings of the 48th Annual Convention of Computer Society of India – Vol I, Series of Advances in Intelligent Systems and Computing*, Vol. 282. Springer, pp. 277–285.
- Sung, W.-T., Hsiao, C.-L. (2013). IHPG algorithm for efficient information fusion in multi-sensor network via smoothing parameter optimization. *Informatica*, 24(2), 291–313.
- Vu, T., Nguyen, V., Nguyen, H. (2014). An energy-aware routing protocol for wireless sensor networks based on K-means clustering. In: Zelinka, I., Duy, V.H., Cha, J. (Eds.), *AETA 2013: Recent Advances in Electrical Engineering and Related Sciences, Lecture Notes in Electrical Engineering*, Vol. 282. Springer, pp. 297–306.
- Yaseen, H.A., Alsalam, M., Jarwan, A., Al-Mistarihi, M.F., Darabkh, K.A. (2018). A secure energy-aware adaptive watermarking system for wireless image sensor networks. In: *Proceedings of the 15th IEEE Multi-Conference on Systems, Signals, and Devices (SSD'18)*, Hammamet, Tunisia.

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