LCHREP: Layer and Cluster based Hierarchical Routing and Energy Optimization Protocol in Wireless Sensor Networks

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Journal of Digital
Information Management

ABSTRACT: *In this work, we propose a new hierarchical routing protocol called LCHREP (Layer and Cluster based Hierarchical Routing and Energy Optimization Protocol) that aims to minimizing energy consumption for wireless sensors network. LCHREP uses clusters formed on a layers and also uses multihop between these different layers. Results of simulations indicate that the proposed protocol allows better remaining energy after clusters heads selection, less amount of energy consumed in terms of sending packets. It allows also to reduce the number of nodes failed, and therefore to keep more nodes alive after sending packets.*

Subject Categories and Descriptors
C.2.1 Network Architecture and Design Wireless communication C.2.2 Network Protocol Routing Protocol

General Terms: Routing Protocols, Wireless Sensor Networks, Sensor Networks, Energy Consumption

Keywords: Wireless Sensors Network, Hierarchical Routing Protocol, Energy Consumption, Network Lifetime, LCHREP

Received: 3 March 2020, Revised 2 June 2020, Accepted 14 June 2020

Review Metrics: Review Scale: 0/6; Review Score: 4. 72; Inter-reviewer consistency: 84%

DOI: 10.6025/jdim/2020/18/4/139-150

1. Introduction and Motivations

In recent years, a new architecture has emerged: wireless sensor networks (WSNs) [9, 3]. A wireless sensor network is the network system composed by a large number of communicating sensor nodes through wireless links. These nodes are distributed over a given area in order to measure a physical size or monitor an event and then transmitting this data to a base station (BS) for further processing [2]. In such network, each node is an electronic device that has computing, storage, communication and energy capability. Due to their very different characteristics and low production cost. The WSNs are widely used in many fields, from military to medical, industry, ecology, domestic automation system, precision farming, etc. For this, WSNs constitute a very promising area of research which is very large and is actually in a state of growth. The main problem in wireless sensor networks is their constraints in terms of computational power, and thereafter for their energy consumption. Today's WSNs see the availability of their services limited by the amount of energy available in the batteries over time. Knowing that a sensor will eventually exhaust the battery. In this case and before the device can continue functioning, replacing or recharging the battery is required. However, in some types of applications, replacing battery is either costly or impractical. This can be seen in the deployment of these sensors which contribute in the majority of the cost for building the wireless sensor network. Hence, ideally such a system should be designed to achieve perpetual functioning without replacing or recharging batteries. To overcome limitations due to the batteries life, many routing algorithms have been proposed due to the challenges in designing an energy efficient network [5]. Among all proposed solutions, hierarchical routing protocols, also known as cluster based routing, satisfy the constraints and limitations [10] in WSNs. Among these hierarchical routing solutions, the Distance-Energy Cluster Structure Algorithm (DECSA) [22] takes into consideration the distance, the residual energy of the nodes and the reduction of the direct communication between the BS and the most distant cluster heeds (CHs). Nevertheless, the hot spots problem may arise with DECSA, which will be avoided with Energy-Ecient Cluster Based Data Aggregation for Wirless Sensor Networks (ECBDA) [16] protocol. In addition, ECBDA protocol reduces the size of the clusters close to the BS, and the energy consumption during the transmission of data following the partitioning of the layered network. However, ECBDA does not guarantee a homogeneous distribution of the CHs on the network, because the only election criterion of the CH is a random probability, and also the inter-cluster data transmission is random which allows the exhaustion of the sensors which are always in case of emission.

In our contribution, we are interested in the same hierarchization as the two protocols ECBDA and DECSA which are in the form of layer with k-clusters. This contribution aims to improve these two protocols by using horizontal partitioning at an angle and eliminating randomness in the selection of CHs and cross-cluster data transmissions.

The use of clustering algorithms in sensor networks allows the construction of groups called clusters, each of which is dominated by a leader called cluster head (CH). Its role is not limited to data aggregation but it is extends also to intra-cluster communication organization by a single hop and inter-cluster by the multi-hop which guarantees a better quality of reception of the data and minimizes the sensors energy consumption. To minimize energy consumption in sensor networks, it is necessary to use different CHs criteria such as residual energy, the distance between CH and BS. The objective therefore is essentially to extend the network life-time and avoid its collapse.

Our protocol uses hierarchical routing. It splits the network into different layers to provide multi-hop routing between the network nodes and the BS. Then each layer in into several clusters of different sizes. The main idea behind our contribution is to build a high number of clusters in the layer closest to the BS with very few node members for each cluster, and the farthest layers contain very few clusters with a large number of member nodes. This solves the problem of the hot spot which DECSA suffers (*the CHs close* to the BS consume more energy and die faster than *the other CHs of the other layers*) and also improve the performance of the network by giving it an opportunity to conserve energy in selected CHs, especially those close to the BS.

2. Literature Review

Hierarchical routing is a strategy that aims to organize the network in a manner that is conducive to reducing energy dissipation in order to preserve this exhaustible and non-rechargeable resource [4, 3]. Among the protocols proposed in the case of wireless sensor networks is the FCA protocol (*fixed clustering algorithm*) [8]. This latter divides the sensor network into fixed groups and places the CH in the center of the group. The placement of the CH at the center minimizes the power consumption of the sensor nodes farthest from the CH, but the CHs lose a lot of energy when transmitting the data to the base station. To improve the FCA protocol, the Hierarchical Routing Protocol (EERFC) is proposed in [19]. This protocol separates the nodes of the network into equal groups and selects the CHs from the nearest location of the base station. EERFC protocol minimizes the energy consumption of the CH, and therefore extends the life of the network better than the FCA. However, the clusters chosen are not balanced in size with EERFC. In order to overcome the unbalanced size limit under EERFC, the Efficient Self-Organization Algorithm for Clustering (ESAC) is proposed in [11]. This technique is based on the clustering approach to optimize energy consumption in this type of network. This technique consists in grouping nodes that are geographically close in clusters. It involves determining parameters to produce a reduced number of homogeneous clusters in size and radius, and that the clusters are stable. The weight of each sensor is calculated based on the following parameters: density, remaining energy and mobility. The sensor with the greatest weight in its 2-hop neighborhood becomes cluster head. In addition, the size of the generated clusters is between two ThreshLower and ThreshUpper thresholds, which represent the minimum and maximum number of sensors in a cluster, respectively. These two thresholds are chosen arbitrarily or depend on the topology of the network. In a cluster, each member sensor is at most two hops from its corresponding CH. The election process for CHs is periodic after a period of time has elapsed in order to fairly distribute energy consumption among the sensors during the lifetime of the network. Thus, this technique offers an editable transmission power, the sensors are supposed to have a topological knowledge at two hops, can modify their transmission powers and operate in an asynchronous manner, without centralized control. However, with the ESAC technique [11], the sensors can not always have a knowledge of two-hop topology and the diffusion of the calculated weights each time overloads the network. Another protocol called Energy Efficient Clustering Scheme in WSN (EECS) [21] is proposed for the election of CHs and the formation of clusters where the candidate CHs must compete to become CHs. These CHs candidate are selected from the nodes network according to a predefined probability and the CH having more residual energy is chosen. With EECS each node chooses the cluster to which it will join according to two parameters: the distance which separates it from the CH and that which separates CH from the base station. Thus, this protocol makes it possible to use dynamic sizes for the clusters. It offers a feasibility similar to that of LEACH [7, 9] in terms of recovery mechanism, with a better use and conservation of energy in the network and thus ensure a better connection and prolongation of the lifetime of the network. However, this protocol uses a single hop during communications to route data to the base station which consumes a lot of power by the remote nodes to reach the base station. Another protocol noted TEEN (*Threshild-sensitive Energy Efficient sensor Network protocol*) has been proposed in [13] which uses data detection to reduce energy consumption. However with this protocol, the base station does not know the nodes having exhausted their energies and that it does not satisfy the applications which require periodic data sending. To overcome the TEEN protocol limitations, the authors proposed an extension of TEEN in [14] called Adaptive Threshold-sensitive Energy Efficient sensor Network Protocol (APTEEN) that allows to change the periodicity and values of the thresholds used in TEEN according to the user needs and to the type of application which offers a great flexibility to the user to choose time interval even if it induces a high additional complexity associated with the formation of multi-layered clusters by TEEN and APTEEN. Another solution is proposed in [23] called Hybrid Energy Efficient Distributed clustering approach for adhoc sensor networks (HEED) which does not make any restriction on the distribution and the density of the nodes. It does not depend on network topology or size, but assumes that sensors have the ability to change their transmission power. This solution extends network lifetime by distributing communication energy and the number of CHs in a uniform way and thus producing compact clusters while minimizing the load of control messages. However, the choice of CHs is a decision that is based only on local information, shortcomings in the cost function arise in the case of inter-cluster communication that is not taken into consideration by this function. The extent of the network is posed as another problem of adequacy of this protocol for large-scale networks, given the strategy adopted for the communication between the CHs and the base station which is done via a single hop. Note in the case of HEED, clusters generated are not so balanced in size. A protocol noted DECSA (*Distance-Energy Cluster Structure Algorithm*) has been proposed in [22] to improve the LEACH protocol [7] considering the distance and the residual energy of the nodes and the reduced direct communication between the BS and the more remote CHs. However, DECSA [22], it particularly suffers from the hot spot problem. We cite also P-LEACH protocol [17] improves the LEACH protocol. In [6] the authors propose FL-EEC/D protocol by using the fuzzy logic model. The minimization of energy holes in wireless sensors network is treated in [15]. The Ant Colony Algorithm is used in [20] to Multicast Optimization in WSNs. In [18] the authors analyze the scalability issues of various protocols in terms of varying the number of nodes and varying the size of sensing area. In that case, EESRA [1] is proposed to extend the network lifespan despite an increase in network size. Another protocol noted ECBDA proposed in [16] (*Energy-Efficient Cluster Based Aggregation Data for Wirless Sensor Networks*) reduces the size of clusters close to the BS, and avoid the problem of hot spots and reduce energy consumption during data transmission following partitioning of the layered network. However, ECBDA does not guarantee a homogeneous distribution of the CHs on the network, because the only criterion of election of the CH is a random probability, and also the inter-cluster data transmission is random which induces the exhaustion of the sensors which are always in transmission state. The next section describes our proposed LCHREP protocol that aims to makes an efficient routing with a controlled energy consumption for WSNs.

3. LCHREP: Hierarchical Routing and Energy optimization Protocol

This section proposes a new low-power hierarchical routing protocol for the wireless sensors network noted LCHREP (*Layer and Cluster based Hierarchical Routing and Energy optimization Protocol*). Our contribution uses static clusters, aims to enhance the performance of both ECBDA (*Energy-Efficient Cluster Based Data Aggregation for Wireless Sensor Networks*) [16] and DECSA (*Distance-Energy Cluster Structure Algorithm*) [22] protocols. The idea of our proposal is to use the k-cluster layer hierarchy, as given by the two protocols ECBDA and DECSA but improving them with an horizontal partitioning according to an angle and also the randomness elimination in the CHs selection and in the transmissions of inter-cluster data.

The strength of our propose approach is to combine the both ideas proposed respectively in ECBDA [16] and in DECSA [22] protocols. Firstly, we use the idea proposed in ECBDA that consist in putting more clusters and thus more CHs in the lower layers (closest to BS) to share the load of transmissions, this which solves the problem of hot spots for which DECSA suffers. Secondly, we use the idea proposed DECSA concern the election of the CH (threshold election based on residual energy and the average distance between each node and all other nodes in the same cluster) and intercluster data transmission (each CH passes its data to the CH of the lower level close to the BS), where both operations are: a random election and a random data transmission in ECBDA which are induce energy consumption. Finally, the strength of our approach is due also to the improvements implemented in the clusters maintenance phase.

3.1 Assumptions

For a better illustration of our protocol, we give some assumptions based on the following network model [16]:

• The sensor nodes are all identical (*same initial energy, same storage capacity and data processing*).

• The nodes are randomly distributed over the capture area.

• The nodes are fixed, no mobility.

• The death of each sensor is caused only by the exhaustion of its energy, and not by other causes of failures.

• The transmission range is assumed to be the same for all nodes in the network.

• The base station is seen as a resource that is no limited, no exhaustible and knows the position of each node.

• The base station is capable to send unidirectional signals with an angle α.

3.2 LCHREP Description

To extend the sensor network life, it is necessary to minimize the energy consumption of each sensor because they are equipped with non-rechargeable and non-replaceable batteries. For this, each node must be designed to manage its energy resources. Our protocol is based on the clustering technique, which is used in sensor networks to minimize energy consumption while ensuring the smooth operation of the network. It adopts a mechanism for configuring the layered network to provide multihop routing between these layers. Also, it proceeds to a horizontal scan of the network with an angle α in order to create clusters.

The operation of our protocol follows three phases which are: the initialization phase, the data routing phase and the clusters maintenance phase.

3.3 Initialization Phase

This phase is executed once during the entire routing process, in order to cluster the sensor nodes. This phase structures the network into static clusters. It is realized in three stages, the first one is characterized by the network layers formation, the second one is realized by dividing each layer into clusters with an angle α and the third one corresponds to the selection of CHs. At the end of this step phase, our network will be divided into several clusters.

3.3.1 Layers Formation Stage

In this step, the BS splits the network into L layers by calculating the distance δ between BS and the farthest node [16]:

$$\delta = max\ \{\forall^{N}_{i=1}\ d\ (sn_i, BS)\} \qquad (1)$$

where $d\ (sn_i, BS)$ is distance between the BS and sensor node sn_i.

The BS uses the minimum radio transmission range to split the network into L layers in order to provide the communication between the CHs in two adjacent layers. The number of layer L depends on the maximum distance δ and the minimum radio transmission range T_{r-min} of the nodes [16]:

$$L = \frac{\delta}{T_{r-min}} \qquad (2)$$

To split the network into layers, the BS uses the hops number of such that the remote nodes with l hops will belong to the lth layers, where l is given as [16]:

$$l = \left\lfloor \frac{d\ (sn_i, BS)}{T_{r-min}} \right\rfloor;\ sn_i \in l^{th}\ layer,\ where\ 1 \le l \le L \qquad (3)$$

The BS sends L messages with different signal strengths depending on the number of hops to have different distances to the BS. Upon message receipt by the nodes, they calculate the distance of the BS and update their id_layer to l. At the end of this stage, the network is partitioned into L layers, where each node has a id_layer.

3.3.2 Clusters Formation Stage

A clustering technique is used in this stage, each layer is divided into a set of K clusters. The BS calculates the number of clusters for each layer, knowing that the lower layer (*the closest to* BS) has the highest K cluster value. This is to prevent the BS near CHs from exhausting their energy early as they will support transmissions from all CHs far from BS. The goal will be to put more clusters and thus more CHs close to BS to share the load of transmissions. The number K clusters in each l layer [16] is given by:

$$K(l) = \left\lceil \frac{n(l)}{l * L} \right\rceil \qquad (4)$$

where $n(l)$ is the number of nodes in layer l.

After calculating K, the BS performs an horizontal scan with an angle $\alpha(l) = 180/K(l)$ on each layer l. Subsequently, the BS sends for each node in each cluster a packet including the identifier $(id\_cluster)$ on all layers of the network. At the end of this stage, nodes in the same layer and cluster have the same id_layer and $id\_cluster$.

Algorithm 1 below illustrates the principle of the two previous stages: the layers and clusters formation:

Algorithm 1: Layers and clusters formation

Input:

sn_i : The sensor node i

$d\ (sn_i, BS)$: The distance between BS and sn_i

T_{r-min} : The minimum radio transmission range of the nodes

Output:

δ : The distance between BS and the farthest node ;

```
L : The number of layer;
N(l) : The number of nods in each layer l;
K(l): The number of clusters in each layer
      l ;
sn_i(id_layer) : the nod sn_i layer number;
sn_i(id_cluster) : the nod sn_i cluster number;
α : the scan angle for each layer l;

δ ← max {d (sn_i, BS)};
L ← δ / T_{r–min} ;
for l = 1 to L do
    for each sn_i do
        if d (sn_i, BS) ≤ l * T_{r–min} then
            sn_i(id_layer) ← l;
            N(l) ← N(l) + 1;
for l = 1 to L do
    K(l) ← ⌈ N(l) / (l * L) ⌉
for l = 1 to L do
    α ← 180 / K(l) ; β ← α ;
    for K = 1 to K(l) do
        scan(sn_i, l, α, K) ; id_cluster assignment
        for each node sn_i in the angle α;
        α ← α + β ;
```

3.3.3 Clusters Head Election

After clusters formation, the *BS* performs a random selection within each cluster a *FCH* (*false cluster head*) whose mission is to elect the *CH* of the associated cluster. The *FCH* sends an election message to all members of its cluster, the latter respond with a message containing their residual energy $Er(i)$.

The *FCH* calculates an election threshold $T(i)$ for each node of its cluster. The node with the largest $T(i)$ is elected as the *CH* of the associated cluster. We define $T(i)$ as follows [22]:

$$T(i) = \frac{Er(i)}{d_0(i)} \tag{5}$$

where $T(i)$ is the *CH* election threshold, $Er(i)$ is the residual energy of node i, $d_0(i)$ is the average distance between node i with all other nodes in the same cluster.

3.4 Data Routing Phase

This phase collects and routes data to the *BS*, using multi-hop to minimize power consumption of the sensor nodes and to increase network lifetime.

3.4.1 Intra-cluster Data Transmission

After cluster formation and the election of *CHs* for each cluster, the member nodes send their captured data to the *CH* of their associated cluster. In order to avoid collisions during data transmission by sensor nodes, we use Time Division Multiple Access (TDMA) scheduling, which allocates to member nodes time slots called frames assigned by their *CHs* in order to transmit their data without risk of collision. This allows the sensor nodes to turn off their communication interface outside their slots in order to save their energies. This data is aggregated by the *CH* to avoid redundancy of data and over-consumption of energy and then sent to the next relay node.

3.4.2 Cross-cluster Data Transmission

Most of the time, the *CHs* transmit their data directly to the BS, which generates a very high energy consumption and therefore a decrease in the lifetime of the network. To overcome this problem, multi-hop is adopted as the routing mechanism for passing relay node data to relay nodes until they arrive at the *BS*. As a result, less energy consumed and longer network life. After aggregating the data by the *CHs*, each *CH* passes its data to the *CH* of its next lower level and close to the *BS*, while the *CHs* of the first level communicate the received data directly to the *BS*. The *BS* assigns to each *CH* the *CHs* to which it can communicate its data. The number of these *CHs* is obtained by the following formula [12]:

$$S = \left\lceil \frac{K\,(l-1)}{K(l)} \right\rceil \tag{6}$$

where $K\,(l-1)$: the number of clusters in layer $(l-1)$ with each *CH* of layer l can communicate and K_i is the number of clusters in layer l.

Therefore, each *CH* can communicate with *S-CHs* of the lower layer whose angles of the *S-CHs* clusters are covered by the angle of the *CH*. After message exchange between the *CH* and the *S-CHs*, it chooses the *CH* with its higher residual energy as a relay node. The procedure is the same until the data arrives at the first layer, where the *CHs* of this layer sends them directly to the *BS*.

3.5 Clusters Maintenance Phase

In the hierarchical routing protocols, the maintenance phase is very expensive thanks to the overload imposed on the CHs with respect to the sensor nodes.

When the energy of the *CH* approaches exhaustion, and the battery reaches the threshold $T = 20\%$ of its initial energy charge, the system detects this depletion and the current *CH* takes the role of *FCH* for the selection of a new *CH* of his cluster. When the cluster nodes have all assumed the CH role, each node sends its data to the nearest neighbor node of another cluster (*either to the cluster of the same layer or other layers*).

If all the nodes of all the clusters of the first layer (*closest to the* BS) took the role of CH, each node of this first layer sends its data directly to the BS. Having learned of this, the BS sends a message to the second layer CHs informing them to transmit their data directly to the BS.

4. Performance Evaluation

4.1 Environment and Simulation Context

This section shows conducted experiments using Matlab toolbox. Our simulated system represents a square sensing area of $(500 * 500)m^2$ with 200 randomly deployed sensors and a BS. The sensor nodes used in the simulation are homogeneous: having the same amount of initial energy, the same computing capacity, memory and the same transmission range, the energy of the base station is unlimited. Table 1 summarizes the used parameters:

Parameters	**Values**
Number of base stations	1
Number of nodes	200
Simulation surface	$(500*500)m^2$
Base Station Location	(250, 500)
Transmission range	100 m
Initial energy	0.7 J
Packet Transmission Energy	$5*10^{-6}J$
Packet Receiving Energy	$5*10^{-6}J$
Data Aggregation Energy	$5*10^{-7}J$

Table 1. Simulation parameters

4.2 Results and Discussions

4.2.1 The Random Deployment of the Sensor Nodes, the FCHs and CHs selection with LCHREP

Figure 1 shows the random deployment of the nodes in the capture field which is divided into layers ($L1$ to $L5$) and clusters. Each type of symbol symbolizes the nodes of the same layer, and each color symbolizes the nodes of the same cluster and the the inversed red triangle represents the base station (BS). Figure 1 also shows the nodes selected as $FCHs$ and CHs of each cluster. The nodes selected as $FCHs$ are surrounded by squares and the CHs by circles.

4.2.2 Remaining Energy after Clusters Head selection with LCHREP vs ECBDA

Figure 2 (a) shows the remaining energy of each sensor after selecting the CHs by the $LCHREP$ proposed protocol. We note that the remaining energy of the majority of nodes is nearly 0.7 J. We also note that the remaining energy of some nodes is less than 0.7 J, where it goes down to less than 0.6998 J. Some nodes have their energy lower than 0.7 J because they are chosen like $FCHs$. They have dissipated their energies in selecting CHs by calculating the T election threshold of each sensor and sending/receiving messages from all the nodes of its cluster. On the other hand, the minimum energy dissipated by the other nodes is due to the packets sending reception by the $FCHs$. Figure 2 (b) represents the remaining energy of each sensor after the selection of CHs by the $ECBDA$ protocol [16]. We notice that the remaining energy of each sensor after the selection of Chs is below 0.6987 J. Each node dissipates a considerable amount of energy due to the computation of the probability, which contains several operations, to become Ch and the sending of the messages containing this probability to all the other odes of the same cluster.

Comparing the $LCHREP$ proposed protocol with the $ECBDA$ protocol [16], we note that the remaining energy of each sensor after the selection of CHs in the $LCHREP$ protocol is higher than the $ECBDA$ protocol, which confirms the efficiency of CHS selection technique used in $LCHREP$.

4.2.3 Average remaining Energy of each Sensor after sending 400 Packets

Figure 3 (a) shows the remaining energy of each sensor after sending 400 packets for the $LCHREP$ protocol. We note that the remaining energy of each sensor does not exceed 0.56 J, each sensor has dissipated on average 0.52 J of its initial energy and this is due to packet sending, packet reception and aggregation of data if it is a CH and the re-election of another CH after the previous has reached its lower energy limit. Comparatively, with $ECBDA$ [16] protocol (*see Figure 3 (b)*) we note that the remaining energy of each sensor does not exceed 0.23 J where each sensor dissipated on average 0.68 J of its initial energy. This is due to the sending/receiving of packets, the aggregation of data if it is Ch, the reelection of Ch at each end of the predefined period and the random selection of Chs during inter-cluster communications under $ECBDA$.

Comparing the results obtained with $LCHREP$ and $ECBDA$, as regards the average remaining energy of the sensors after the sending of 400 packets, we can say that it is higher with $LCHREP$ than that obtained with $ECBDA$. This efficiency is due to the condition of election and re-election of Ch and intercluster routing.

4.2.4 Average Amount of Energy Consumed in Terms of Sending Packets

Figure 4 shows the average amount of energy consumed when sending packets with the $LCHREP$ and $ECBDA$ protocols. We note that when increasing the packet sending, the energy consumed increases for both protocols caused by the energy dissipated by each node whether it is sensor or CH. Comparatively, the two protocols, we notice that the number of packets that $LCHREP$ can send

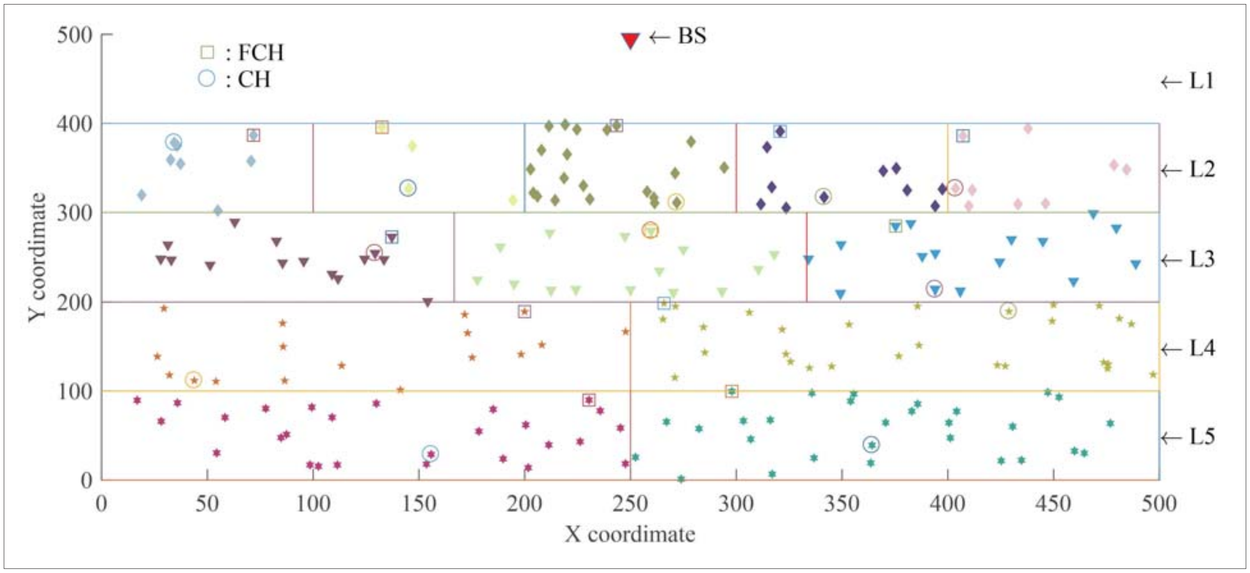
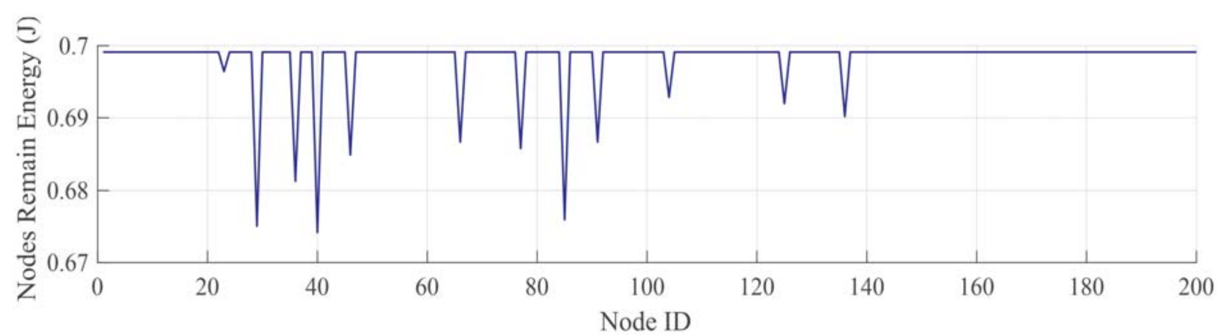
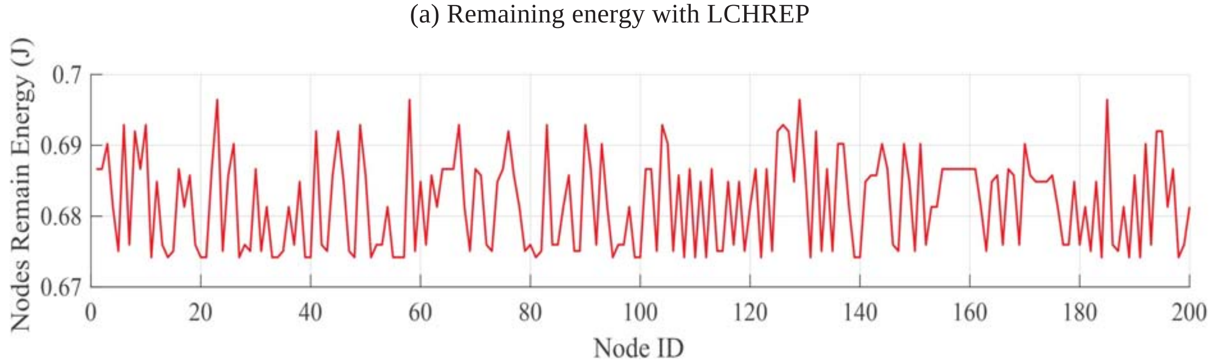


Figure 1. The random deployment of the sensor nodes, the FCHs and CHs selection with LCHREP



(a) Remaining energy with LCHREP



(b) Remaining energy with ECBDA

Figure 2. Remaining energy of the nodes after Chs selection with LCHREP and ECBDA

before the network failure is greater than the number of packets that *ECBDA* can send. We note that *LCHREP* manages to send up to 600 packs against *ECBDA* just 516 packets. On the other hand, the energy consumed by *ECBDA* exceeds that of *LCHREP* and this is due to the inter-cluster routing technique, the *CH* re-selection condition and the maintenance phase.

4.2.5 Number of Failed Nodes and those alive after Sending Packets

Figures 5, 6 show the number of failed nodes and those alive according to sending packets sent by under both protocols. We notice that by increasing the number of packets sent, the number of failures increases. The increase of failed nodes has the effect of reducing the number of functional nodes in the network and consequently those chosen as *CHs*, which increase the load of the other nodes and consume more energy for the management of the clusters. Comparing results of the two protocols, we notice that the number of nodes failing as a function of sending packets for *ECBDA* higher than that of *LCHREP*, and contrary for the number of functional nodes.

This efficiency is due to all the improvements made for ECBDA that are implemented in LCHREP.

4.2.6 Average Energy Consumed in Terms of sending Packets with varying Messages size or Simulation Surface

We have conducted other simulations in order to compare LCHREP and ECBDA protocols in terms of 4.2.6 Average energy consumed in terms the average energy consumed during the change in message (*packet*) size or the variation in simulation surface.

We use 10 different values of message size and 10 variations in simulation surface in order to show the average energy consumed in terms of sending packets.

Figure 7 shows the average energy consumed after sending 600 packets with varying messages size from 8 bits to 80 bits when using 100 or 300 sensor nodes with LCHREP and ECBDA protocols. We note that the LCHREP protocol induces less energy consumption compared to that induced by ECBDA when changing the message size with either 100 or 300 nodes. We note also

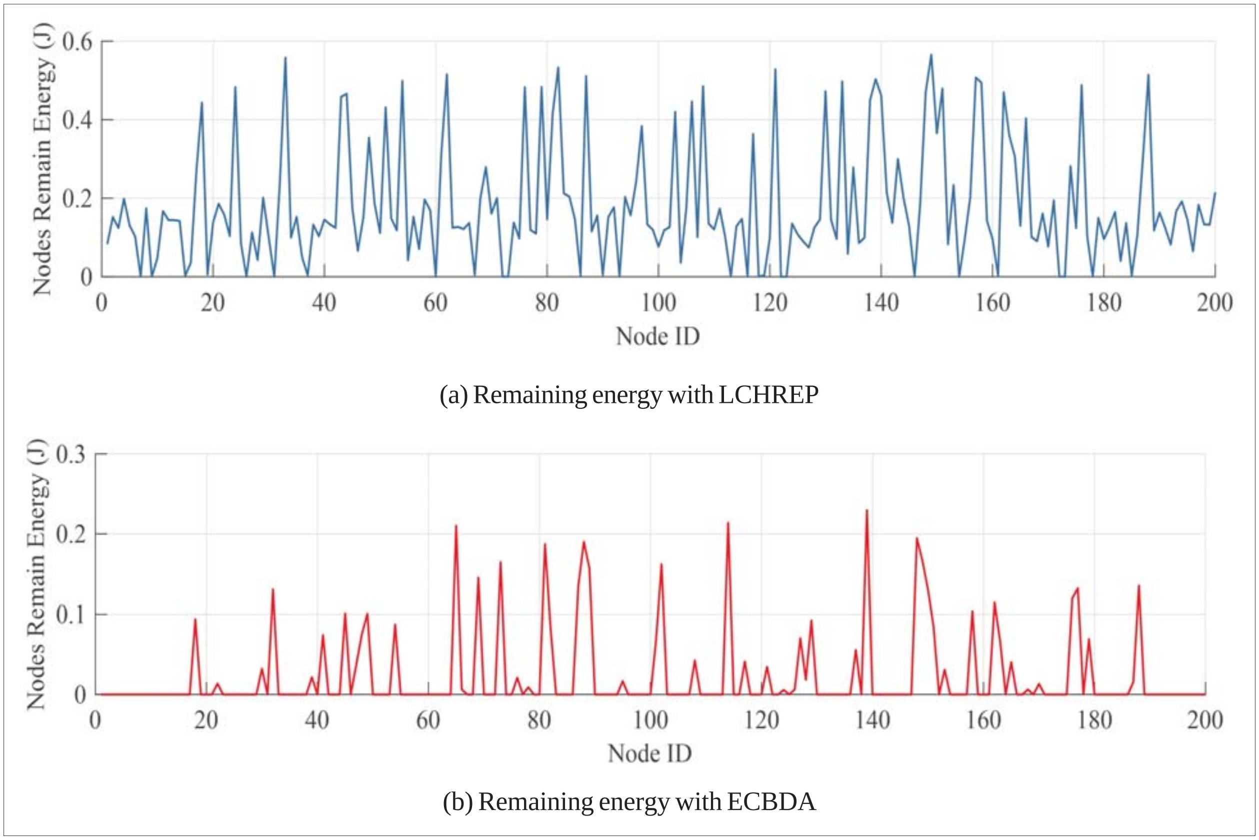


Figure 3. Remaining energy of each sensor after sending 400 packets with LCHREP and ECBDA protocols

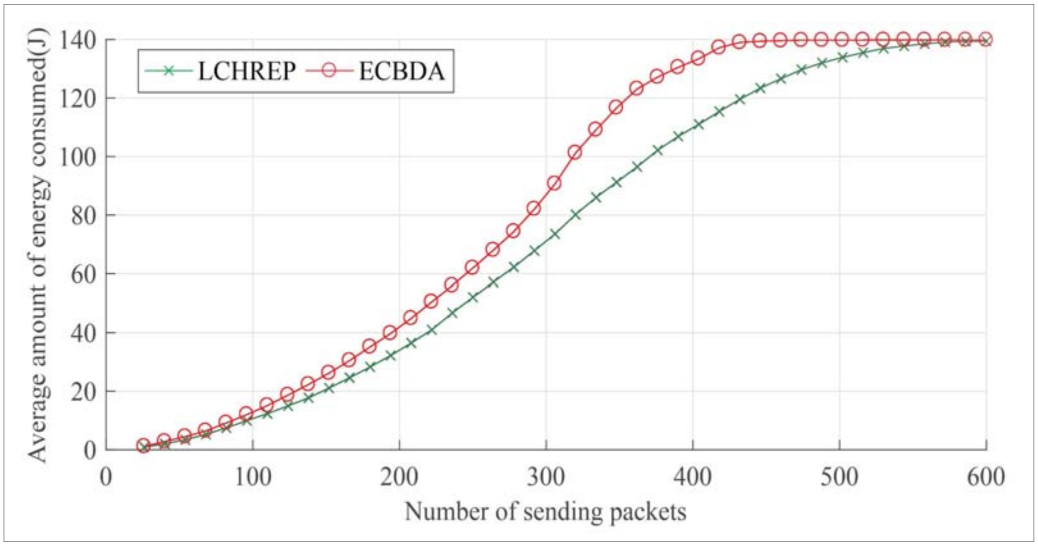


Figure 4. Average energy consumed in terms of sending packets

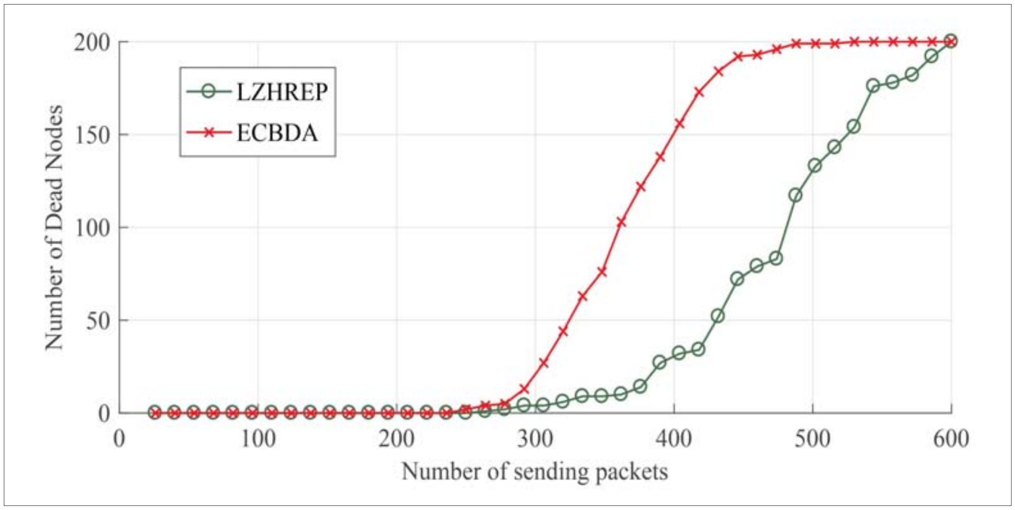


Figure 5. Number of nodes failing (dead) based on packet sending.

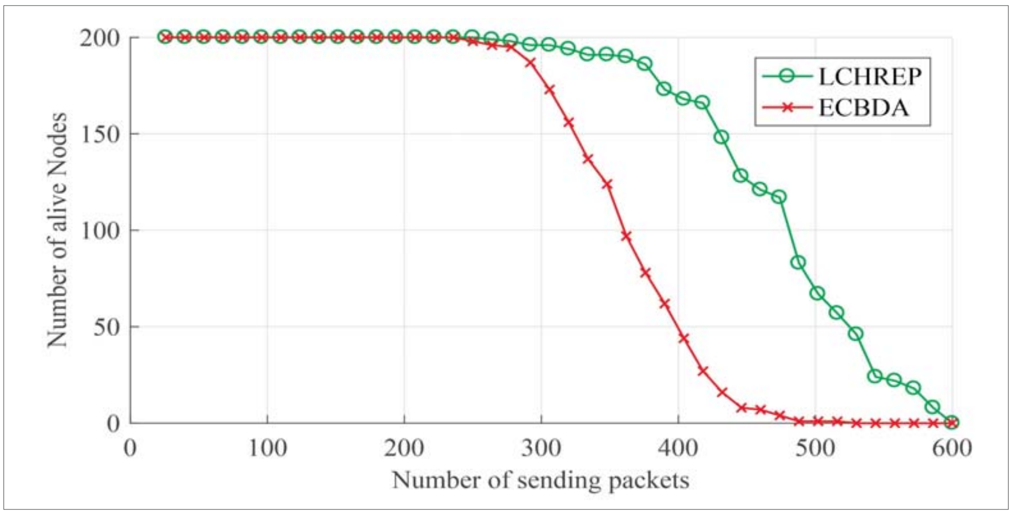


Figure 6. Number of nodes alive based on packet sending

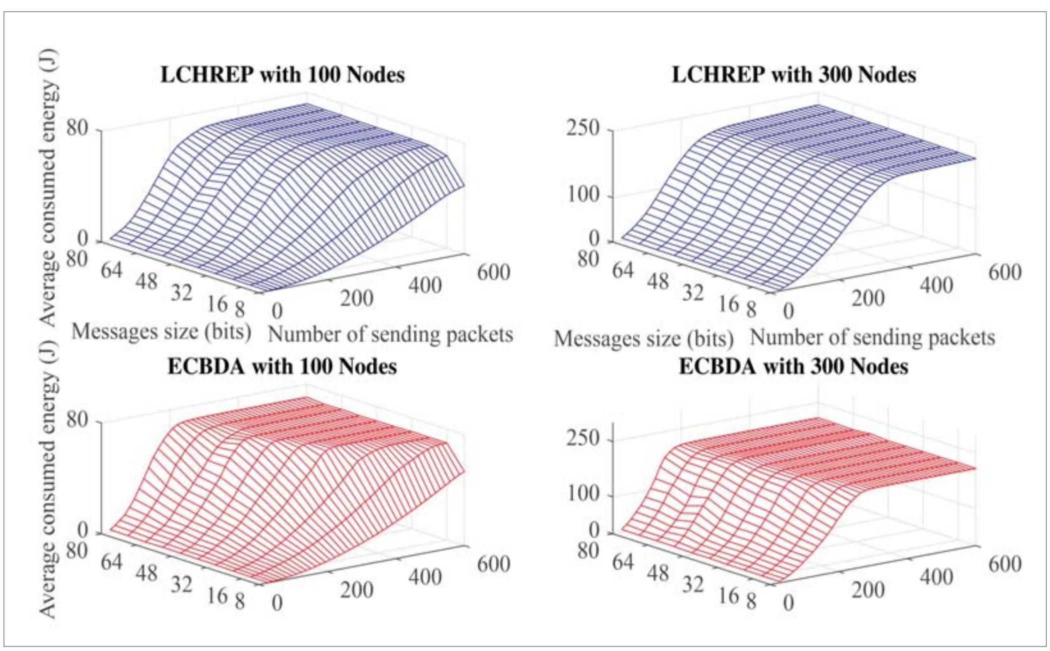


Figure 7. Average amount of energy consumed in terms of sending packets with varying messages size

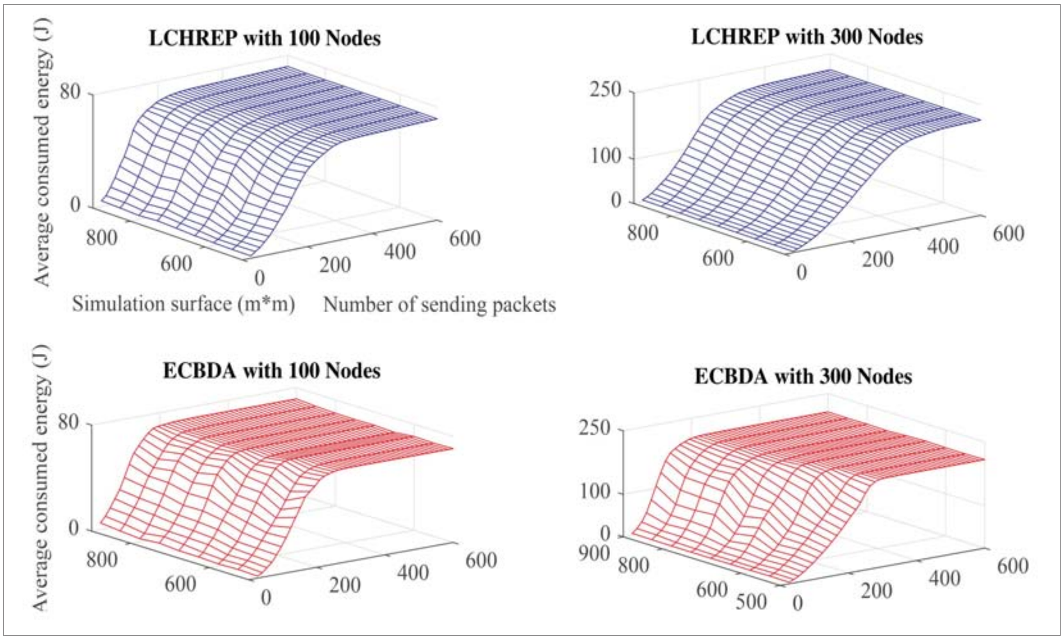


Figure 8. Average amount of energy consumed in terms of sending packets with varying surface size

that this variation does not inflate much consumption with *LCHREP* but which influences the consumption under *ECBDA* where the inter-cluster data transmission is random which induces the exhaustion of the sensors which are always in transmission state. Knowing that the energy consumed when sending or receiving messages takes into account the size of the message and the distance between each node and the cluster head in intra-cluster data transmission or between clusters heads in inter-cluster data transmission.

Figure 8 shows the average energy consumed after sending 600 packets with varying simulation surface from 500*500 m^2 to 900*900 m^2 when using 100 or 300 sensor nodes with *LCHREP* and *ECBDA* protocols. We notice that the increase of the surface area does not affect the energy consumed in the same protocol and with the same number of nodes. By comparing the two protocols, we can say that *LCHREP* induces on average less energy consumed than that induced by *ECBDA*.

4.2.7 Number of Dead Nodes in Terms of sending Packets with varying Messages or Surface Size

We have conducted simulations in order to compare *LCHREP* and *ECBDA* protocols in terms of the number of dead nodes regarding the variation in messages size or in simulation surface.

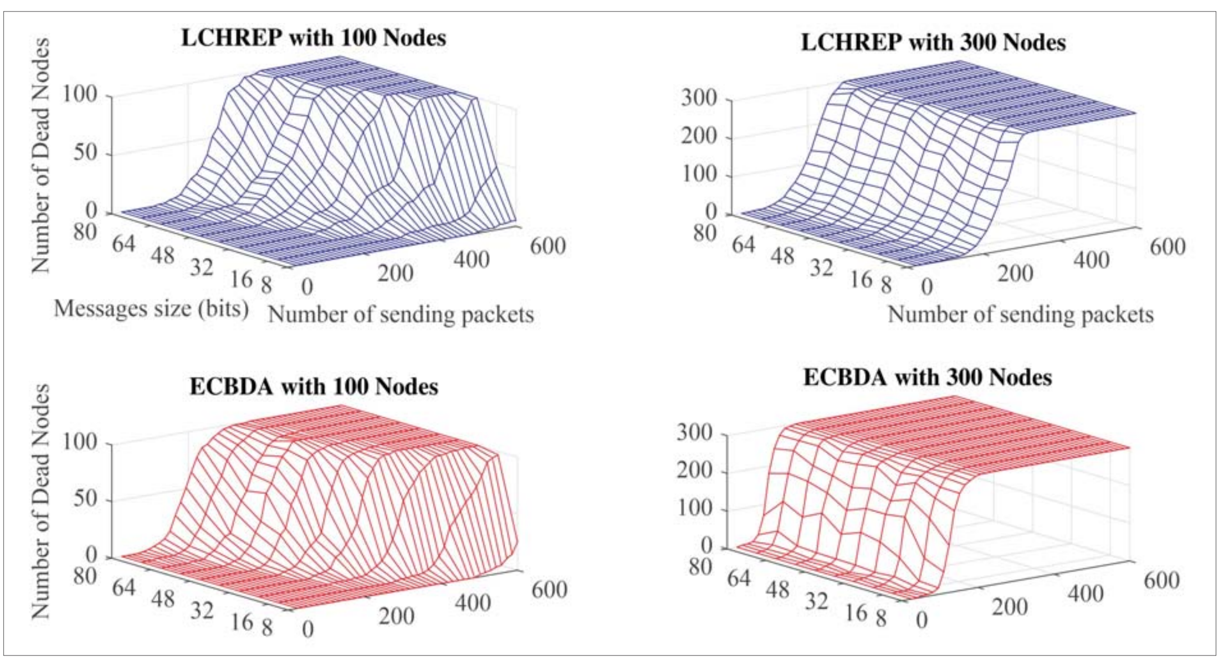


Figure 9. Number of dead nodes in terms of sending packets with varying messages size

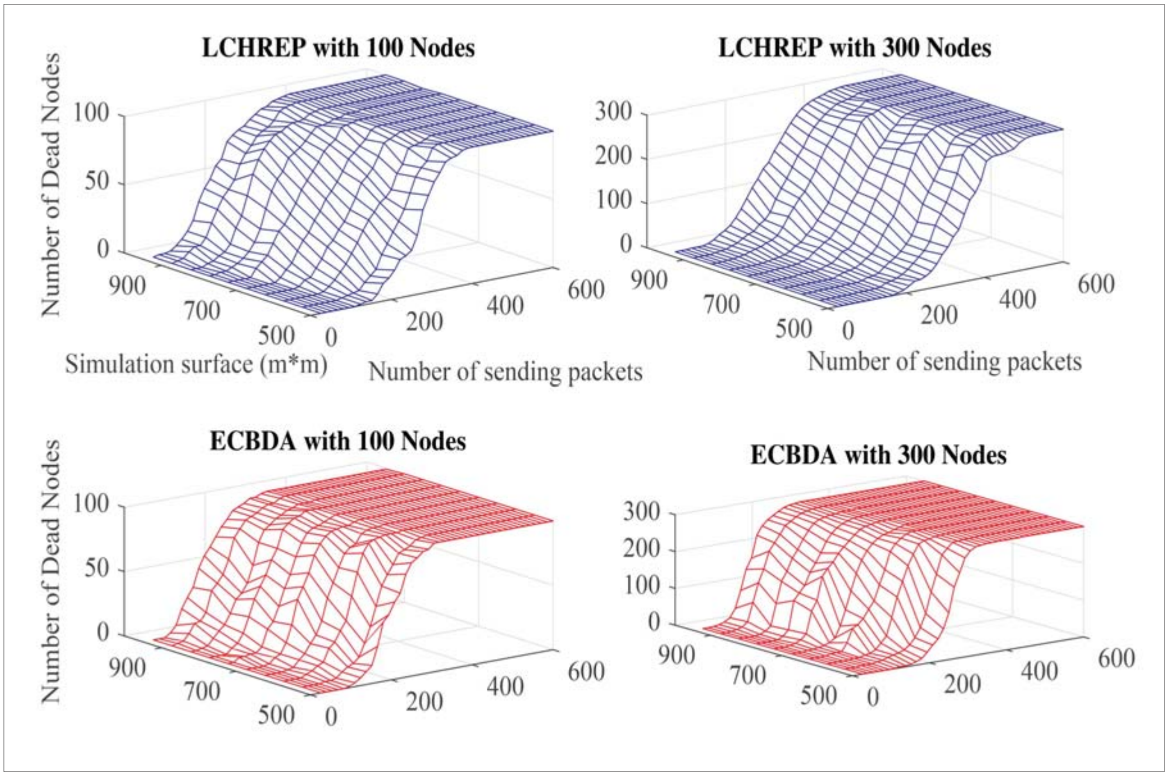


Figure 10. Number of dead nodes in terms of sending packets with varying surface size

We use 10 different values of message size or 10 variations in simulation surface in order to show the number of dead nodes in terms of sending packets. First, we notice in Figure 9 that with the same protocol, the same small message size (*eg. 16 bits*) and a simulation surface of $500\,m^2$ the number of failed or dead nodes when using 100 nodes is less than the use case of 300 nodes. We can say that the increase of number of nodes in the sensor network causes the increase of the faulty nodes. We explain this observation by the fact that cluster head (CH) selected supports intra-cluster data transmission (*control messages and data captured*) of several nodes of its cluster which will cause the rapid depletion of its energy which requires its replacement by another node that will suffer by the same effects. Secondly, comparing LCHREP and ECBDA protocols, we find that ECBDA causes faster network failure especially when the message size is high and with a large number of sensor nodes. Figure 10 shows the number of failed nodes according to the simulation surface variation and the number of packets sent with messages size equal to 80 bits. We notice that the increase of the simulation surface causes the increase of the dead nodes especially when sending from 100 to 300 packets. This is explained by the fact that the increase of the surface increases the distance between the nodes and their cluster heads which leads them to use more energy when sending or receiving different types of messages and by the following exhausts their energy and causes their failures. We also note that *LCHREP* delays the network failure better when increasing number of nodes (*for example the use of 300 instead of 100 nodes*) which is not the case with *ECBDA*.

5. Conclusion

This paper has addressed the problem of the routing and wasting energy in the context of wireless sensor networks. Our main contribution is the proposal of a new protocol of hierarchical routing with low energy consumption for the networks of sensors called LCHREP (*Layer and Cluster based Hierarchical Routing and Energy Optimization Protocol*), it takes into account the constraints imposed by the sensors, low storage capacity and limited lifetime, allowing more efficient management of the energy resource when communicating data in the network. It adopts an organization of the nodes in level (*according to the distance compared to the base station*). This layered configuration provides flexibility in communicating the sensed data to the base station. Our protocol forms clusters in each layer. However, the number of clusters in the different layers is different, the cluster number is indirectly proportional to the number of the layer, it means that the number of clusters in the first layer exceeds the number of clusters in all the other layers, this which solves the problem of hot spots. Multi-hop routing is done in our protocol between the relay nodes of the different layers, which allows to consume less energy to reach the base station. The performance evaluation of our protocol was simulated in Matlab in which we found that our proposal is much better than the *ECBDA* protocol.

In the near future, we plan to study the behavior of our protocol in a mobile environment. We plan also to enhance the problem of routing and wasting energy in context of ambient energy harvesting systems.

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