Improved and Balanced LEACH for heterogeneous wireless sensor networks

BEN ALLA Said*, EZZATI abdellah**
Lab. Systems Analysis and Processing Information
Faculté des Sciences et Techniques
Settat Morocco, BP:577
*saidb_05@hotmail.com, **abdezzati@gmail.com

Abderrahim BENI HSSANE *, Moulay Lahcen HASNAOUI **
MATIC Laboratory, Department of Mathematics and Computer Science,
Faculty of Sciences, Chouaïb Doukkali University, El Jadida, Morocco
*abenihssane@yahoo.fr,**mlhnet2002@yahoo.ca*

Abstract: While wireless sensor networks (WSN) is a power constrained system, since nodes run on limited power batteries which shorten its lifespan. Prolonging the network lifetime depends on efficient management of sensing node energy resource. Energy consumption is therefore one of the most crucial design issues in WSN. Hierarchical routing protocols are best known in regard to energy efficiency. By using a clustering technique hierarchical routing protocols greatly minimize energy consumed in collecting and disseminating data. In this paper we propose Improved and Balanced LEACH (IB-LEACH), a heterogeneous-energy protocol propose a new method to decrease probability of failure nodes and to prolong the time interval before the death of the first node (we refer to as stability period) and increasing the lifetime in heterogeneous WSNs, which is crucial for many applications. We study the impact of heterogeneity of nodes, in terms of their energy, in wireless sensor networks that are hierarchically clustered. In these networks some high-energy nodes called NCG nodes (Normal node/Cluster Head/ Gateway) become "cluster heads" to aggregate the data of their cluster members and transmit it to the chosen "Gateways" that requires the minimum communication energy to reduce the energy consumption of cluster head and decrease probability of failure nodes. The simulation results demonstrated that new protocol is more energy efficient and is more effective in prolonging the network life time and a stability period compared to LEACH and SEP.

Keywords: Network Clustering, Nodes failure, routing protocol, Wireless Sensor Networks, Gateway

I. INTRODUCTION

Routing techniques are the most important issue for networks where resources are limited. WSNs technology's growth in the computation capacity requires these sensor nodes to be increasingly equipped to handle more complex functions. Each sensor is mostly limited in their energy level, processing power and sensing ability. Thus, a network of these sensors gives rise to a more robust, reliable and accurate network. Lots of studies on WSNs have been carried out showing that this technology is continuously finding new application in various areas[5,6,7], like remote and hostile regions as seen in the military for battle field surveillance, monitoring the enemy territory, detection of attacks and security etiquette. Other applications of these sensors are in the health sectors where patients can wear small sensors for physiological data and in deployment in disaster prone areas for environmental monitoring. It is noted that, to maintain a reliable information delivery, data aggregation and information fusion that is necessary for efficient and effective communication between these sensor nodes. Only processed and concise information should be delivered to the sinks to reduce communications energy, prolonging the effective network life-time with optimal data delivery.

An inefficient use of the available energy leads to poor performance and short life cycle of the network. To this end, energy in these sensors is a scarce resource and must be managed in an efficient manner. We present a novel protocol which is an extension of the LEACH [2], to properly distribute energy and ensure maximum network life time. Our simulation result shows an improvement in effective network life time and increased robustness of performance in the presence of energy heterogeneity.

The remaining part of this paper is organized as follows. We briefly review related work in section 2. Section 3 summarizes Energy Analysis of Routing protocols. In section 4, we present our IB-LEACH protocol. Our simulation result is presented in section 5. Finally, in section 6, we conclude the paper and highlights future directions for other aspects of improvement in WSN.

II. RELATED WORKS

Similar to other communication networks, scalability is one of the major design attributes of sensor networks. A single-tier network can cause the gateway to overload with the increase in sensor density. Such overload might cause latency in communication and in adequate tracking of events.

In addition, the single-gateway architecture is not-scalable for a larger set of sensors covering a wider area of interest since the sensors are typically not capable of long-haul communication. To allow the system to cope with additional load and to be able to cover a large area of interest without degrading the service, networking clustering has been pursued in some routing approaches.

The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. LEACH [2] is one of the first hierarchical routing approaches for sensors networks. The idea proposed in LEACH has been an inspiration for many hierarchical routing protocols [3, 9, 10, 11, 12, 13].We explore hierarchical routing protocols LEACH and SEP in this section.

A. *LEACH*

Low-energy adaptive clustering hierarchy (LEACH) [2] is one of the most popular hierarchical routing algorithms for sensor networks. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. This will save energy since the transmissions will only be done by such cluster heads rather than all sensor nodes.

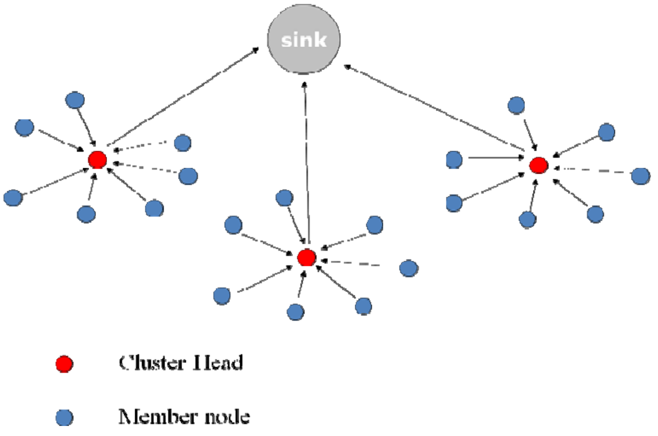


Figure 1. Network style with clustering

All the data processing such as data fusion and aggregation are local to the cluster. Cluster heads change randomly over time in order to balance the energy dissipation of nodes. This decision is made by the node choosing a random number between 0 and 1. The node becomes a cluster head for the current Round if the number is less than the following threshold:

$$T(n) = \begin{cases} \dfrac{P}{1 - P * (r \bmod \frac{1}{P})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

- P = Desired cluster head percentage
- r = Current Round
- G = Set of nodes which have not been cluster heads in 1/P rounds

LEACH achieves over a factor of 7 reduction in energy dissipation compared to direct communication and a factor of 4–8 compared to the mini- mum transmission energy routing protocol[7]. The nodes die randomly and dynamic clustering increases lifetime of the system. LEACH is completely distributed and requires no global knowledge of network. However, LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions. Furthermore, the idea of dynamic clustering brings extra overhead, e.g. Head changes, advertisements etc., which may diminish the gain in energy consumption.

B. *SEP Protocol*

SEP (A Stable Election Protocol) protocol [1] was improved of LEACH protocol. Main aim of it was used heterogeneous sensor in wireless sensor networks. This protocol have operation like LEACH but with this difference that, in SEP protocol sensors have two different level of energy. SEP based on weighted election probabilities of each node to become cluster head according to their respective energy. This approach ensures that the cluster head election is randomly selected and distributed based on the fraction of energy of each node assuring a uniform use of the nodes energy. In the SEP, two types of nodes (two tier in-clustering) and two level hierarchies were considered.

III. ENERGY ANALYSIS OF ROUTING PROTOCOLS

For this project, three routing protocols, namely LEACH and SEP and our protocol IB-LEACH (Improved and balanced LEACH) had been analyzed based on according to the radio energy dissipation model illustrated in Figure 2, in order to achieve an acceptable Signal-to-Noise Ratio (SNR) in transmitting a K bit message over a distance d.

The Radio Energy Dissipation Model is illustrated in Figure 2 and the characteristics are summarized in Table 1[1].

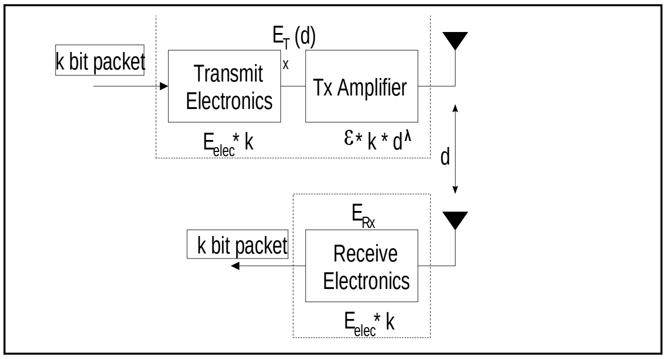


Figure 2. The Radio Energy Dissipation Model

The energy expended by the radio is given by:

$$E_{Tx}(k,d) = \begin{cases} (E_{elec} * k) + (\varepsilon_{fs} * k * d^{2}) & if \ d \le d_{0} \\ (E_{elec} * k) + (\varepsilon_{mp} * k * d^{4}) & if \ d \succ d_{0} \end{cases}$$

Where E_{elec} is the energy dissipated per bit to run the transmitter or the receiver circuit, ε_{fs} and ε_{mp} depend on the transmitter amplifier model we use, and d is the distance between the sender and the receiver. By equating the two expressions at d=do, we have: $d_0 = \sqrt{(\frac{\varepsilon_{fs}}{\varepsilon_{mp}})}$.

To receive a K-bit message the radio expends

$$E_{Rx}(k) = E_{elec} * k \ .$$

TABLE I. RADIO CHARACTERISTICS

Operation	Energy Dissipated
Transmitter/Receiver Electronics	Eelec=50nJ/bit
Data Aggregation	EDA=5nJ/bit/signal
Transmit Amplifier if dmaxtoBS ≤ d0	Єƒs=10pJ/bit/m2
Transmit Amplifier if dmaxtoBS ≥ d0	єmp=0.0013pJ/bit/m4

IV. THE IMPROVED AND BALANCED LEACH PROTOCOL (IB-LEACH)

In this section we describe IB-LEACH which is an extension of the LEACH, which improves the stable region of the clustering hierarchy and decrease probability of failure nodes using the characteristic parameters of heterogeneity.

Routing in IB-LEACH works in rounds and each round is divided into two phases, the Setup phase and the Steady State; each sensor knows when each round starts using a synchronized clock. Let us assume the case where a percentage of sensor nodes are equipped with more energy resources than the rest of the nodes. Let m be the fraction of the total number of nodes N which are equipped with a times more energy than the others and b is the fraction of the total number of nodes N which are elected Gateways. We refer to these powerful nodes as NCG nodes (node selected as normal node or cluster head or gateway), and the rest (1-m) * N as normal nodes. We assume that all nodes are distributed uniformly over the sensor field.

A. Gateway Selection Algorithm

Each sensor i elects itself to be a gateway at the beginning of round r+1 with probability Pgi(t). Pgi(t) is chosen such that the expected number of Gateway nodes for this round is kg. Thus, if there are N*m advanced nodes in the network, node i become a gateway at round r with probability Pgi(t)

$$P_g = \frac{K_g}{N \times m}$$

We define as $T(s_{gat})$ the threshold for Gateway nodes

$$T(s_{gat}) = \begin{cases} \dfrac{P_g}{1 - P_g * (r \bmod \frac{1}{P_g})} \times \dfrac{E_{s\_current}}{E_{s\_initial}} & \text{if } s \in G_{gat} \\ 0 & \text{otherwise} \end{cases}$$

- Kg= Desired Gateway number
- r = Current Round
- G_g = Set of nodes which have not been Gateway in 1/Pg rounds
- $E_{s\_current}$ is the current energy of the node.
- $E_{s\_initial}$ is the initial energy of the node.

We assume that the expect number of the Gateways is the same with the optimum number of the Gateways for the sensor network called kg_{opt}. We implement Gateway selection algorithm by adding two steps. At step 1, we change the system parameter kg, and let kg is larger than kg_{opt}. All nodes have more probability to become Gateways, if the nodes elect themselves to be Gateway; they send their ID and energy information to the base station. At the step 2, if the number of IDs received by base station is larger than kg_{opt}, the base station selects the kg_{opt} nodes with more energy to be Gateways, and others not to be Gateways. If the number of IDs received by base station is equal or less than kg_{opt}, the base station selects those nodes to be Gateways.

B. Cluster Head Selection Algorithm

The main idea is for the sensor nodes to elect themselves with respect to their energy levels autonomously. The goal is to minimize communication cost and maximizing network resources in other to ensure concise information is sent to the sink. Each node transmits data to the closest cluster head and the cluster heads performs data aggregation. Assume an optimal number of clusters kopt in each round. It is expected that as a cluster head, more energy will be expended than being a cluster member. Each node can become cluster head with a probability Popt and every node must become cluster head once every 1/Popt rounds. Intuitively, it means we have N*Popt clusters and cluster heads per round. Let the non-elected nodes be a member of set G in the past 1/Popt rounds.

Our approach is to assign a weight to the optimal probability Popt. This weight must be equal to the initial energy of each node divided by the initial energy of the normal node. Let us define as Pnrm the weighted election probability for normal nodes, and Padv the weighted election probability for the advanced nodes.

Virtually there are n*(1+a*m) nodes with energy equal to the initial energy of a normal node. In order to maintain the minimum energy consumption in each round within an epoch, the average number of cluster heads per round per epoch must be constant and equal to n*Popt. In the heterogeneous scenario the average number of cluster heads per round per epoch is equal to n*(1+a*m)*Pnrm (because each virtual node has the initial energy of a normal node.) The weighed probabilities for normal and advanced nodes are, respectively:

$$P_{nrm} = \frac{P_{opt}}{1 + a \times m}$$

$$P_{adv} = \frac{P_{opt}}{1 + a \times m} \times (1 + a)$$

In Equation (1), we replace Popt by the weighted probabilities to obtain the threshold that is used to elect the cluster head in each round. We define as T(s_{nrm}) the threshold for normal nodes, and T(s_{adv}) the threshold for advanced nodes. Thus, for normal nodes, we have:

$$T(s_{nrm}) = \begin{cases} \dfrac{P_{nrm}}{1 - P_{nrm} \times (r \bmod \dfrac{1}{P_{nrm}})} \times \dfrac{\mathrm{E}_{\text{s\_current}}}{\mathrm{E}_{\text{s\_initial}}} & if \quad s_{nrm} \in G_{nrm} \\ 0 & otherwise \end{cases}$$

where r is the current round, Gnrm is the set of normal nodes that have not become cluster heads within the last 1/Pnrm rounds of the epoch, and T(snrm) is the threshold applied to a population of n*(1-m) normal nodes.

Similarly, for advanced nodes, we have:

$$T(s_{adv}) = \begin{cases} \dfrac{P_{adv}}{1 - P_{adv} \times (r \bmod \dfrac{1}{P_{adv}})} \times \dfrac{\mathrm{E}_{\text{s\_current}}}{\mathrm{E}_{\text{s\_initial}}} & if \quad s_{adv} \in G_{adv} \\ 0 & otherwise \end{cases}$$

where G_{adv} is the set of advanced nodes that have not become cluster heads within the last 1/Padv rounds of the epoch, and T(s_{adv}) is the threshold applied to a population of n*m advanced nodes

C. Optimum Number of Clusters

We know that the energy dissipation of the cluster-head node during a signal frame is

$$E_{CH} = [l * E_{elec} * (\frac{N(1-b)}{K} - 1)] + [l * E_{DA} * (\frac{N(1-b)}{K})] + [l * E_{elec} + l * \varepsilon_{amp} * d^2_{toGAT}]$$

Where dtoGAT is the distance from the cluster head to the Gateway and and b is the fraction of the total number of nodes N which are elected Gateways the energy used in each non-cluster-head node is

$$E_{non-CH} = [l * E_{elec} + l * m * d^2_{toCH}]$$

Where d_{toCH} is the distance from the node to the cluster head and the energy dissipation of the Gateway node is

$$E_{Gat} = [2 * l * E_{elec} + l * m * d^2_{toBS}]$$

Where d_{toBS} is the distance from the gateway to the base station. If the density of node is uniform through the cluster area:

$$E[(d_{toCH})^2] = \frac{1}{2\pi}\frac{M^2}{K}$$

$$E[(d_{toGAT})^2] = \frac{1}{2\pi}\frac{M^2}{K}$$

The total energy for the frame is:

$$E_{total} = K * [E_{CH} + (\frac{N(1-b)}{K}) * E_{non-CH}] + N * b * E_{Gat}$$

We can find the optimum number of clusters kopt by setting the derivative of E_{total} with respect to k to zero

$$K_{opt} = \frac{\sqrt{N(1-b)}}{\sqrt{2\pi}} \frac{M}{d_{toBS}}$$

D. Cluster Formation Algorithm

1) Steady-State Phase

The operation of IB-LEACH is divided into rounds. Each round begins with a set-up phase followed by a steady-state phase, as shown in Figure 3.

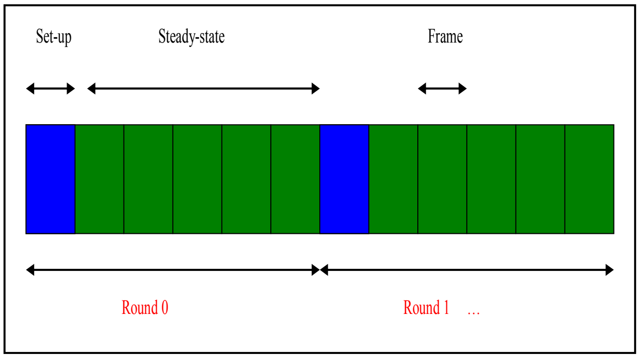


Figure 3. Time line showing IB-LEACH operation

During the set-up phase the gateways are elected and the clusters are organized. It is constituted by gateway selection algorithm and cluster selection algorithm and cluster formation algorithm. After the set-up phase is the steady-state phase when data are transmitted from the nodes to the cluster head and on to the gateway that requires the minimum communication energy and transmit it to the BS. The duration of the steady phase is longer than the duration of the setup phase in order to minimize overhead.

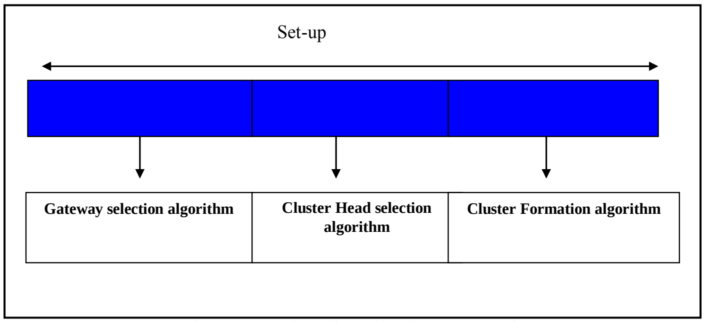


Figure 4. Time line showing set-up phase

2) *Flow Chart of IB-LEACH Protocol*

we describe summary of IB-LEACH communication protocol, and Figure 7 shows the flow chart.

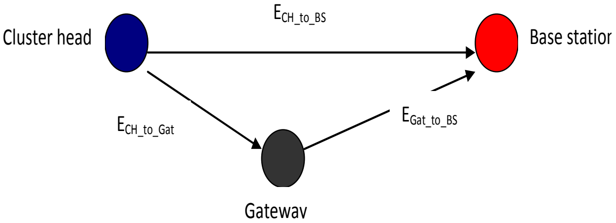
IB-LEACH is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the network. Thus includes randomized rotation of the high-energy cluster-head position such that it rotates among the various sensors in order to not drain the energy of a single sensor.

Sensor nodes elect themselves to be gateway at any given time with a certain probability. Base station confirms that whether those nodes suit to be gateway. These cluster-head nodes broadcast their status to the other sensors in the network using advertisement message (ADV). The non-gateway nodes elect themselves to be cluster-heads with a certain probability. These cluster-head nodes broadcast their status to the other sensors in the network using advertisement message (ADV). The non-cluster-head nodes wait the cluster-head announcement from other nodes. Each sensor node determines to which cluster it wants to belong by choosing the cluster-head that requires the minimum communication energy, and send the join-request (Join-REQ) message to the chosen cluster head, and the cluster-head nodes wait for join-request message from other nodes.

Once all the nodes are organized into clusters, each cluster-head creates a schedule for the nodes in its cluster. This allows the radio components of each non-cluster-head node to be turned off at all times except for its transmit time, thus minimizing the energy dissipated in the individual sensors. Once the cluster-head has all the data from the nodes in its cluster, the cluster-head node aggregates the data and then transmits the compressed data:

- To the Gateway if :

$$E_{CH\_to\_BS} \succ E_{CH\_to\_Gat} + E_{Gat\_to\_BS}$$



$E_{CH\_to\_BS}$: total energy dissipated for send data from cluster head to the base station.

$E_{CH\_to\_Gat}$: total energy dissipated for send data from cluster head to the Gateway.

$E_{Gat\_to\_BS}$: total energy dissipated for send data from Gateway to the base station.

- To the Base station if :

$$E_{CH\_to\_BS} \leq E_{CH\_to\_Gat} + E_{Gat\_to\_BS}$$

3) *The IB-LEACH Network model:*

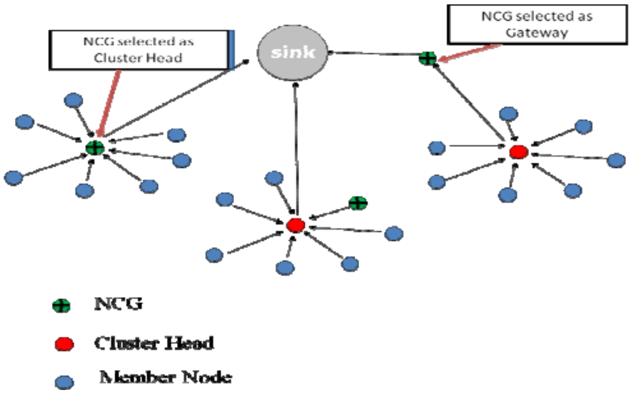


Figure 5. The IB-LEACH Network model

4) *Flow Chart of IB-LEACH Protocol*

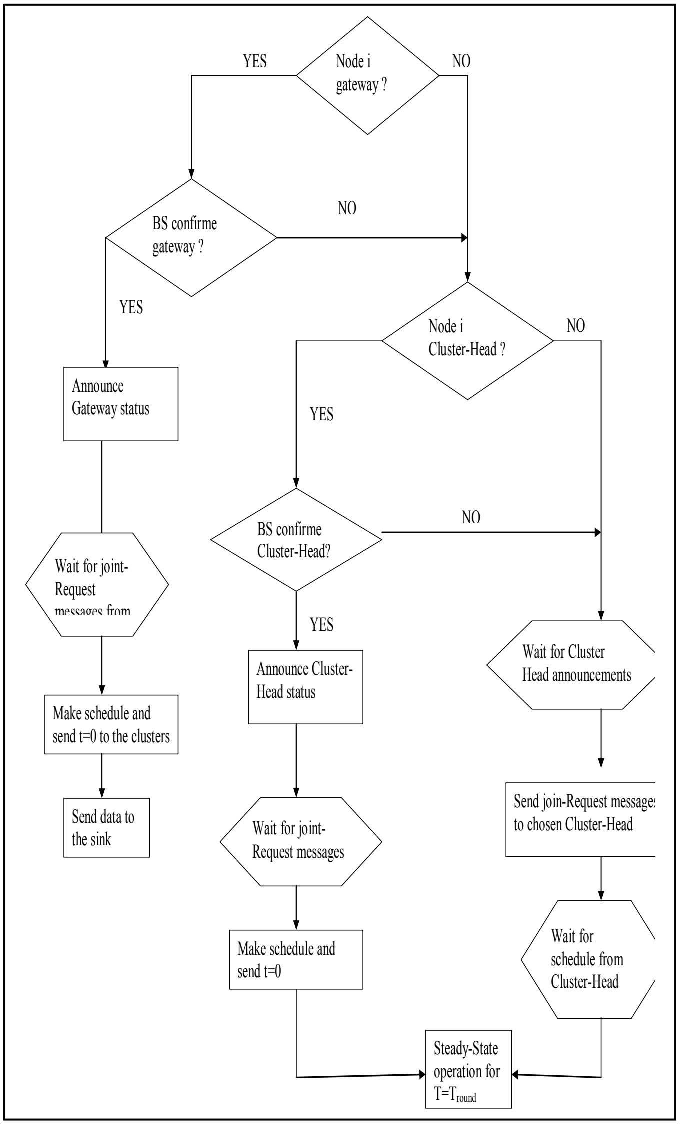


Figure 6. Flow Chart of IB-LEACH Protocol

V. SIMULATION

A. *Simulation settings*

We use a 100m×100m region of 100 sensor nodes scattered randomly. MATLAB is used to implement the simulation. To make a fair comparison, we introduce advanced energy levels to LEACH and SEP nodes with same settings as in our IB-LEACH protocol, so as to assess the performance of these protocols in the presence of heterogeneity.

Specifically, we have the parameter settings:

TABLE II. PARAMETER SETTINGS

Parameter	Value
E_{elect}	50 nJ/bit
E_{DA}	5 nJ/bit/message
εfs	10pJ/bit/m2
εmp	0.0013 pJ/bit/m4
Eo	0.5 J
k	4000
Popt	0.1
n	100
a	1
K_{opt}	5
kg_{opt}	4

Performance metrics used in the simulation study are:

i. Stability period, the period from the start of the network operation and the first dead node. We also refer to this period as "stable region."

ii. Improvement of Stability period.

$$\text{Im}\,provement = \frac{Stable\ period\ of\ IBLEACH - Stable\ period\ of\ LEACH}{Stable\ period\ of\ LEACH}$$

iii. Length of stable region for different values of heterogeneity.

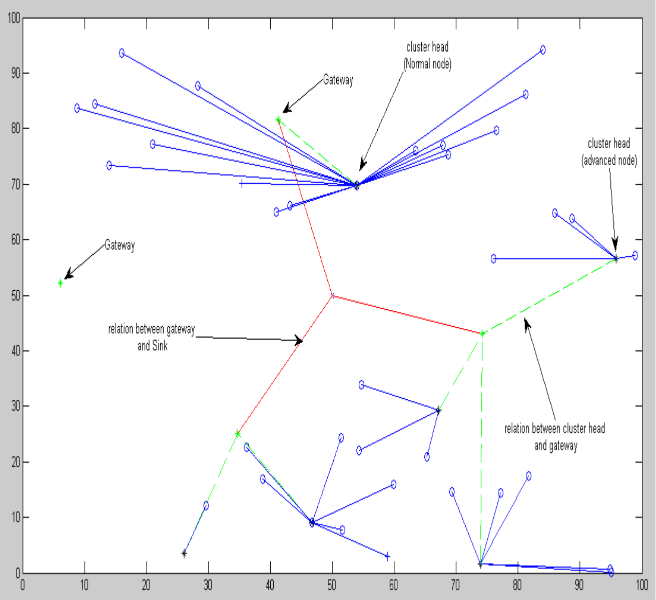


Figure 7. A wireless sensor network with IB-LEACH Model

B. Simulation results

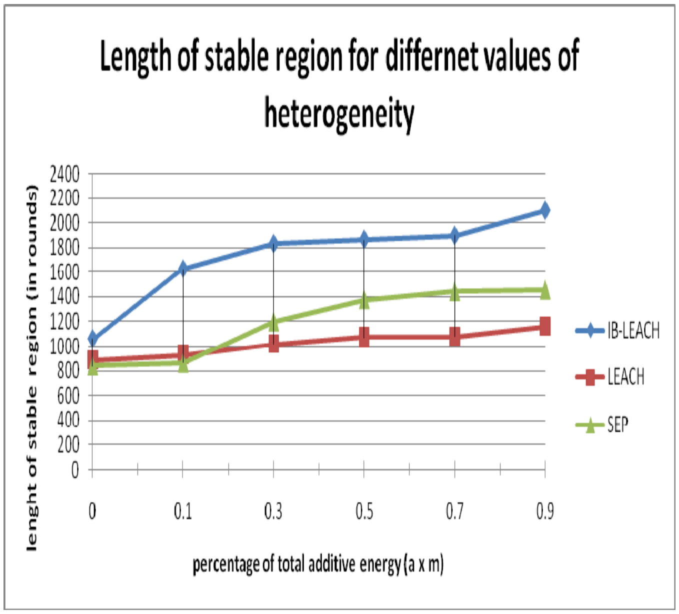


Figure 8. Length of stable region for differnet values of heterogeneity

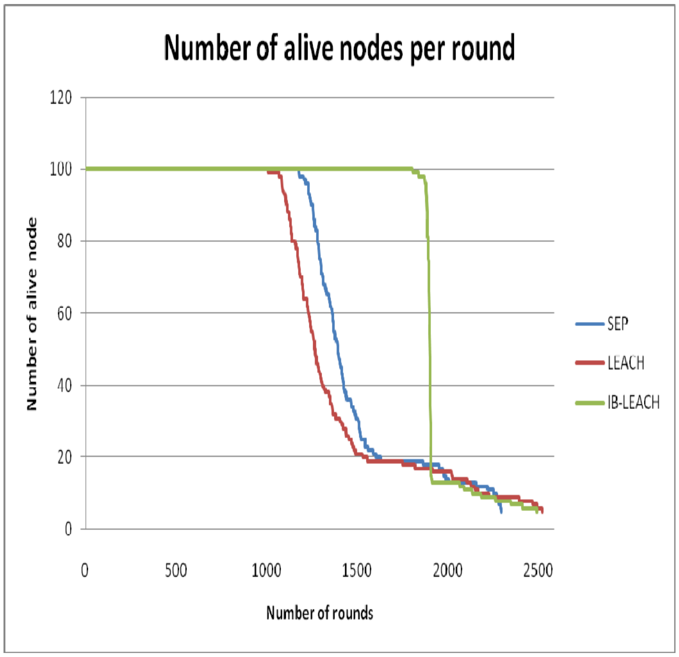


Figure 9. Number of alive nodes per round with m=0.2 and a=1

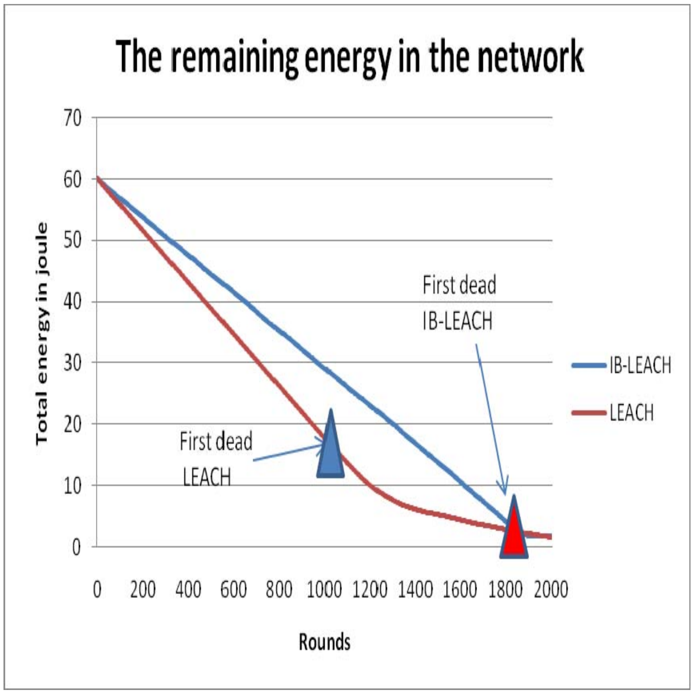


Figure 10. Evolution of the remaining energy in the network with m=0.2 and a=1

TABLE III. IMPROVEMENT OF IB-LEACH COMPARED TO LEACH WITH M=0.2 AND A=1

	LEACH	IB-LEACH	Improvement
FND (First Node Dies)	1049	1839	75,30%
HNA (Half of the Nodes Alive)	1263	1920	52,01%
5% alive	2544	2532	-0,4%

TABLE IV. IMPROVEMENT OF IB-LEACH COMPARED TO SEP WITH M=0.2 AND A=1

	SEP	IB-LEACH	Improvement
FND (First Node Dies)	1138	1839	61,6%
HNA (Half of the Nodes Alive)	1412	1920	35,97%
LND (Last Node Dies) – 5% alive	2359	2532	7,3%

From our simulations, we observed the followings:

1. The stability period of the IB-LEACH was prolonged than LEACH and SEP in heterogeneous settings.
2. The instability period was shortened for IB-LEACH compared to LEACH and SEP in heterogeneous settings

3. Energy dissipation is balanced between normal nodes and advanced nodes in the IB-LEACH compared to LEACH and SEP.

To sum up, in our simulation we obtained a prolonged stability period and a reduction in the instability region. Ideally the advance nodes become cluster heads more than normal nodes. The gateways nodes take up the role to reduce the energy consumption of cluster head and decrease probability of failure nodes.

VI. CONCLUSION AND FUTURE WORKS

IB-LEACH is an extension of the LEACH, which improves the stable region of the clustering hierarchy and decrease probability of failure nodes using the characteristic parameters of heterogeneity in networks. In these networks some high-energy nodes called NCG nodes (Normal node or Cluster Head or Gateway) become "cluster heads" to aggregate the data of their cluster members and transmit it to the chosen "Gateways" that requires the minimum communication energy to reduce the energy consumption of cluster head and decrease probability of failure and this increase the lifetime of the network. Simulation results shows that the IB-LEACH achieves better performance in this respect, compared to SEP and LEACH in both heterogeneous and homogenous environments.

In this article it is supposed that nodes called NCG nodes are distributed randomly and fixed. On the other program we will research to predict the choice of becoming cluster head or gateway that will depend on the density of nodes in an area and we will research the mobile gateways.

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