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Improving Lifetime in Heterogeneous Wireless Sensor Networks

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***Abstract*—Wireless Sensor Networks (WSNs) consist of a large number of energy-limited sensor nodes that are densely deployed in a large geographical region. For WSNs, energy efficiency is always a key design issue to improve the life span of the network. The clustering Algorithm is a kind of key technique used to reduce energy consumption and to increase scalability and lifetime of the network. In this paper, we propose and evaluate a distributed energy-efficient clustering algorithm for heterogeneous WSNs, which is called Improved LEACH-E (ILE). This protocol is a LEACH-E improvement. In ILE, the cluster-heads are elected by a probability based on the ratio between residual energy of each node and the remaining energy of the network. Also, it uses a second hierarchical level by selecting a cluster head for data transmission. Furthermore, we consider a multi-level heterogeneous network in order to study the impact of heterogeneity on wireless sensor Networks. In this case we propose an energy-efficient multi-level clustering algorithm called ILE-M. Finally, Simulation results show that the network lifetime and energy efficiency are much better in our proposed protocols ILE and ILE-M than the existing protocols.**

***Keywords*— WSN; Clustering; Lifetime; Energy Effeciency; Heterogeneity.**

I. INTRODUCTION

Recent advances in wireless communications and electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate in short distances. A wireless sensor network (WSN) is composed of a large number of sensor nodes that are deployed in ad hoc manner in an unreachable field to give the end-user, the ability to instrument, observe, and react to events and phenomena in a specified environment. Wireless Sensor Networks provide unforeseen applications: from military applications such as battlefield mapping and target surveillance, to creating context-aware homes; the number of applications is endless [1]. In most of the applications, sensors are required to detect events and then communicate the collected information to a distant base station (BS) where parameters characterizing these events are estimated. Since the cost of transmitting information is higher than computation.

Clustering sensors into groups, so that they communicate information only to cluster heads and then the cluster heads communicate the aggregated information to the processing center, saves energy [2], [3] and [4]. Thus, it is advantageous to organize the sensors into clusters; where the data gathered and fused by the sensors is communicated to the BS through a hierarchy of cluster-heads. The cluster-heads, which are elected periodically by certain clustering algorithms, aggregate the data of their cluster members and send it to the base station, from where the end-users can access the sensed data. Thus, only some nodes are required to transmit data over a long distance and the rest of the nodes will need to complete short distance transmission only. Therefore, more energy is saved and the overall network lifetime can be extended.

There are two kinds of clustering schemes. The clustering algorithms applied in homogeneous networks are called homogeneous clustering schemes, where all nodes have the same initial energy, such as LEACH [3], PEGASIS [5], and HEED [6], and the clustering algorithms applied in heterogeneous networks are referred to as heterogeneous clustering schemes [7], where all the nodes of the sensor network are equipped with different amount of energy, such as SEP [8], M-LEACH [9], EECS [10], LEACH-B [11]. WSNs are more possibly heterogeneous networks than homogeneous ones. Thus, the protocols should be fit for the characteristic of heterogeneous wireless sensor networks. Moreover, in [12, 13], they propose LEACH-E protocol, which uses a new conception based on the energy left in the network.

Based on LEACH-E protocol, we develop and validate a newest Improved LEACH-E algorithm called ILE. This protocol is proposed to increase the whole network lifetime on a heterogeneous network with a BS located far away from the sensing area. ILE introduces the second level hierarchical concept based on maximum energy, which improves and optimizes the use of the energy dissipated in the network like TL-LEACH [14]. The use of two levels of clusters for transmitting data to the BS, leverages the advantages of small transmit distances and reduces the number of transmission data to the BS. As a consequence, fewer cluster heads are required to transmit far distances to the BS. This permits a better distribution of the energy load through the sensors in the network and increases the whole network lifetime.

The remainder of this paper is organized as follows. Section 2 presents the related work. Section 3 exhibits the details and analyzes the properties of ILE. Section 4 evaluates the performance of ILE by simulations and compares it with LEACH and LEACH-E. Finally, Section 5 gives concluding remarks.

II. RELATED WORKS

The main goal of cluster-based routing protocol is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink and transmission distance of sensor nodes [16-18]. In this section, we make a few statements and assumptions about the network scheme and introduce the radio model used in this work.

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A. *Heterogeneous Network Model*

In this study, we describe the network model. Assume that there are N sensor nodes, which are uniformly dispersed within a M x M square region (Fig. 1). The nodes always have data to transmit to a base station, which is often far from the sensing area. This kind of sensor network can be used to track the military object or monitor remote environment. The network is organized into a clustering hierarchy, and the cluster-heads execute fusion function to reduce correlated data produced by the sensor nodes within the clusters. The cluster-heads (Fig. 2) transmit the aggregated data to the base station directly. We assume that the nodes are stationary as supposed in [12].

In the two-level heterogeneous networks, there are two types of sensor nodes, i.e., the advanced nodes and normal nodes. Note E_0 the initial energy of the normal nodes, and m the fraction of the advanced nodes, which own a times more energy than the normal ones. Thus there are Nm advanced nodes equipped with initial energy of $E_0(1+a)$, and $N(1-m)$ normal nodes equipped with initial energy ofE_0. The total initial energy of the two-level heterogeneous networks is given by:

$$E_{total} = N(1-m)E_0 + NmE_0(1+a) = NE_0(1+am) \quad (1)$$

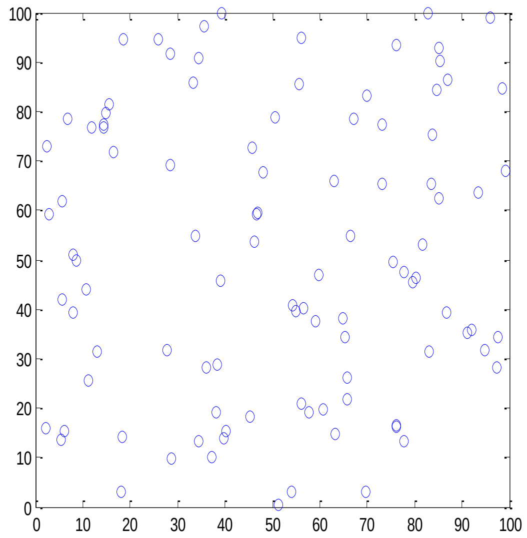

Fig.1. 100 nodes randomly deployed in the network

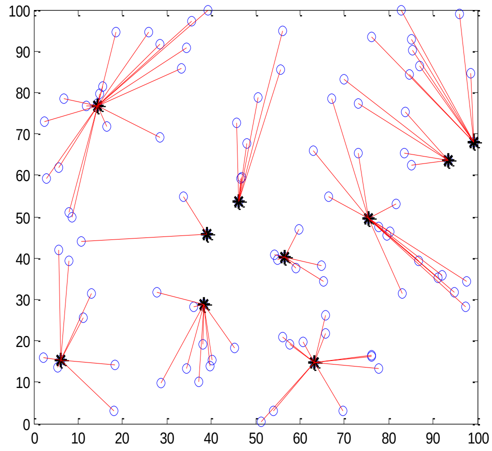

Fig.2. Dynamic cluster structure by ILE algorithm:

o (simple node), * (cluster head).

Furthermore, we use in this study a similar energy model as proposed in [12]. According to the radio energy dissipation model illustrated in (Fig. 3), and in order to achieve an acceptable Signal-to-Noise Ratio (SNR) in transmitting an L-bit message over a distance d, the energy expended by the radio is given by :

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\epsilon_{fs}d^2\ , & d < d_0 \\ lE_{elec} + l\epsilon_{mp}d^4, & d \geq d_0 \end{cases} \quad (2)$$

Where E_{elec} is the energy dissipated per bit to run the transmitter E_{Tx} or the receiver E_{Rx} circuit, and $\epsilon_{fs}d^2$and $\epsilon_{mp}d^4$ depend on the transmitter amplifier model used and d is the distance between the sender and the receiver. We have fixed the value of d_0 at 70 meters.

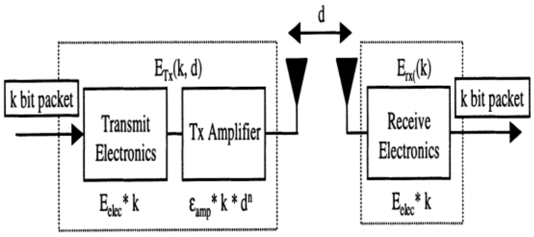

Fig.3. Radio Energy Dissipation Model

B. *Problem Speech*

Since in most WSN applications the energy source is a battery, energy plays an important role in WSN [19-21]. Therefore, preserving the consumed energy of each node is an important goal that must be considered when developing a routing protocol for WSNs. To increase the whole network lifetime, we have developed energy efficient clustering algorithms called ILE. Based on a balanced way to elect networks clusters heads, ILE achieves a large reduction in the energy dissipation. In the next section, we describe the ILE algorithm in details.

III. IMPROVES LEACH-E (ILE)

Our ILE uses the same clustering algorithm as LEACH-E that is it uses the same strategy in Clusters Head selection, Clusters formation, and Schedule Creation (TDMA) but differs in Data transmission. ILE algorithm can be summarized as follow:

```
For each node_i
    If (node_i is NCH) then
        Appropriate CH election
        Send data to CH
    Else
        If(node_i is not MaxCH) then
            Data aggregation(nodes)
            If (dtoBS>dtoMaxCH) then
                Send to MaxCH
            Else
                Send to BS
            End if
        Else
            first data aggregation (nodes)
            Second data aggregation (CHs)
            Send to BS
        End if
    End if
End for
```

NCH: not a CH
CH: Cluster head
MaxCH : the CH with the maximum report between residual energy and dtoBS
dtoBS: distance to the BS
dtoMaxCH : distance to MaxCH

Furthermore, ILE introduces two level hierarchical concept of clusters for transmitting data to the BS. Thus, it leverages the advantages of multi-hop transmission and reduces the disadvantages of single-hop transmission. In this way, fewer cluster heads are required to transmit far distances to the BS. We consider a network with N nodes, uniformly distributed within M×M square region and that the network topology remains unchanged over time and the BS location is (x = 50, y = 175). In ILE, We get the probability threshold, which each node s_i uses to determine whether itself to become a cluster-head in each round, as follow:

$$T(s_i) = \begin{cases} \frac{p_i}{1-p_i(r \bmod \frac{1}{p_i})} & if\, s_i \in G \\ 0 & otherwise \end{cases} \qquad (3)$$

Where G is the set of nodes that are eligible to be cluster heads at round$r$. In each round$r$, when node s_i finds it is eligible to be a cluster head, it will choose a random number between 0 and 1. If the number is less than the threshold$T(s_i)$, the node s_i becomes a cluster head during the current round. Also, $p_i$is defined as follow:

$$p_i(r) = min\left\{\frac{E_i(r)}{E_{total}(r)}k, 1\right\} \qquad (4)$$

Where $E_i(r)$ is the current energy of node i, k is the desired number of cluster, and $E_{total}(r)$ is the remaining energy of the network per round r:

$$E_{total}(r) = \sum_{i=1}^{N} E_i(r) \qquad (5)$$

To use the probabilities in (Eq. 4), each node must have an estimate of the remaining energy of all nodes in the network per round. To compute $E_{total}(r)$ by (Eq. 5), each node should have the knowledge of the total energy of all nodes in the network. We will give an estimate of $E_{total}(r)$ as follow:

$$E_{total}(r) = E_{initial}\left(1 - \frac{r}{R}\right) \qquad (6)$$

where R denotes the total rounds of the network lifetime. It means that every node consumes the same amount of energy in each round, which is also the target that energy-efficient algorithms should try to achieve. The value of R is:

$$R = \frac{E_{initial}}{E_{Round}} \qquad (7)$$

Where E_{Round}denotes the total energy dissipated in the network during a round r is given by:

$$E_{Round} = L\left[2NE_{elec} + NE_{DA} + (k-1)\epsilon_{mp}d^4_{toMaxCH} + N\epsilon_{fs}d^2_{toCH} + E\epsilon_{mp}d^4_{toBS}\right] \qquad (8)$$

Where k is the number of clusters, E_{DA} is the data aggregation cost expended in the cluster-heads, dtoBS is the average distance between the cluster-head and the base station, dtoMaxCH is the distance between the cluster-heads and the Maximum energy Cluster Head (MaxCH), and dtoCH is the average distance between the cluster members and the cluster-head. Assuming that the nodes are uniformly distributed, by using the result in [12, 15] we can get the equations as follow:

$$d_{toCH} = \frac{M}{\sqrt{2k\pi}} \qquad (9)$$

$$d_{toMaxCH} = \frac{1}{M^2}\iint \sqrt{(x_i + x_j)^2 + (y_i + y_j)^2}\, dxdy \approx \frac{M}{2} \qquad (10)$$

$$d_{toBS} = \sqrt{2\pi}\frac{M}{2} \qquad (11)$$

$$k = \frac{\sqrt{E_{fs}}}{\sqrt{E_{mp}}}\frac{\sqrt{N}}{\sqrt{2\pi}}\frac{M}{d^2_{toMaxCH}} \qquad (12)$$

Substituting equations (12, 11, 10, 9, 8, 7, 6, 5, and 4) into equation (3), we obtain the probability threshold. Each node that has elected itself a cluster-head for the current round broadcasts an advertisement message to the rest of the nodes. For this “cluster-head-advertisement” phase, the cluster-heads use a

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CSMA MAC protocol, and all cluster-heads transmit their advertisement using the same transmit energy. The non-cluster-head nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the cluster-head nodes. The sent messages content in addition the Id nodes, the information coordinates.

After this phase is complete, each non-cluster-head node decides the cluster to which it will belong for this round. This decision is based on the received signal strength of the advertisement. Assuming symmetric propagation channels, the cluster-head advertisement heard with the largest signal strength is the cluster-head to whom the minimum amount of transmitted energy is needed for communication. In the case of ties, a random cluster-head is chosen [3].

Based on the information coordinates included on the message broadcasted, the CHs elected can select the Maximum energy Cluster Heads MaxCH. Consequently, the CH with the important energy will be the MaxCH in this round. This last node collects all data coming from all CHs, compress it into a single signal and send it directly to the base station. We have chosen the MaxCH as intermediate hierarchical level, because the latter granted the transmission for long time. In fact, they have not waste energy in long transmission to the BS.

Each non cluster heads sends its data during their allocated transmission time (TDMA) to the respective cluster head. The CH node must keep its receiver on in order to receive all the data from the nodes in the cluster. When all the data is received, the cluster head node performs signal processing functions to compress the data into a single signal. When this phase is completed, each cluster head can send the aggregated data to the MaxCH. After that, each non cluster head can turn off to sleep mode.

TABLE I. RADIO CHARACTERISTICS USED IN OUR SIMULATIONS

Parameter	Value
E_{elec}	5 nJ/bit
ϵ_{fs}	10 pJ/bit/m^2
ϵ_{mp}	0.0013 pJ/bit/m^4
E_0	0.5 J
E_{DA}	5 nJ/bit/message
d_0	70 m
Message size	4000 bits
p_{opt}	0.1
Round	20 seconds

Initially, all the nodes need to know the initial energy $E_{initial}$ and lifetime R of the network, which can be determined a priori. In our ILE protocol, the base station could broadcast the initial energy $E_{initial}$ and estimate value R of lifetime to all nodes. When a new epoch begins, each node s_i will use this information to compute its probability p_i by Eqs. (6) and (4). Node s_i will substitute pi into Eq. (3), and get the election threshold $T(s_i)$, which is used to decide if node s_i should be a cluster-head in the current round.

IV. SIMULATION RESULTS

In this section, we evaluate the performance of ILE protocol using MATLAB. We consider a wireless sensor network with N = 100 nodes randomly distributed in a 100m x 100m field. We assume the base station is far away from the sensing region. To compare the performance of ILE with other protocols, we ignore the effect caused by signal collision and interference in the wireless channel. The radio parameters used in our simulations are shown in TABLE I. We assume that all nodes know their location coordinates. The protocols compared with ILE include LEACH, and LEACH-E. The Base station is located far away from the sensing area. It was placed at location (x=50, y=175). We will consider following scenarios and examine several performance measures.

After deployment of WSN, the nodes consume energy during the course of the WSN lifetime. In fact, energy is removed whenever a node transmits or receives data and whenever it performs data aggregation using the radio parameters shown in TABLE I. Once a node runs out of energy, it is considered dead and can no longer transmit or receive data.

First, we observe the performance of LEACH, LEACH-E, and ILE under two kinds of two-level heterogeneous networks. Fig. 4 shows the results of the case with m = 0.1 and a = 5, and Fig.5. shows the results of the case m = 0.2 and a = 3.

We define stable time as time until the first node dies, and unstable time the time from the fist node dies until the last node dies. In other words, lifetime is the addition of stable time and unstable time.

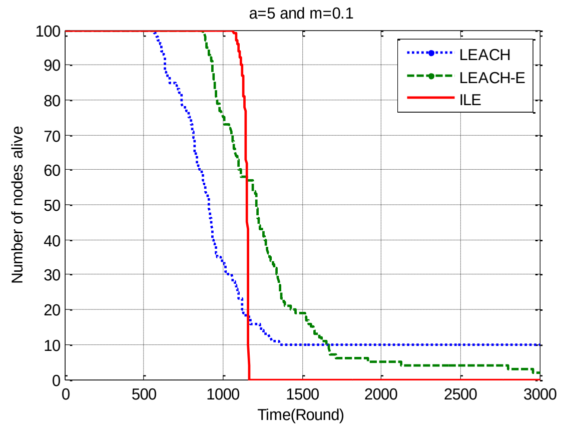

Fig.4. Performance of LEACH, LEACH-E, and ILE under two-level heterogeneous networks a=5, m =0.1: Number of nodes alive over time.

It is obvious that the stable time of ILE is large compared to that of LEACH and LEACH-E Fig.4. and Fig.5. The stable time metric is important to be longer in the sense that it gives the end user with reliable information of the sensing area. This reliability

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is vital for sensitive application like tracking fire in forests. LEACH-E performs better than LEACH, but we can see that the unstable time of LEACH-E is also larger than our ILE protocol. It is because the advanced nodes die more slowly than normal nodes in LEACH-E. This metric is important to be narrow in order to give clear idea about time of reenergizing the WSN to extend the network lifetime and to avoid unreliable information from sensing field.

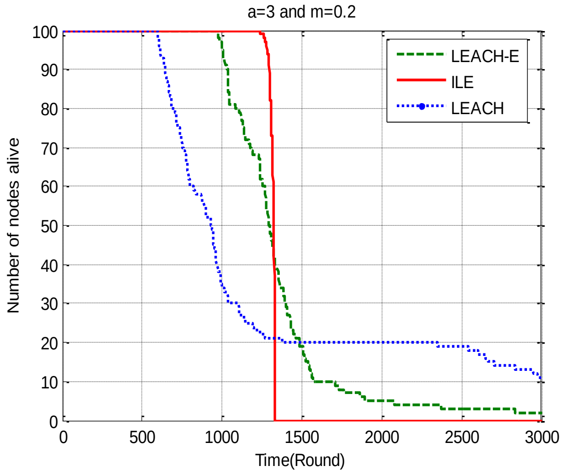

Fig.5. Performance of LEACH, LEACH-E, and ILE under two-level heterogeneous networks a=3, m =0.2: Number of nodes alive over time.

TABLE II

a=3, m =0.2	LEACH	LEACH-E	ILE
FND	597	976	1238
HNA	932	1279	1322

TABLE III

a=5, m =0.1	LEACH	LEACH-E	ILE
FND	615	858	1175
HNA	867	1132	1213

TABLE II and TABLE III show the comparison between all nodes in terms of FND (First Node Dies) and HNA (Half Node Alive).

- FND: indicate the round when first node dies.
- HNA: indicate the round when half node still alive.

The TABLE II and TABLE III show that ILE increases the lifetime of the whole network and performs better than LEACH and LEACH-E in term of the first node dies.

Second, we run simulation for our proposed protocol ILE to compute the round of the first node dies when m and a are varying and compare the results to LEACH and LEACH-E protocols.

We increase the fraction a of the advanced nodes from 0.5 to 5, Fig. 6 shows the number of round when the first node dies. We increase the fraction m of the advanced nodes from 0.1 to 0.9, Fig.7. shows the number of round when the first node dies. We observe that LEACH takes few advantages from the increase of total energy caused by increasing of m and a. The stability period of LEACH keeps almost the same in the process.

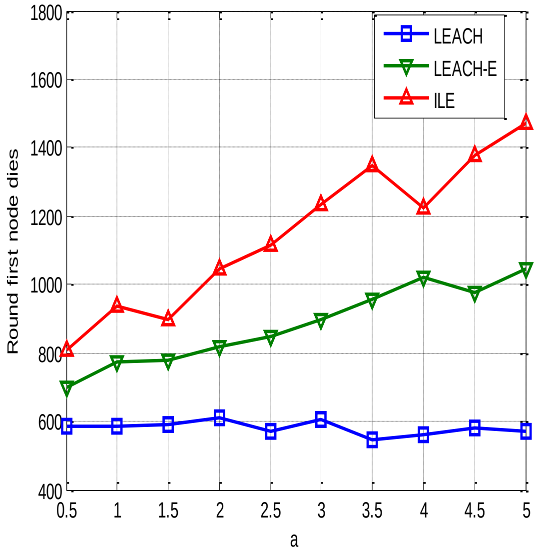

Fig.6. Round first node dies when a is varying.

We observe that LEACH fails to take full advantage of the extra energy provided by the heterogeneous nodes. The stability period of LEACH is very short and nodes die at a steady rate. This is because LEACH treats all the nodes without discrimination. The stability period of ILE is much longer than that of LEACH and LEACH-E. This is because ILE is an energy-aware protocol, which elects cluster-head by taking initial energy and residual energy into account at the same time.

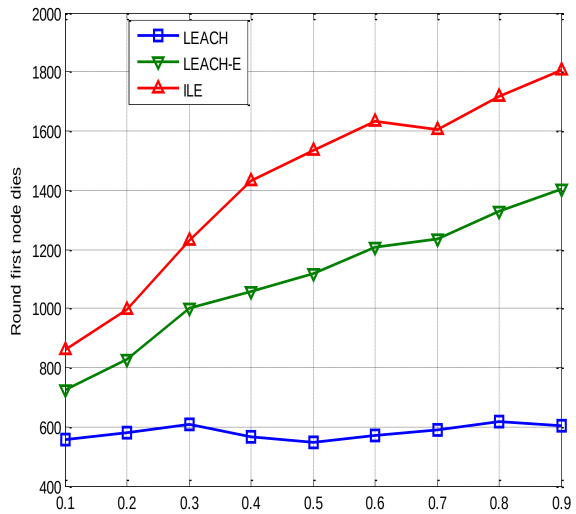

Fig.7. Round first node dies when m is varying.

Third, we run simulation for our proposed protocol ILE to compute the number of received messages by the BS over time and compare the results to LEACH and LEACH-E protocols. Fig.8. shows that the number of messages delivered by ILE to the BS are greater than the others ones; this means that ILE is a more efficient protocol.

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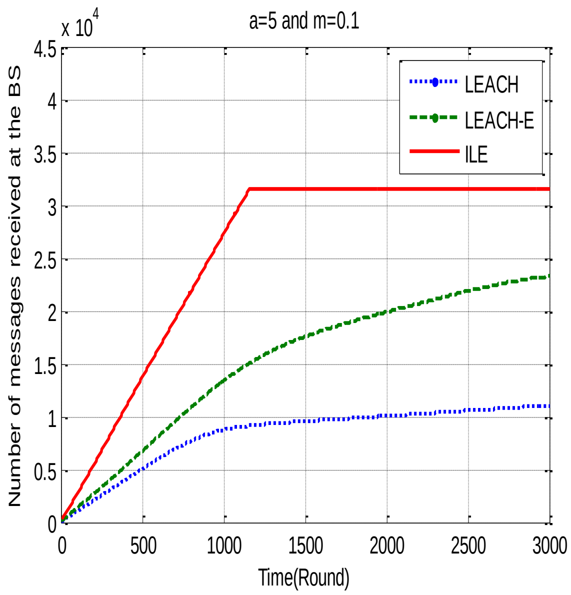

Fig.8. Performance of LEACH, LEACH-E, and ILE under two-level heterogeneous networks a =5, m =0.1: Number of message received in base station over time.

Fourth, we run simulation for our proposed protocol ILE to compute the number of received messages at the BS over energy dissipation and compare the results of LEACH and LEACH-E protocols. Fig.9. shows that the number of messages delivered by ILE to the BS are greater than the others ones; this means that ILE is a more efficient of energy consumption protocol. In other words, it is an energy-aware adaptive clustering protocol.

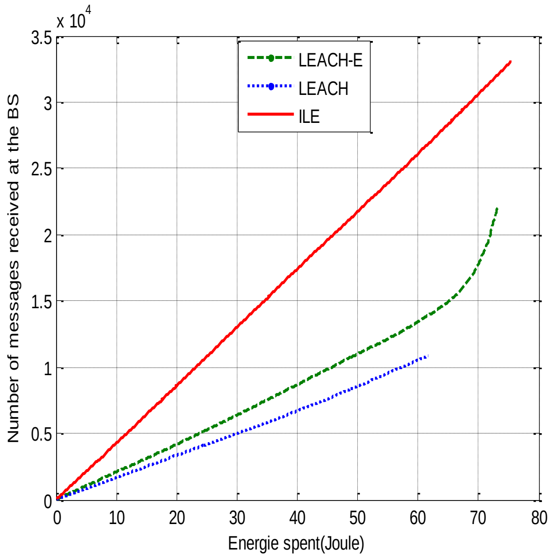

Fig.9. Performance of LEACH, LEACH-E and ILE under two-level heterogeneous networks a =5, m =0.1: Number of messages received at BS over Energy dissipation (Joules).

Fifth, we run simulation for our proposed protocol ILE to compute the number of received messages at the BS over the size of the experiment region and compare the results to LEACH and LEACH-E protocols. Fig.10. shows that the round first dies remain greater than the others ones, when the experiment region is greater than 25x25 m2.

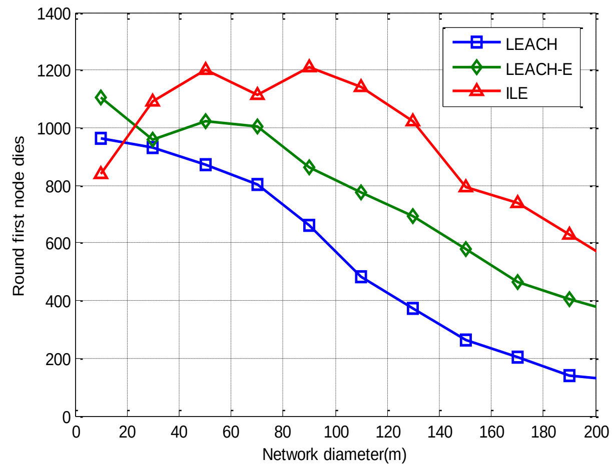

Fig.10. Performance of LEACH, LEACH-E and ILE under two-level heterogeneous networks a =5, m =0.1: Round first node dies over the size of the experiment region (Network diameter).

Sixth, we run simulation for our proposed protocol ILE to compute the number of received messages at the BS over the size of the experiment region and compare the results to LEACH and LEACH-E protocols.

Fig.11. shows that the number of messages delivered by ILE to the BS remain greater than the others ones; even if the experiment region changes.

According to the simulation results, we can obviously state that ILE is more efficient than LEACH and LEACH-E.

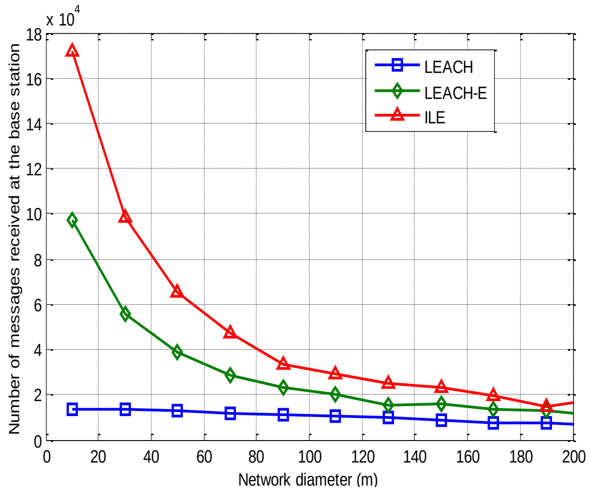

Fig.11. Performance of LEACH, LEACH-E and ILE under two-level heterogeneous networks a =5, m =0.1: Number of messages received at BS over the size of the experiment region (Network diameter).

V. ILE-M : MULTI-LEVEL ILE

We consider the multi-level heterogeneous network in order to study the impact of heterogeneity on wireless sensor Networks. In this case we propose an energy-efficient multi-level clustering algorithm called ILE-M. For multi-level heterogeneous networks, initial energy of sensor nodes is randomly distributed over the close set $[E_0, E_0(1 + a_{max})]$, where E_0 is the lower bound and a_{max} determine the value of the maximal energy. Initially, the node s_i is equipped with initial energy of $E_0(1 + a_i)$, which is a_i times more energy than the lower bound E_0.

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The total initial energy of the multi-level heterogeneous networks is given by:

$$E_{total} = \sum_{i=1}^{N} E_0(1 + a_i) = E_0(N + \sum_{i=1}^{N} (a_i))$$

As in two-level heterogeneous networks, the clustering algorithm should consider the discrepancy of initial energy in multi-level heterogeneous networks. For multi-level heterogeneous networks, the initial energy of nodes are randomly distributed in $[E_0, 4E_0]$. To prevent the affection of random factors, the network is equipped with the same amount of initial energy.

In Fig.12. detail views of the behavior of LEACH, LEACH-E, and ILE-M are illustrated. We observe that LEACH fails to take full advantage of the extra energy provided by the heterogeneous nodes. The stability period of LEACH is very short and nodes die at a steady rate. This is because LEACH treats all the nodes without discrimination. We observe that the stable region of ILE-M is also larger than LEACH and LEACH-E.

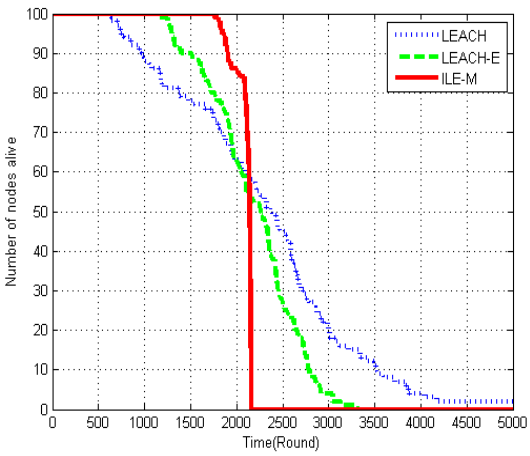

Fig.12. Performance of LEACH, LEACH-E, and ILE-M under multi-level heterogeneous networks. Number of nodes alive over time.

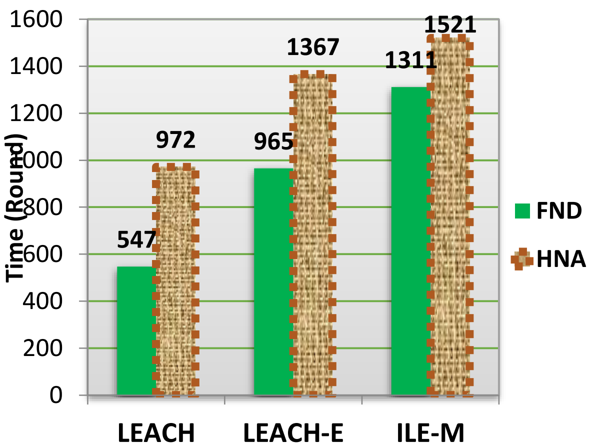

Fig.13. Round for FND and round for HNA in the network.

Fig.13. shows the comparison between all nodes in terms of FND (First Node Dies) and HNA (Half Node Alive). Obviously, we can remark that our protocol ILE-M have a larger period of stability time than LEACH and LEACH-E, which increases the efficiency of the network. We notice the same results for HNA. A longer stable time metric is important because it gives the end user reliable information of the sensing area, which extend the network lifetime. This reliability is vital for sensitive applications such as tracking fire in forests.

TABLE IV

	LEACH	LEACH-E	ILE-M
FND	547	965	1311
HNA	972	1367	1521

The TABLE IV shows that ILE-M increases the lifetime of the whole network and performs better than LEACH and LEACH-E in term of the first node dies.

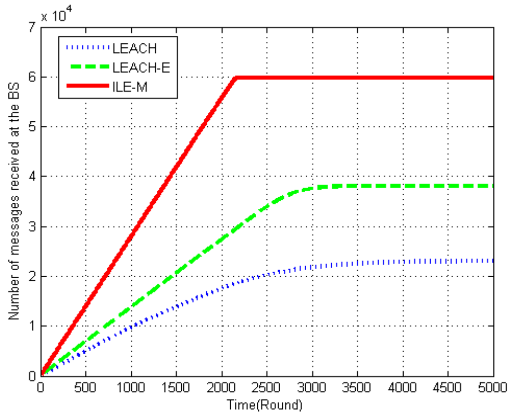

Fig.14. Performance of LEACH, LEACH-E, and ILE-M under multi-level heterogeneous networks. Number of message received in base station over time.

Moreover, Fig.12., Fig.13. and Fig.14. show that the performances due to our modifications are very important. Also, the messages delivered by ILE-M are more than that of LEACH and LEACH-E. This means that ILE-M is more efficient than LEACH-E.

Fig.15. gives the total network energy dissipation in every transmission round. The network remaining energy decreases rapidly in the LEACH and LEACH-E protocols.

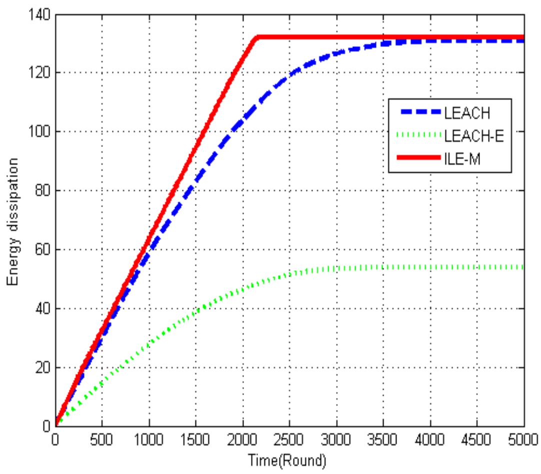

Fig.15. Performance of LEACH, LEACH-E, and ILE-M under multi-level heterogeneous networks. Energy dissipation over time.

Fig.16. shows the results of number of nodes alive over number of message received in base station. It's obvious that the number of messages delivered by ILE-M to the BS are greater than the others ones, this means that ILE-M is a more efficient protocol in terms of energy consumption. In other words, it is an energy-aware adaptive clustering protocol.

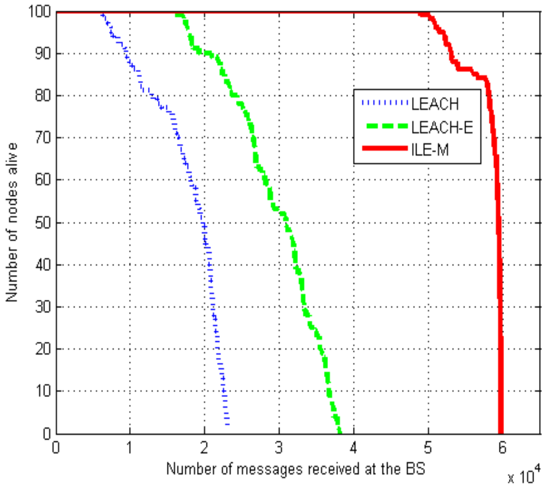

Fig.16. Performance of LEACH, LEACH-E, and ILE-M under multi-level heterogeneous networks. Number of nodes alive over number of message received in base station.

VI. CONCLUSION

We describe ILE, an energy-aware adaptive clustering protocol used in heterogeneous wireless sensor networks. In ILE, every sensor node independently elects itself as a cluster-head based on its initial energy and residual energy. To control the energy expenditure of nodes by means of adaptive approach, ILE use the average energy of the network as the reference energy. Thus, ILE does not require any global knowledge of energy at every election round. Therefore, ILE uses the two level hierarchical concept which offers a better use and optimization of the energy dissipated in the network. We also study the impact of multi-level heterogeneous networks. Simulation results demonstrate that our proposed protocols ILE and ILE-M are effective in prolonging the network lifetime.

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