Developed Distributed Energy-Efficient Clustering (DDEEC) for heterogeneous wireless sensor networks

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***Abstract*—Typically, a wireless sensor network contains an important number of inexpensive power constrained sensors, which collect data from the environment and transmit them towards the base station in a cooperative way. Saving energy and therefore, extending the wireless sensor networks lifetime, imposes a great challenge. Clustering techniques are largely used for these purposes. In this paper, we propose and evaluate a clustering technique called a Developed Distributed Energy-Efficient Clustering scheme for heterogeneous wireless sensor networks. This technique is based on changing dynamically and with more efficiency the cluster head election probability. Simulation results show that our protocol performs better than the Stable Election Protocol (SEP) by about 30% and than the Distributed Energy-Efficient Clustering (DEEC) by about 15% in terms of network lifetime and first node dies.**

***Index Terms*—Energy Consumption, DEEC, Clustering, Wireless Sensor Networks, Heterogeneous environment**

I. Introduction

Wireless sensor network (WSN) consists of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations [1]. This network contains a large number of nodes which sense data from an impossibly inaccessible area and send their reports toward a processing center which is called "sink". Since, sensor nodes are power-constrained devices, frequent and long-distance transmissions should be kept to minimum in order to prolong the network lifetime [2], [3]. Thus, direct communications between nodes and the base station are not encouraged. One effective approach is to divide the network into several clusters, each electing one node as its cluster head [4]. The cluster head collects data from sensors in the cluster which will be fused and transmitted to the base station. Thus, only some nodes are required to transmit data over a long distance and the rest of the nodes will need to do only short-distance transmission. Then, more energy is saved and overall network lifetime can thus be prolonged. Many energy-efficient routing protocols are designed based on the clustering structure where cluster-heads are elected periodically [5], [6]. These techniques can be extremely effective in broadcast and data query [7], [8]. DEEC is a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks which is based on clustering, when the cluster-heads are elected by a probability based on the ratio between residual energy of each node and the average energy of the network. The round number of the rotating epoch for each node is different according to its initial and residual energy. DEEC adapt the rotating epoch of each node to its energy. The nodes with high initial and residual energy will have more chances to be the cluster-heads than the low-energy nodes.Thus DEEC can prolong the network lifetime, especially the stability period, by heterogeneous-aware clustering algorithm [9]. This choice penalizes always the advanced nodes, specially when their residual energy deplete and become in the range of the normal nodes. In this situation, the advanced nodes die quickly than the others. The DDEEC, Developed Distributed Energy-Efficient Clustering, permits to balance the cluster head selection over all network nodes following their residual energy. So, the advanced nodes are largely solicited to be selected as cluster heads for the first transmission rounds, and when their energy decrease sensibly, these nodes will have the same cluster head election probability like the normal nodes.// An outline of this paper is as follows. Section II describes a review related work. In section III, a presentation of heterogeneous network is set. Additionally, in section IV, we present the details of DDEEC algorithm. Section V gives the simulation results. Finally, conclusion is presented.

II. The Developed Distributed Energy-Efficient Clustering protocol

DDEEC is based on DEEC scheme, where all nodes use the initial and residual energy level to define the cluster-heads. To evade that each node needs to have the global knowledge of the networks, DEEC and DDEEC estimate the ideal value of network lifetime, which is use to compute the reference energy that each node should expend during each round. In this section, we consider a network with N nodes, which are uniformly dispersed within a $M \times M$ square region.

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The network is organized into a clustering hierarchy, and the cluster-heads collect measurements information from cluster nodes and transmit the aggregated data to the base station directly. Moreover, we suppose that the network topology is fixed and no-varying on time. We assume that the base station is located at the center.Furthermore, this last figure show a two-level heterogenous network, where we have two categories of nodes, a mN *advanced* nodes with initial energy $Eo(1+a)$ and a $(1-m)N$ *normal* nodes, where the initial energy is equal to Eo. The total initial energy of the heterogeneous networks is given by:

$$E_{total} = N(1-m)Eo + NmEo(1+a) = NEo(1+am) \quad (1)$$

A. Radio model

on the first, for the purpose of this study we use similar energy model and analysis as proposed in [10]. According to the radio energy dissipation model illustrated in figure [10] 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:

$$E_{tx}(L,d) = \begin{cases} LE_{elec} + LEfsd^2 & \text{if} \quad d < do \\ LE_{elec} + LEmpd^4 & \text{if} \quad d \geq do \end{cases} \quad (2)$$

where E_{elec} is the energy dissipated per bit to run the transmitter(E_{TX}) or the receiver circuit(E_{RX}). The E_{elec} depends on many factors such as the digital coding, the modulation, the filtering, and the spreading of the signal. *Efs* and *Emp* depend on the transmitter amplifier model used, and d is the distance between the sender and the receiver. For the experiments described here, both the free space (d^2 power loss) and the multi path fading (d^4 power loss) channel models were used, depending on the distance between the transmitter and the receiver. If the distance is less than a threshold, the free space (**fs**) model is used; otherwise, the multi path (**mp**) model is used. we have fixed the value of do like on DEEC at $do = 70$.

B. DDEEC details

DDEEC implements the same strategy like DEEC en terms of estimating average energy of networks and the cluster head selection algorithm which is based on residual energy where:

- The average energy of rth round is set as follow

$$\overline{E}(t) = \frac{1}{N} E_{total}(1 - \frac{r}{R}) \quad (3)$$

where R denote the total rounds of the network lifetime and is defined as

$$R = \frac{E_{total}}{E_{Round}} \quad (4)$$

- E_{Round} is the total energy dissipated in the network during a round, is equal to:

$$E_{Round} = L(2NE_{elec} + NE_{DA} + kEmpd^4_{toBS} + NEfsd^2_{toCH}) \quad (5)$$

where k is the number of clusters, E_{DA} is the data aggregation cost expended in the cluster heads, d_{toBS} is the average distance between the cluster head and the base station, and d_{toCH} is the average distance between the cluster members and the cluster head.

- Because we assuming that the nodes are uniformly distributed, we can get:

$$d_{toCH} = \frac{M}{\sqrt{2k\pi}}, \qquad d_{toBS} = 0.765\frac{M}{2} \quad (6)$$

- The optimal number of clusters is defined as:

$$k_{opt} = \frac{M}{d^2_{toBS}} \frac{\sqrt{N}}{\sqrt{2\pi}} \frac{\sqrt{Efs}}{\sqrt{Emp}} \quad (7)$$

The difference between DDEEC and DEEC is localized in the expression which define the probability to be a cluster head for normals and advanced nodes:

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+am)\overline{E}(r)} & \text{for normal nodes} \\ \frac{(1+a)p_{opt}E_i(r)}{(1+am)\overline{E}(r)} & \text{for advanced nodes} \end{cases} \quad (8)$$

In this expression we observe that nodes with more residual energy - $\overline{E}_r$ at round r- are more probable to be a clusters head. Certainly, the objective of this strategy is to distribute correctly the energy consumption on the network and to increase more the lifetime of nodes with low-energy, which is not the case on LEACH. However, it's possible on one moment some of advanced nodes will have the same residual energy like normal ones. Although, DEEC continues to penalize just the advanced nodes. This case is not the optimal way, because these nodes will be continuously a clusters head, then they will die quickly than the others.

Let us explain why? Because the advanced probability is higher, it's possible that an advanced node will be a cluster head through all rounds of simulations. Then, at each iteration the residual energy is decreased by:

$$E_{disAN} = L(E_{TX} + Emp(DoptBS^4) + (E_{RX} + E_{DA})n/Kopt) \quad (9)$$

Where E_{disAN} is the Energy dissipated by an Advanced Node by round. Then, the number of iterations possible for a CH Nb_{CH} with a initial energy equal to $(1+a)Eo$ is

$$Nb_{CH} = (1+a)Eo/E_{disAN} \quad (10)$$

With the same way we can define the Energy dissipated by a Normal Nodes E_{disNN} in each round:

$$E_{disNN} = L(E_{TX} + Efs(DtoCH^2)) \quad (11)$$

We can define the number of iterations possible for a normal node Nb_{NN} with Eo initial energy by:

$$Nb_{NN} = Eo/E_{disNN} \quad (12)$$

In figure 1, we observe that, for critical round, the advanced and normal nodes will have the same residual energy. Although and according to Li Qing and all [9], the advanced nodes probability to be a cluster head is greater than the normal one.

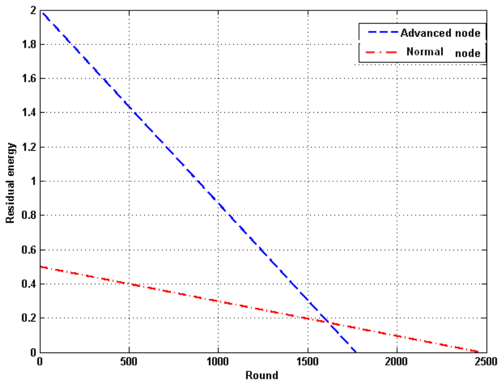

Fig. 1. variation of residual energy for an advanced and normal nodes

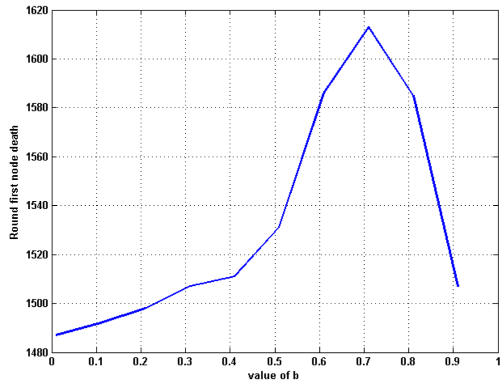

Fig. 2. Round first node dies when b is varying

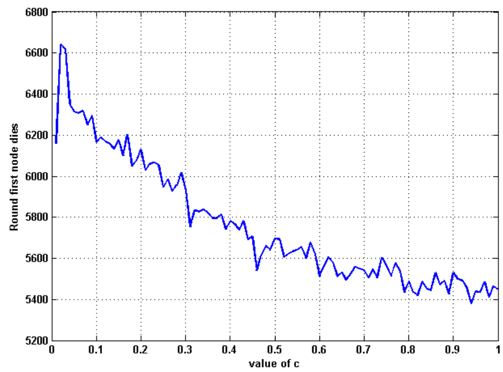

Fig. 3. Round first node dies when c is varying

TABLE I
RADIO CHARACTERISTICS USED IN OUR SIMULATIONS

Parameters	Value
Eelec	5 nJ/bit
efs	10 pJ/bit/m2
emp	0.0013 pJ/bit/m4
E0	0.5 J
E_{DA}	5 nJ/bit/message
do	70 m
Message size	4000 bits
Popt	0.1

In this way, we continue to punish more just these nodes, so they spent more energy and they will die quickly 1. To avoid this unbalanced case, our protocol DDEEC introduce some changes on the equation 8. These changes is based on using a threshold residual energy value Th_{REV}, which is equal to:

$$Th_{REV} = Eo(1 + \frac{aE_{disNN}}{E_{disNN} - E_{disAN}}) \tag{13}$$

It represents the theoretical value, which is the intersection lines value on the figure 1. The idea is that under this Th_{REV} all nodes, the advanced an normal ones, must have the same probability to be cluster head. Therefor, the cluster head election will be balanced and more equitable. So, the equation 8 which represents the nodes average probability p_i to be a cluster head will changed as fellow:

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+am)\overline{E}(r)} & \text{for Nml nodes, } E_i(r) > Th_{REV} \\ \frac{(1+a)p_{opt}E_i(r)}{(1+am)\overline{E}(r)} & \text{for Adv nodes, } E_i(r) > Th_{REV} \\ c\frac{(1+a)p_{opt}E_i(r)}{(1+am)\overline{E}(r)} & \text{for Adv, Nml nodes, } E_i(r) \leq Th_{REV} \end{cases} \tag{14}$$

The value of Th_{REV} is written as $Th_{REV} = bEo$ where

$$b = (1 + \frac{aE_{disNN}}{E_{disNN} - E_{disAN}}) \tag{15}$$

Where $b \in [0, 1[$ and if $b = 0$, we'll have the traditional DEEC. But in a reality and durante simulation, all advanced nodes can not be even a cluster heads. The same case for normal nodes, it's probable that some of them will be a cluster heads. Then, this last value of b is not exact. So, through lot of simulations with a random topology, we had try to find the nearest value of b which gives the performs results attended. In figure 2, using the parameters described in Table I, we represent the first node dies variation in function of b through 30 simulations. This figure presents the perfect value of b which equal to $b = 0.7$, then:

$$Th_{REV} \simeq (7/10)Eo \tag{16}$$

c is a reel positive variable which control directly the clusters head number. On one hand, if c is higher, the number of cluster heads will increase. Then, the network scheme will be like a direct communication because all nodes will be a cluster head and transmit directly here information to the base station, in this case the network performances will increase. On the other hand, if $c = 0$, the probability to be a cluster heads will be equal to zero for all nodes. So, they go to transmit directly their measurement to the base station, thus, they die quickly. That we wont certainly to avoid. To solve this compromise and find the correct value of c which gives an important results, we have run 30 random simulations and in each one, we compute the first node dies (FND). The figure 3 shows how c affect the round value of the FND. We observe that if c is nearest to 0.02 we have more network performances.

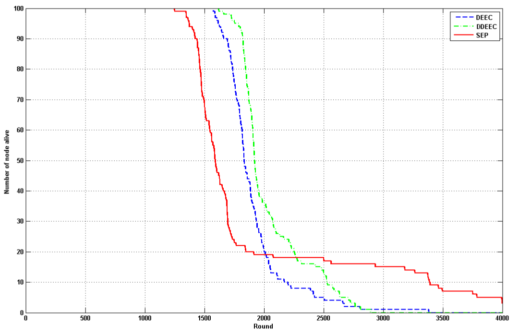

Fig. 4. Number of nodes alive over time of SEP, DEEC, and DDEEC under two-level heterogeneous networks over 20 simulations

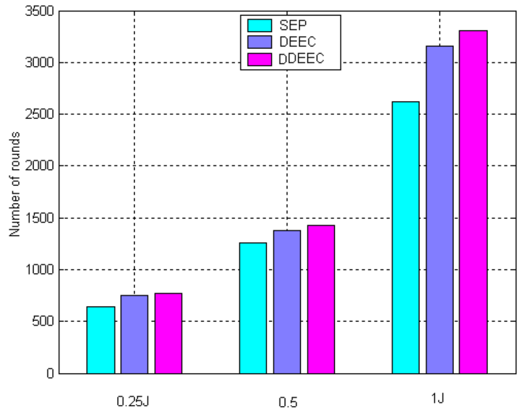

Fig. 5. Performance results for a 100m x 100m network with difference value of Eo

III. Simulation Results

In this section, we evaluate the performance of DDEEC protocol using MATLAB. We simulated this, DEEC and SEP using a wireless sensor network with $N = 100$ nodes randomly distributed in a $100m \times 100m$ field. The sink is located in the center of the sensing area. Such as on DEEC protocol, we ignore the effect caused by signal collision and interference in the wireless channel and the radio parameters used are shown in I. In our simulations we fixed both of c and b value which give more performances. where $c = 0.02$ and $b = 0.7$. The figure 4 is given through 20 random simulations. In these figures we observe that the unstable region of SEP is also larger than our DEEC protocol. It is because the advanced nodes die more slowly than normal nodes in SEP. For the reason that, DEEC take into account both the initial and residual energy, the stability period of DEEC is much longer than that of SEP. Moreover, we observe that DDEEC takes some advantage than DEEC in terms of first node dies and the prolongment of the stable time. It is due to the fusion between DEEC techniques and the balanced way in term of cluster head election introduced by the DDEEC. The simulation results on 4 show that DDEEC is better than DEEC with 15% in term of First Node Died. Certainly, this performances its due to our modifications and because the protocol introduce a balanced way through all simulations steps. Now, we run 20 simulations for our proposed protocol to compute the mean maximum possible rounds of communications for different value of Eo and compare the results to SEP and DEEC protocols. The figure 5 presents for different value of the initial energy the First Node Died round (FND). The results of the figure 5 prove more the DDEEC performances, where its FND round is always larger than the SEP and DEEC ones.

IV. Conclusion

We have explained DDEEC protocol which is a Developed Distributed Energy-Efficient Clustering for heterogeneous wireless sensor. It's an energy-aware adaptive clustering protocol and with an adaptive approach which employ the average energy of the network as the reference energy like in DEEC. When every sensor node independently elects itself as a cluster head based on its initial and residual energy and without any global knowledge of energy at every election round. To increase more the DEEC protocol performances, the DDEEC implemented a balanced and dynamic way to distribute the spent energy more equitably between nodes. These modifications introduced enlarges better the performances of our DDEEC protocol than the others.

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