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Stochastic Distributed Energy-Efficient Clustering (SDEEC) for heterogeneous wireless sensor networks

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Abstract

Many new protocols are specifically designed for wireless sensor networks, where the objectives is to save energy and extend the lifetime of the network. The clustering Algorithm is a kind of key technique which is largely used to answer these purposes. In this paper, we present and evaluate a Stochastic Distributed Energy-Efficient Clustering (SDEEC) scheme for heterogeneous wireless sensor networks. This protocol is based on dividing the network into dynamic clusters. The cluster's nodes communicate with an elected node called cluster head, and then this cluster head aggregates and communicates the information to the base station. SDEEC introduces a dynamic method where the cluster head election probability is more efficient. Moreover, It introduces a stochastic scheme detection to prolong the network lifetime. Simulation results show that our protocol performs better than the Stable Election Protocol (SEP) and than the Distributed Energy-Efficient Clustering (DEEC) in terms of network lifetime. In the proposed protocol the first node death occurs over 80% times longer than the first node death in DEEC protocol and by about 110% than SEP.

Keywords: *Heterogeneous environment, Energy Consumption, DEEC, Clustering, Wireless Sensor Networks.*

1 Introduction

Due to the fastest growing in electronics industry, small inexpensive battery-powered wireless sensors have already started to make an impact on the communication with the physical world.
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]. The development of wireless sensor networks was originally motivated by military applications for battlefield surveillance. Thereafter, wireless sensor networks are used in many civilian application areas, including environment and habitat monitoring, health care applications, home automation, and traffic control. 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. Because the large part of energy in the network is consumed in wireless communication in a WSN [4], several communication protocols have been proposed to realize power-efficient communication in these networks. One effective approach is to divide the network into several clusters, each electing one node as its cluster head [5]. 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 [6, 7]. These techniques can be extremely effective in broadcast and data query [8, 9]. 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 adapts 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 [10]. The Stochastic Energy-Efficient Clustering (SDEEC), permits to balance the cluster head selection over all network nodes following their residual energy. Moreover, an other key idea of this algorithm is to reduce better the intra-clusters transmission when the objective is to collect the maximum or minimum data values in a region (like temperature, humidity...). With this second idea our protocol will be stochastic.

The remainder of the paper is organized as follows: Section (2) describes a review related work. Section (3) describes the radio energy dissipation model. Section (4) emphasizes on the details of SDEEC algorithm. Additionally, section (5) gives the simulation results. Finally, conclusion is presented.

2 Related work

Because the large part of energy in a WSN is consumed when the wireless communications are established [4], several communication protocols have been proposed to realize power-efficient communication in these networks. Moreover, many techniques were proposed to allow transmission in WSN providing energy efficiency multi-hop communication in ad hoc networks. Currently, there are several energy efficient communication models and protocols that are designed for specific applications, queries, and topologies.

The Directed Diffusion protocol proposed in [4] is data centric in that all communication is for named data. All nodes in a directed diffusion-based network are application aware.

M. Ettus [11] and T. Shepard [12] proposed the so-called MTE (Minimum Transmission Energy) routing scheme which selects the route that uses the least amount of energy to transport a packet from the source to the destination. Assuming that the energy consumption is proportional to square distance between nodes, the intermediate nodes, which operate as routers, are chosen for minimizing the sum of squared distances over the path. For example, assume that a network is formed by nodes A, B, and C. The node A would transmit to node C. In the MTE, the node B participates to the route only if:

$$d_{AC}^2 > d_{AB}^2 + d_{BC}^2 \quad (1)$$

Heinzelman and al. proposed LEACH (Low-Energy Adaptive Clustering Hierarchy) [13] a protocol based on network clustering. Basically any clustering algorithm is concerned with the management of clusters, which includes forming a suitable number of clusters, selecting a cluster head for each cluster and controlling the data transmission within clusters and from cluster heads to the base station [2]. There are two kinds of clustering schemes. The clustering algorithms applied in homogeneous networks which are called homogeneous schemes, where all nodes have the same initial energy, like LEACH, PEGASIS (Power-Efficient Gathering in Sensor Information Systems) [14], and HEED (Hybrid, Energy-Efficient Distributed clustering) [15]. The LEACH chooses cluster heads periodically and distributes energy consumed uniformly by role rotation. Under the heterogeneous network this protocol will become poor and not efficient. In the PEGASIS protocol all network become like a one chain which is calculated by nodes or by the base station. Only one node of the chain which aggregates all data and send it to the Sink. The difficulty of this protocol is based on the requirement of the global knowledge of the network topology. The heterogeneity of nodes in term of their initial energy defines the second type of clustering algorithms which are applied in heterogeneous networks. There are plenty of heterogeneous clustering algorithms, such as LEACH-E [16], SEP (Stable Election Protocol) [17], M-LEACH [18], EECS (Energy Efficient Clustering Scheme) [19], LEACH-B [20] and EDEEC (Equitable Distributed Energy-Efficient Clustering) [21]. The SEP protocol is a two-level heterogeneous networks, these tow levels are defined by the initial energy of each nodes. It is based only on the initial energy but not on the residual one. M. Ye et al, develop the EECS which chooses the cluster- heads with more residual energy through local radio communication. In cluster formation phase, EECS considers the trade-off of energy expenditure between nodes to the cluster-heads and the cluster heads to the base station. But on the other hand, it increases the requirement of global knowledge about the distances between the cluster heads and the base station. The EDEEC is developed for heterogenous network, using an intermediate cluster-based hierarchical solution, but this protocol is suitable only if the Base Station is far away from the network. In addition, in [10], Li Qing et al propose and validate a newest protocol DEEC, which uses a new conception based on the ratio between residual energy of each node and the average energy of the network. The simulation results of DEEC (Distributed Energy-Efficient Clustering) show clearly its performances than the others. Certainly, our SDEEC is a self-organized network with dynamic clustering concept. This protocol is based on DEEC but with a new proposal strategies. These last ones, develop more the performance of all nodes and increase more the network lifetime. The Stochastic strategy is the key idea where the number of transmission intra-clusters is reduced. This strategy is used when the objective is to collect the maximum or minimum data values (like temperature, humidity ...)in a region of the network.

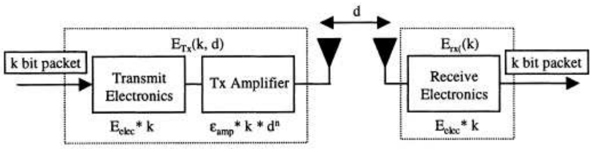

Figure 1: Radio Energy Dissipation Model

3 Radio energy dissipation model

On the first, for the purpose of this study we use similar energy model and analysis as proposed in [13]. According to the radio energy dissipation model illustrated in figure 1. 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:

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

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 do, 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 $do = 70$.

4 Problem Formulation and the SDEEC Proposed Solution

SDEEC 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 SDEEC 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 paper, we consider a network with N nodes, which are uniformly dispersed within a $M \times M$ square region. The network is organized into a clustering hierarchy, and the cluster heads collect measurements information from cluster nodes and transmit, directly, the aggregated data to the base station. 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. The figure 2 represents this topology.

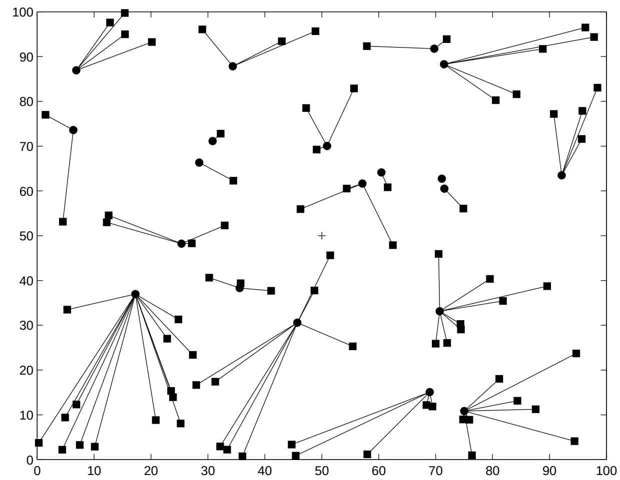

Figure 2: Heterogeneous random network with 100-nodes (80 normal nodes and 20 advanced nodes)

Furthermore, the figure 2 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:

$$E_{total} = N(1-m)Eo + NmEo(1+a) = NEo(1+am) \tag{3}$$

SDEEC implements the same strategy like DEEC in terms of estimating average energy of networks and the cluster head selection algorithm. This strategy is based on the initial and the residual energy where:

- The average energy of rth round is set as follows

$$\overline{E}(t) = \frac{1}{N} E_{total}(1 - \frac{r}{R}) \tag{4}$$

R denotes the total rounds of the network lifetime and is defined as

$$R = \frac{E_{total}}{E_{Round}} \tag{5}$$

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

$$E_{Round} = L(2NE_{elec} + NE_{DA} + kEmpd^4_{toBS} + NEfsd^2_{toCH}) \tag{6}$$

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 [10], we can get:

$$d_{toCH} = \frac{M}{\sqrt{2k\pi}}, \qquad d_{toBS} = 0.765\frac{M}{2} \tag{7}$$

- The optimal number of clusters is defined as:

$$k_{opt} = \frac{M}{d^2_{toBS}} \frac{\sqrt{N}}{\sqrt{2\pi}} \frac{\sqrt{Efs}}{\sqrt{Emp}} \tag{8}$$

The next equation define the probability to be a cluster head for ,both, normals and advanced nodes:

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+am)\overline{E}(r)} & \text{for normal nodes} \\ \frac{(1+a)p_{opt}E_i(r)}{(1+am)\overline{E}(r)} & \text{for advanced nodes} \end{cases} \tag{9}$$

In this expression we observe that nodes with more residual energy (Advanced nodes) - $\overline{E}_r$ 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 the low-energy nodes which is not the case on LEACH.
In many applications, the collected data are used to determine the maximal or minimal value of observed phenomena in the region [22]. Thus, the cluster head selects the pertinent information (the minimum or the maximum) between those received and send it to the base station. In this case, if the clusters head receives only from nodes with significant information and the others nodes must be in sleep mode, the total number of transmission and reception will be largely reduced. Therefor, the energy consumption strategy will be more efficient and the overall network lifetime can thus be prolonged. The cluster head broadcasts its sensed information assuming it the searched data, only nodes with significant data send its message to the cluster head which updates its data and send it towards the base station. Let suppose that each node i on the network has a probability S_i to have the searched value in the considered cluster. The total energy consumed E_{total} in the network to transmit the significants data to the sink is:

$$E_{total} = K_{opt}(E_{CHtoBS} + \sum S_i E_{itoCH}) \tag{10}$$

where E_{CHtoBS} is the energy consumed when the cluster head transmit data to the base station.
E_{itoCH} is the energy consumed to transmit data from node i to the cluster head.
K_{opt} as is defined on 8 is the cluster heads optimal number.
The equation 10 will be :

$$E_{total} = LK_{opt}[Empd^4_{toBS} + E_{elec} + (E_{elec} + E_{DA} + Efsd^2_{toCH}) \sum S_i] \tag{11}$$

Table 1: 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

This equation show clearly that the total energy consumed by round is largely reduced. In this situation, the network life time will be more prolonged.

Once clusters, CHs are created, each cluster head knows which nodes are in its group then it creates a TDMA schedule assigning each node a slot of time telling them when they can transmit. Only nodes with state value larger then CH one must keep their receivers on. After this step data transmission can begin.

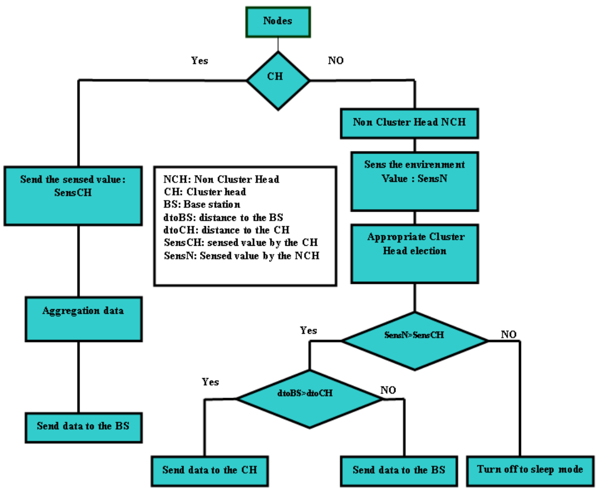

Figure 3: SDEEC flow chart

Initially, each non cluster heads sends its data during their allocated transmission time 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 its primer cluster head. In this phase, in order to reduce the energy consumed, each non cluster heads can turn off the sleep mode. The diagram in figure 3 shows on details the SDEEC protocol steps.

5 Simulation Results

In this section, we evaluate the performance of SDEEC 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. 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 table 1.

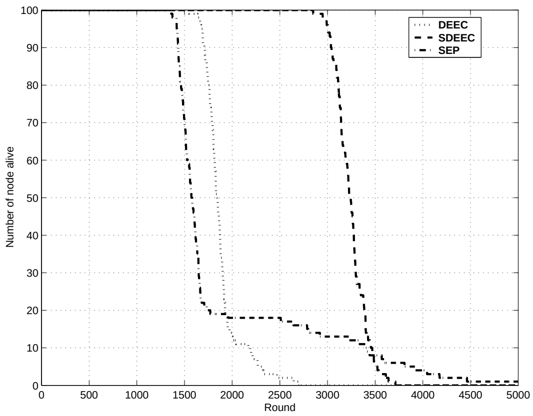

Figure 4: Number of nodes alive over time of SEP, DEEC, and SDEEC under two-level heterogeneous networks

We run simulation for our proposed protocol SDEEC introducing the stochastic technique. In the figure 4 the first node death happens in SEP protocol. In the first 1600 transmissions rounds, the nodes death rate is important in SEP compared to DEEC and SDEEC. The network nodes die randomly in the supervised area, and the network monitoring is better while the number of nodes still alive is important and the stability period is long. So, SDEEC grant a maximal network lifetime compared to SEP and DEEC. This extension of the network service duration is due to the reduction of the number of messages transmitted intra-cluster. Consequently to this reduction, the transmissions and reception nodes energy is economized. Therefore, the total energy consumption is reduced, then the network lifetime is extended.

The figure 5 gives the total network remaining energy in every transmission round. The network remaining energy decreases rapidly in the SEP and DEEC protocols. So, it presents a slope approximately -0.04J/Round, compared to -0.03J/Round in SDEEC. Then, the network energy depletion is fast in SEP and DEEC. In addition, we can see that, in the 2000 first transmissions rounds, approximately 96% and 85% of the total network energy is consumed respectively in DEEC and SEP. Whereas, the SDEEC consumed only 47% of this total energy of the network.

As shown in figure 6, we represent the number of

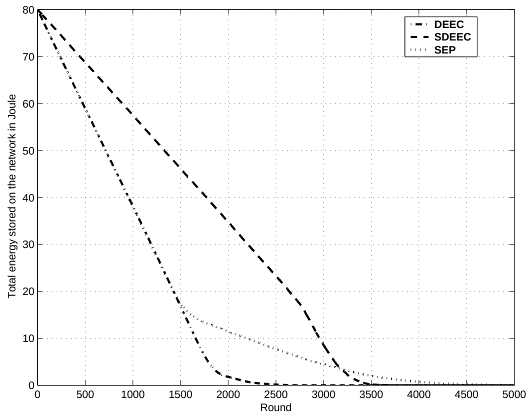

Figure 5: Evolution of the remaining energy in the network when the transmission rounds succeed

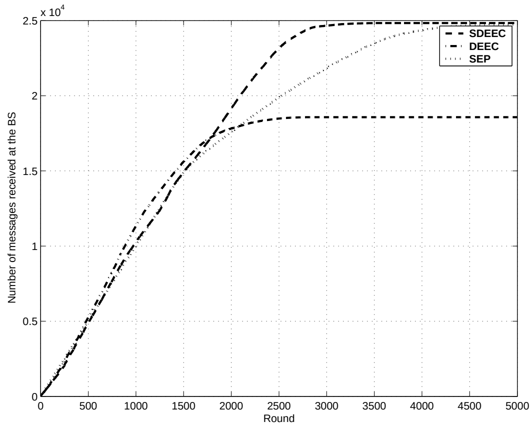

Figure 6: Number of message received at base station over time

data messages received at the base station. We observe that this number of messages received at the base station varies linearly for all protocols, SEP, DEEC and SDEEC, for the first 1500 transmissions rounds. After that, we observe a stagnation of this number for DEEC. The raison is that the number of death nodes increases quickly, and consequently, the number of messages to transmit towards the base station decreases. Moreover, we can notice that, when the entire network nodes are dead, the total number of messages transmitted to the base station is substantial for the SDEEC protocol. This means that SDEEC is more efficient than SEP and DEEC.

6 Conclusion

We have explained SDEEC protocol which is a Stochastic 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. 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, our protocol is adapted in situations where we have to monitor the whole area, and then, the data aggregation consists to select the important information in the cluster. These modifications introduced enlarges better the performances of our SDEEC protocol than the others. We can note that, in the proposed protocol the first node death occurs over 80% times longer than the first node death in DEEC protocol and by about 110% than SEP.

Acknowledgements

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7 Biographies

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