Distributed Cluster Head Election (DCHE) Scheme for Improving Lifetime of Heterogeneous Sensor Networks

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Abstract

Due to environmental characteristics, limited power and processing capabilities of wireless sensor networks, it is essential to find new techniques that improve the flow of information in the network. The cluster head election among the sensor nodes is an effective technique in wireless sensor networks to increase the network efficiency, scalability and lifetime. In this paper, we have proposed and evaluated a distributed cluster head election scheme for heterogeneous sensor networks. The election of cluster heads is based on different weighted probability. The cluster's member nodes communicate with the elected cluster head and then cluster heads communicate the aggregated information to the base station via single hop communication. Adopting this approach, our simulation results demonstrate that the proposed scheme offers a much better performance than the existing protocols in terms of stability and network lifetime.

Key Words: Heterogeneous, Cluster Head Election, Lifetime, Wireless Sensor Networks

1. Introduction

With the fastest growth in electronics industry, small inexpensive battery-powered wireless sensors have already started to make an impact on the communication with the physical world. Recent advances in wireless communication made it possible to develop Wireless Sensor Networks (WSNs) consisting of small devices, which collect information by cooperating with each other. These small sensing devices are called nodes that consist of CPU (for data processing), memory (for data storage), battery (for energy) and transceiver (for receiving and sending signals or data from one node to another). The size of each sensor node varies with application. For example, in some military or surveillance applications it might be microscopically small. The cost of these devices depends on its parameters like memory size, processing speed and battery as described in [1].

Many existing clustering techniques consider homogeneous sensor networks where all sensor nodes are designed with the same battery energy. There are two types of clustering techniques. The clustering technique applied in homogeneous sensor networks is called homogeneous clustering schemes, and the clustering technique applied in the heterogeneous sensor networks is referred to as heterogeneous clustering schemes. The energy saving schemes for homogeneous wireless sensor networks do not perform efficiently when applied to heterogeneous wireless sensor networks.

Most of the existing clustering schemes such as LEACH [2], PEGASIS [3], and HEED [4], all assume the homogeneous sensor networks. These schemes per-

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form poorly in heterogeneous environments. The low energy nodes will die quickly than the high energy nodes, because these clustering schemes are unable to treat each node discriminatorily in terms of the energy discrepancy.

More recent research works in [5–7] consider heterogeneous network models, which assume that two different types of nodes are deployed with the high energy sensor nodes having greater processing power and better hardware specifications as compared to other nodes. The energy consumption and lifetime of the heterogeneous networks have been analyzed in [8] on the assumption that given a number of high-end sensors, only a subset of them will be active cluster heads (CHs) at any point of time. The lifetime estimation is expressed as function of number of data collection rounds, together with other variables.

Putting few heterogeneous nodes in wireless sensor network is an effective way to increase the network lifetime and stability. In this paper, we present the study of the performance of the clustering scheme in saving energy and improving lifetime for heterogeneous wireless sensor networks. We have considered three types of nodes where type-3 and type-2 nodes are equipped with more battery energy than type-1 node. All the nodes are uniformly distributed over the field and they are not mobile. Under this model, we have developed a new distributed clustering scheme that significantly increases the lifetime and stability of the heterogeneous sensor network.

The rest of the paper is organized as follows. In section 2, our DCHE scheme is described. Section 3 presents simulation results and discussion. Section 4 deals with the related work. Finally, section 5 concludes the paper.

2. DCHE Architecture

In this section, we consider the heterogeneous cluster-based wireless sensor network with hundred sensor nodes dispersed in a field. Base Station (BS), an observer, is located at far away from the network field. Each cluster has one cluster head which acts as a local control centre to coordinate the data transmissions. First, we describe a few terms that are used in defining our protocol. A cluster head is a sensor node that transmits an aggregated data to the distant base station. Non-cluster heads are sensor nodes that transmit the collected or sensed data to their cluster head. The cluster heads are responsible to coordinate the data transmissions in their cluster.

The cluster head node sets up a Time Division Multiple Access (TDMA) schedule and transmits this schedule to the nodes in the cluster. This ensures that there are no collisions among data messages and also allows the radio components of each non-cluster head node to be turned off at all times except during their transmit time, thus reducing the energy consumed by the individual sensors. After the TDMA schedule is known by all nodes in the cluster, the set-up phase is complete and the steady-state operation (data transmission) can begin. The steady-state operation is broken into frames, where nodes send their data to the cluster head at most once per frame during their allocated transmission slot. The duration of each slot in which a node transmits data is constant, so the time to send a frame of data depends on the number of nodes in the cluster.

The cluster head must be awake to receive all the data from the nodes in the cluster. Once the cluster head receives all the data, it performs data aggregation to enhance the common signal and reduce the uncorrelated noise among the signals. In our analysis, we assume perfect correlation such that all individual signals can be combined into a single representative signal. The resultant data are sent from the cluster head to the base station.

Most of the analytical results for LEACH-type schemes are obtained assuming that the nodes of the sensor network are equipped with the same amount of energy this is the case of homogeneous sensor networks. In this paper, we have studied the impact of heterogeneity in terms of node energy. Let us assume that a percentage of the node population is equipped with more energy than the nodes that are already in use, which creates heterogeneity in terms of node energy. The cost constraint is not always possible to satisfy the optimal distribution between different types of nodes as proposed in [5].

We have described our developed model for a wireless sensor network with nodes heterogeneous in their initial amount of energy. In this model, we have taken three types of nodes in the sensor field with different energy (type-3, type-2 and type-1 node). Type-3 and type-2 nodes are equipped with β and α times more energy than type-1 nodes.

In LEACH [2], there is an optimal percentage p_{opt} of nodes that has to become cluster heads in each round assuming uniform distribution of nodes in space utilized. If the nodes are homogeneous, which means that all the nodes in the field have the same initial energy, the LEACH protocol guarantees that everyone of them will become a cluster head exactly once every $1/p_{opt}$ rounds. In this paper, we have referred $1/p_{opt}$ as epoch of the clustered sensor network to the number of rounds. Initially each node can become a cluster head with a probability p_{opt}. On average, p_{opt} . n nodes must become cluster heads per round per epoch. Nodes that are elected to be cluster heads in the current round can no longer become cluster heads in the same epoch. The non-elected nodes belong to the set G and in order to maintain a steady number of cluster heads per round, the probability of nodes $\in G$ to become a cluster head increases after each round in the same epoch. The decision is made at the beginning of each round by each node $s \in G$ independently choosing a random number in [0, 1]. If the random number is less than a threshold $T(s)$ then the node becomes a cluster head in the current round. The threshold is set as:

$$T(s) = \begin{cases} \dfrac{p_{opt}}{1 - p_{opt}.(r \bmod \dfrac{1}{p_{opt}})} & if \quad s \in G \\ 0 & otherwise \end{cases} \tag{1}$$

where r is the current round number. The election probability of nodes $s \in G$ to become cluster heads increases in each round in the same epoch and becomes equal to 1 in the last round of the epoch. We defined round as a time interval when all the cluster members have to transmit their data to their cluster head. In this paper, we have explained how the election process of cluster heads should be adapted appropriately to deal with heterogeneous nodes, which means that not all the nodes in the field have the same initial energy.

2.1 Optimal Cluster Head Election

In [2,9], the authors have studied either by simulation or analytically the optimal probability of a node being elected as a cluster head as a function of spatial density when nodes are uniformly distributed over the sensor field. This clustering is optimal in the sense that energy consumption is well distributed over all sensors and the total energy consumption is minimum. Such optimal clustering highly depends on the energy model. We have used similar energy model and analysis as proposed in [2]. 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, energy expanded by the radio is given by Equation (2).

$$E_{Tx}(L,d) = \begin{matrix} L.E_{elec} + L.\varepsilon_{fs}.d^2 & if\ d \le d_0 \\ L.E_{elec} + L.\varepsilon_{mp}.d^4 & if\ d \ge d_0 \end{matrix} \tag{2}$$

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, and d is the distance between the sender and the receiver. By equating the two expressions at $d = d_0$. To receive an L bit message the radio expends $E_{Rx} = L \,.\, E_{elec.}$

We have assumed an area $A = M \times M\,\text{m}^2$ over which n number of nodes are uniformly distributed. The base station is located outside of the network field, and that the distance of any node to the BS its cluster head is $\le d_0$. Thus, the energy dissipated in the cluster head node during a round is given by the following formula:

$$E_{ch} = \left(\frac{n}{k} - 1\right) L.E_{elec} + \frac{n}{k} L.E_{DA} + L.E_{elec} + L.\varepsilon_{fs}.d_{BS}^2 \tag{3}$$

where k is the number of cluster heads, E_{DA} is the processing cost of a bit report to the BS, and d_{BS} is the average distance between a cluster head and the base station. The energy used in a non-cluster head node is equal to:

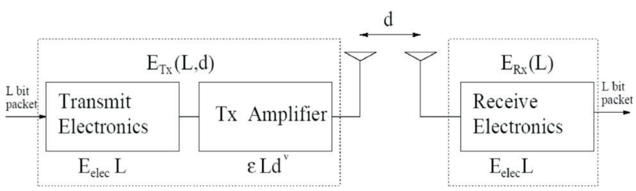

Figure 1. Radio energy dissipation model.

$$E_{nonch} = L.E_{elec} + L.\varepsilon_{fs} d_{CH}^2 \tag{4}$$

where d_{CH} is the average distance between a cluster member and its cluster head. Assuming that the nodes are uniformly distributed, it can be shown that:

$$d_{CH}^2 = \int_0^{x_{\max}} \int_0^{y_{\max}} (x^2 + y^2)\rho(x, y)dxdy = \frac{M^2}{2\pi k} \tag{5}$$

where ρ(x, y) is the node distribution.

The total energy dissipated in the network is given by Equation (6).

$$E_t = L.(2.n.E_{elec} + n.E_{DA} + \varepsilon_{fs}.(k.d_{BS}^2 + n.d_{CH}^2)) \tag{6}$$

By differentiating, E_t with respect to k and equating to zero the optimal number of constructed clusters head to the sink is given by Equation (7):

$$k_{opt} = \sqrt{\frac{n}{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}\frac{M}{d_{BS}^2} \tag{7}$$

If the distance of a significant percentage of nodes to the sink is greater than d_0 then, the following the same analysis [2] we obtain by Equation (8).

$$d_{BS}^2 = \int_A (x^2 + y^2)\frac{1}{A} = 0.765\frac{M}{2} \tag{8}$$

The optimal probability of a node to become a cluster head, p_{opt}, can be computed as follows:

$$p_{opt} = \frac{k_{opt}}{n} \tag{9}$$

The optimal probability for a node to become a cluster head is very important. In [2,9,10], the authors showed that if the clusters are not constructed in an optimal way, the total energy consumed by the sensor network per round is increased exponentially either when the number of clusters that are created is greater or especially when the number of the constructed clusters is less than the optimal number of clusters.

2.2 Proposed Network Model

The original version of LEACH does not take into consideration the heterogeneity of nodes in terms of their initial energy, and as a result the consumption of energy resources of the sensor network is not optimized in the presence of such heterogeneity. The reason is that LEACH depends only on the spatial density of the sensor network. Using LEACH in the presence of heterogeneity, and assuming type-3, type-2 and type-1 nodes are uniformly distributed in space, we expect that the first node dies on average in a round that is close to the round when the first node would die in the homogeneous case wherein each node is equipped with the same energy as that of a type-1 node in the heterogeneous case. Furthermore, we expect the first dead node to be a type-1 node. We also expect that in the following rounds the probability of a type-1 node to die is greater than the probability of type-2 and type-3 node to die. During the last rounds only type-2 and type-3 nodes would be alive. Our expectations are confirmed by simulation results. Let us consider a sensor network in M × M sensor field, as shown in Figure 2. For this setting we can compute from Equation (7) the optimal number of cluster heads per round, we denote with 'o' a type-1 node, with '+' type-2 node, with '^' type-3 node, with '*' cluster head and with 'x' the base station (BS) as shown in Figures 2(a)–2(b).

In this section, we have presented the DCHE scheme, which has improved the lifetime of the network by using the characteristic parameters of heterogeneity, namely the few type-3 and type-2 nodes of β and α times more energy than the type-1 nodes in order to prolong the lifetime of the sensor network. Intuitively, type-3 and type-2 nodes have to become cluster heads more often than the type-1 nodes, which is equivalent to a fairness constant on energy consumption. The new heterogeneous setting has changed the total initial energy of the network and has not affected on the spatial density of the network. We have assumed that E_2, E_1, and E_0 is the initial energy of each type-3, type-2 and type-1 node is as follows:

$$E_2 = E_0 . (1 + \beta) \tag{10}$$

$$E_1 = E_0 . (1 + \alpha) \tag{11}$$

The total initial energy of the new heterogeneous network setting is equal to:

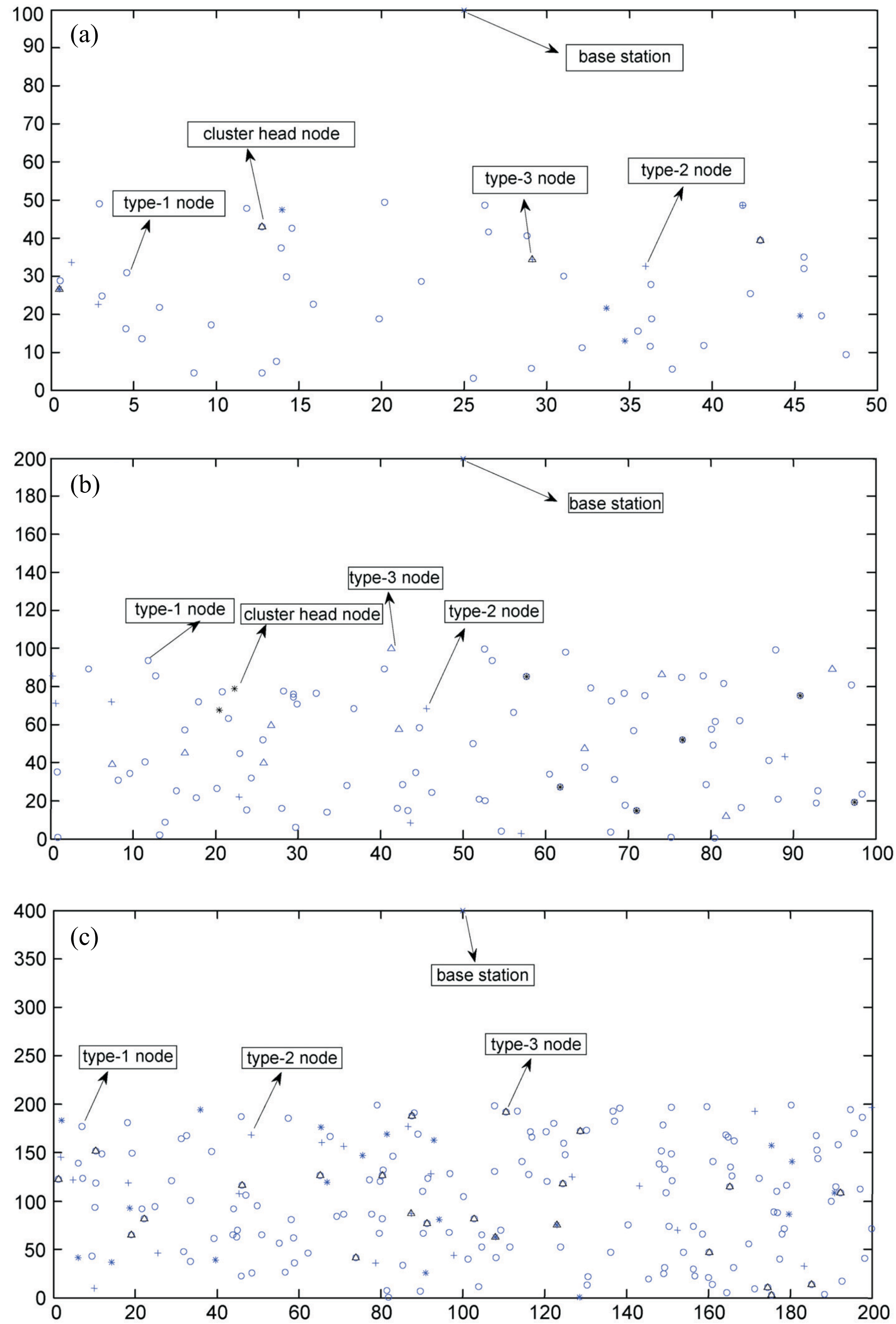

Figure 2. (a) Heterogeneous Network: 50 m × 50 m with m = 0.2, p = 0.5, α = 2, β = 1, *BS* is located at (25,100). (b) Heterogeneous Network: 100 m × 100 m with m = 0.2, p = 0.5, α = 2, β = 1, *BS* is located at (50,200). (c). Heterogeneous Network: 200 m × 200 m with m = 0.2, p = 0.5, α = 2, β = 1, and BS is located at (100,400).

$$E_t = n \cdot E_0 \cdot (1 + m \cdot Q) \quad (12)$$

where $Q = \alpha - p \cdot (\alpha - \beta)$, m is the proportion of non-type-1 nodes, and p is the proportion of type-3 nodes among those non-type-1 nodes.

New epoch of the heterogeneous network is given by Equation (13).

$$N_e = (1 + m \cdot Q)/p_{opt} \quad (13)$$

The new epoch (N_e) must be changed accordingly as the energy of the system is increased. The stable region of the sensor network is increased by $(1 + m . Q)$ times, if (i) each type-1 node becomes a cluster head once every $(1 + m . Q)/p_{opt}$ rounds per epoch; (ii) each type-2 node becomes a cluster head exactly $(1 + \alpha)$ times every $(1 + m . Q)/p_{opt}$ rounds per epoch; (iii) each type-3 node becomes a cluster head exactly $(1 + \beta)$ times every $(1 + m . Q)/p_{opt}$ rounds per epoch; and (iv) the average number of cluster heads per round per epoch is equal to $p_{opt} . n$. If at the end of each epoch the number of election of a cluster head of type-3 and type-2 node is not equal to the factor $(1 + \alpha)$ and $(1 + \beta)$ then the energy is not well distributed. The net number of cluster heads per round per epoch will be less than $p_{opt} . n$. This problem can be reduced by setting of optimal threshold $T(s)$ in Equation 1, with the constraint that each node has to become a cluster head as many times as its initial energy divided by the energy of a type-1 node.

2.3 Energy Consumption Problem in Heterogeneous Network

If the same threshold is set for type-3, type-2 and type-1 nodes with the difference that each type-1 node ∈ G becomes a cluster head once every $(1 + m . Q)/p_{opt}$ rounds per epoch, each type-2 node ∈ G becomes a cluster head $(1 + \alpha)$ times every $(1 + m . Q)/p_{opt}$ rounds per epoch, and each type-3 node ∈ G becomes a cluster head $(1 + \beta)$ times every $(1 + m . Q)/p_{opt}$ rounds per epoch, then there is no guarantee that the number of cluster heads per round per epoch will be $p_{opt} . n$. The reason is that there are a significant number of cases where this number can not be maintained per round per epoch with probability 1. Suppose that every type-1 node becomes a cluster head once within the first $(1 - m)/p_{opt}$ rounds of the epoch. In order to maintain the well distributed energy consumption constraint, all the remaining nodes, which are type-3 and type-2 nodes, have to become cluster heads with probability 1 for the next rounds of the epoch. But the threshold $T(s)$ is increasing with the number of rounds within each epoch and becomes equal to 1 only in the last round when all the remaining nodes become cluster heads with probability 1. The above constraint $p_{opt} . n$ of cluster heads in each round is violated.

2.4 Solution for Energy Consumption in Heterogeneous Network

In this section, we have given a solution for the above said problem; the solution is based on the extra energy of type-2 and type-3 nodes. This energy is forced to be expended within sub epochs of the original epoch. Our approach is to assign a weight to the optimal probability p_{opt}. This weight must be equal to the initial energy of each node divided by the initial energy of the type-1 node. Let us define P_1, P_2 and P_3 are the weighted election probability for the type-1, type-2 and type-3 nodes. 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 $p_{opt} . n$. In this type of scenario, the average number of cluster heads per round per epoch is equal to $n . (1 + m . Q)$. The weighed probabilities for type-1, type-2 and type-3 nodes are respectively:

$$P_1 = \frac{p_{opt}}{1+m.Q} \tag{14}$$

$$P_2 = \frac{p_{opt}}{1+m.\mathrm{Q}}.(1+\alpha) \tag{15}$$

$$P_3 = \frac{p_{opt}}{1+m.\mathrm{Q}}.(1+\beta) \tag{16}$$

In Equation (1), we have replaced p_{opt} by the weighted probabilities to obtain the threshold that is used to elect the cluster head in each round. We define $T(s_1)$, $T(s_2)$ and $T(s_3)$ are the threshold for type-1, type-2 and type-3 nodes. Thus, $T(s_1)$ is the new threshold for type-1 nodes and is given by Equation (17).

$$T(s_1) = \begin{cases} \dfrac{P_1}{1 - P_1.(r \bmod(\frac{1}{P_1}))} & \text{if } s_1 \in G' \\ 0 & \text{otherwise} \end{cases} \tag{17}$$

where r is the current round, G′ is the set of type-1 nodes that have not become cluster heads within the last $1/P_1$ rounds of the epoch, and $T(s_1)$ is the threshold applied to a population of $n . (1 - m)$ type-1 nodes. This guarantees that each normal node will become a cluster head exactly once every $(1 + m . Q)/P_1$ rounds per epoch, and the average number of cluster heads that are type-1 nodes per round per epoch is equal to $n \cdot (1 - m) \cdot P_1$.

Similarly, new threshold $T(s_2)$ and $T(s_3)$ can be evaluated for type-2 and type-3 nodes are given by Equation (18) and Equation (19).

$$T(s_2) = \begin{cases} \dfrac{P_2}{1 - P_2 \cdot (r \bmod (\frac{1}{P_2}))} & if \quad s_2 \in G' \\ 0 & otherwise \end{cases} \quad (18)$$

$$T(s_3) = \begin{cases} \dfrac{P_3}{1 - P_3 \cdot (r \bmod (\frac{1}{P_3}))} & if \quad s_3 \in G'' \\ 0 & otherwise \end{cases} \quad (19)$$

Thus the total number of cluster heads per round per heterogeneous epoch is equal to: $(n \cdot (1 - m) \cdot P_1 + n \cdot m \cdot (1 - p) \cdot P_2 + n \cdot m \cdot p \cdot P_3) = n \cdot p_{opt}$ which is the desired number of cluster heads per round per epoch.

The DCHE deals with heterogeneous networks where short-term link failures occur due to the radio communication characteristics. This technique could be triggered whenever a certain energy threshold is exceeded at one or more nodes. The non-cluster head nodes send the status of their remaining energy periodically during the handshaking process with their cluster heads, and the cluster heads send this information to the base station as well. The base station can check the heterogeneity in the field by examining whether one or a certain number of nodes reach this energy threshold and broadcast the values of p_1, p_2 and p_3 to the cluster heads for the current round.

3. Simulation Results

In this section, we have evaluated the performance of DCHE scheme through simulations by using MATLAB. We have considered a first order radio model for energy in the sensor network. This is the same radio model as discussed in LEACH, which is the first order radio model [2]. Equations (3) and (4) are used to obtain the transmission cost and the receiving cost. We made the assumptions that the radio channel is symmetric. For our simulations, we have also assumed that all the sensors are sensing the environment at a fixed rate and thus, they always have data to send to the base station. To compare the performance of DCHE with other protocols, we have ignored the effect caused by signal collision and interference in the wireless channel. We have introduced some parameters for performance evaluation as mentioned in Table 1. Simulations are carried out in different network topologies. In each network topology, the n nodes are randomly scattered in a square area. First, we have evaluated the network lifetime by examining the number of rounds until the first node die and half nodes die. In particular, the DCHE is better than other protocols in terms of energy consumption, since the rounds of the DCHE scheme is achieved until the first node die and half nodes die are much longer than that of Direct Transmission (DT) [2], Distributed Energy Efficient Clustering) (DEEC) [11] and LEACH.

Lifetime is the criterion for evaluating the performance of routing protocols in sensor networks. In our previous work [12], we have considered only one metric of lifetime for evaluation i.e. when the first node dies. In

Table 1. Simulation parameters

Description	Symbol	Value
The number of nodes	n	50, 100, 200
Transmit amplifier if $d_{BS} <= d_0$	ε_{fs}	10 pJ/bit/m^2
Transmit amplifier if $d_{BS} >= d_0$	ε_{mp}	0.0013 pJ/bit/m^4
Transmitter/Receiver energy	E_{elec}	50 nJ/bit
Data aggregation energy	E_{DA}	5 nJ/bit/report
Size of network	$M \times M$	50 m × 50 m, 100 m × 100 m, 200 m × 200 m
The location of base station	BS	(25,100), (50,200), (100,400)
Data packet Size	D_{pkt}	2000 bit, 4000 bit, 6000 bit
Initial energy level	E_0	0.25 J, 0.5 J, 1 J
Proportion of non-type-1 nodes	m	0.2
Proportion of type-3 nodes among the non-type-1 nodes	p	0.5

this work, we measure the lifetime in terms of the round when the first node and half of the nodes die. The stability period is the time interval from the start of the network operation until the death of the first alive node.

We have simulated and investigated the lifetime and stability of LEACH, DT (Direct Transmission) [2], DEEC [11] and proposed protocol in the presence of different initial energy levels, data packet size, base station location and number of nodes in the different network fields as shown in Table 1; whereas the scheme proposed in [12] was compared only with LEACH protocol.

In Figures 3−5, a detailed view of the behavior of proposed protocol, DEEC, LEACH and DT is illustrated the number of alive nodes for the different network scenarios as shown in Figure 2.

We have compared the lifetime performance of LEACH, DEEC, DT and proposed protocol (DCHE) in the same setting of heterogeneity. Figure 6 shows that the first node dies earlier in case of DT, LEACH, and DEEC and Figure 7 shows that the half of the nodes are also die earlier in case of DT, LEACH, and DEEC as compared to proposed protocol. More specifically, the proposed protocol offers a longer lifetime than DT, LEACH and DEEC. Figure 8(a) shows the percentage improvement of lifetime of DCHE scheme when the first node dies over a different network area. Figure 8(b) shows the percentage improvement of lifetime of DCHE scheme when the half node dies over different network area. This indicates that the DCHE scheme is a better option to prolong the network lifetime and stability for all the three scenarios of heterogeneous network as shown in Figure 2.

Figure 6 also indicates that the stable time of proposed protocol is prolonged compared with LEACH, DEEC and DT. DEEC performs better than LEACH and DT, but we can see that the unstable region of DEEC is also larger than our protocol.

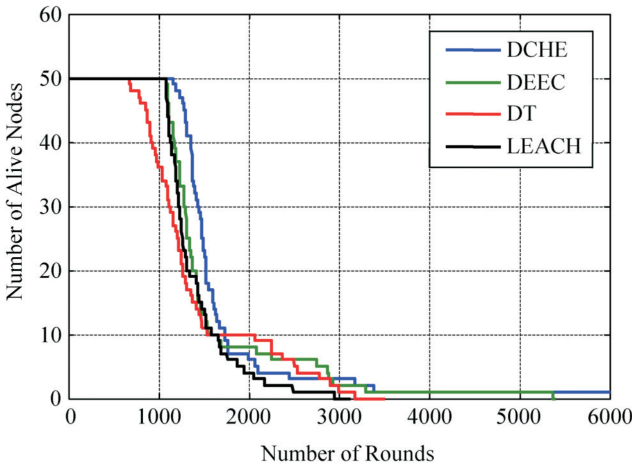

Figure 3. Number of alive nodes for a 50 m × 50 m network when $E_0 = 0.25$ J, $n = 50$, $D_{pkt} = 2000$ bit and BS is located at (25,100).

4. Related Works

In this section, we review specific prior studies that dealt with the clustering schemes and heterogeneous networks. LEACH is the first work that questioned the behavior of clustering protocols in the presence of hetero-

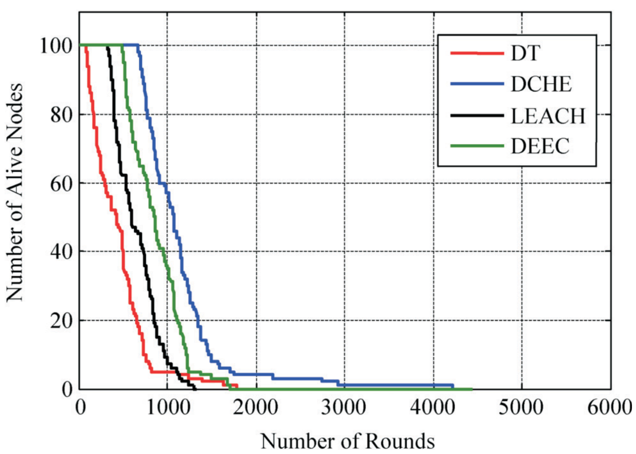

Figure 4. Number of alive nodes for a 100 m × 100 m network when $E_0 = 0.5$ J, $n = 100$, $D_{pkt} = 4000$ bit & BS is located at (50,200).

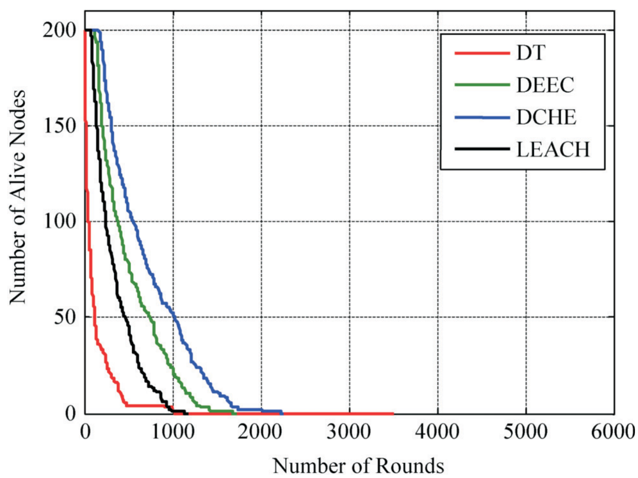

Figure 5. Number of alive nodes for a 200 m × 200 m network when $E_0 = 1$ J, $n = 200$, $D_{pkt} = 6000$ bit and BS is located at (100,400).

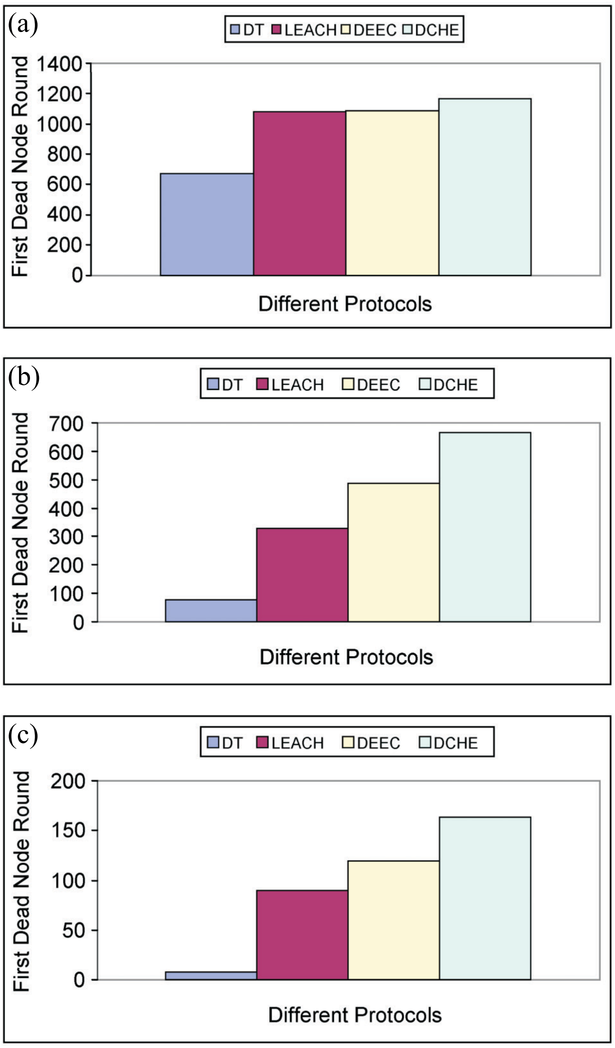

Figure 6. (a) First dead node round for a 50 m × 50 m network when $E_0 = 0.25$ J, $n = 50$, $D_{pkt} = 2000$ bit and *BS* is located at (25,100). (b) First dead node round for a 100 m × 100 m network when $E_0 = 0.5$ J, $n = 100$, $D_{pkt} = 4000$ bit and *BS* is located at (50,200). (c) First dead node round for a 200 m × 200 m network when $E_0 = 1$ J, $n = 200$, $D_{pkt} = 6000$ bit and *BS* is located at (100,400).

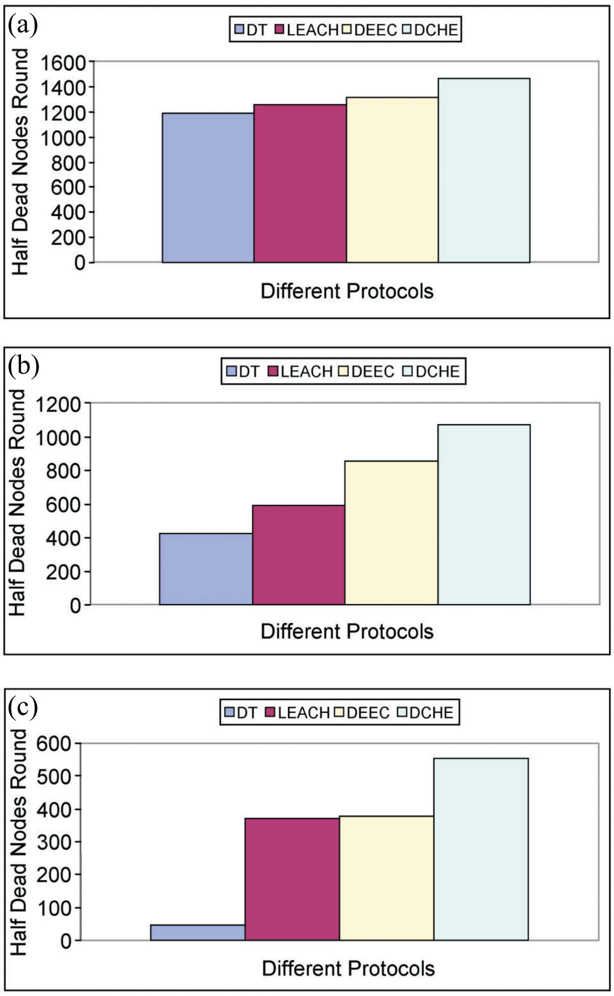

Figure 7. (a) Half dead nodes round for a 50 m × 50 m network when $E_0 = 0.25$ J, $n = 50$, $D_{pkt} = 2000$ bit and *BS* is located at (25,100). (b) Half dead nodes round for a 100 m × 100 m network when $E_0 = 0.5$ J, $n = 100$, $D_{pkt} = 4000$ bit and *BS* is located at (50,200). (c) Half dead nodes round for a 200 m × 200 m network when $E_0 = 1$ J, $n = 200$, $D_{pkt} = 6000$ bit and *BS* is located at (100,400).

geneity in clustered wireless sensor networks. In this work, authors have analyzed a method to elect cluster heads according to the energy left in each node. The drawback of this method is that this decision was made per round and assumed that the total energy left in the network was known. The assumption of global knowledge of the energy left in the whole network makes this method difficult to implement. Even a centralized approach of this method would be very complicated and very slow, as the feedback should be reliably delivered to each sensor in every round.

In [5,8], the authors presented a cost-based comparative study of homogeneous and heterogeneous clustered wireless sensor networks. They proposed a method to estimate the optimal distribution among different types of sensors, but again this result is hard to use if the heterogeneity is due to the operation of the network. They also studied the case of multi hop routing within each cluster (called M-LEACH). Again the drawback of the method is that only powerful nodes can become cluster heads (even though not all powerful nodes are used in each round.) Furthermore, M-LEACH is valid under

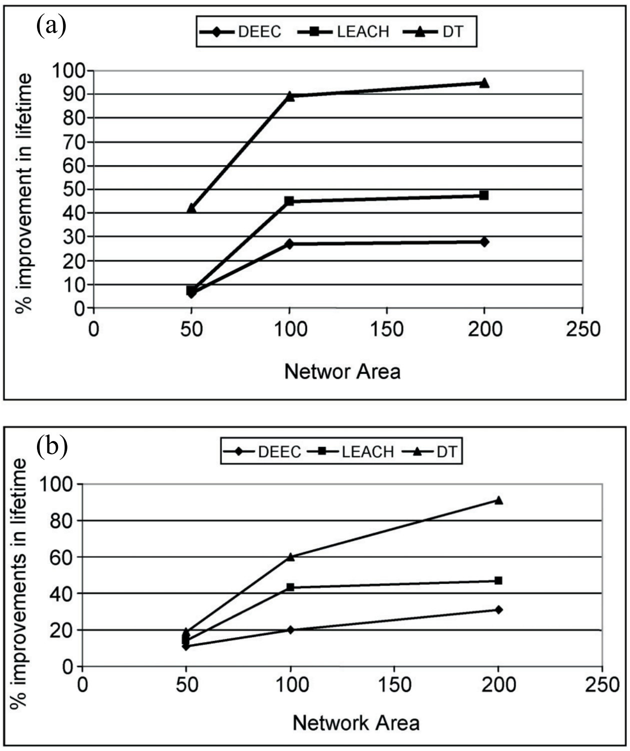

Figure 8. (a) Percentage improvement of lifetime in DCHE over DT, DEEC and LEACH. (b) Percentage improvement of lifetime in DCHE over DT, DEEC and LEACH.

many assumptions and only when the population of the nodes is very large.

In [10], the authors have investigated the existing clustering algorithms. The algorithms have been classified and some representatives are described in each category. After analyzing the strengths and the weaknesses of each category, an important characteristic of WSNs is pointed out for further improvement of energy efficiency for WSNs. The proposed algorithm can be further improved by equalizing the cluster lifetime by taking into account that the directional data traffic burdens the clusters differently.

In [11], the authors consider two types of heterogeneous sensor nodes in a wireless sensor network. The cluster heads are elected by a probability based on the ratio between the residual energy of each node and the average energy of the overall network. Thus the authors proposed a distributed energy efficient clustering (DEEC) scheme for a heterogeneous sensor network and achieved a longer network lifetime than exiting protocols (such as SEP [13] and LEACH [2]).

In [13], the authors have studied the impact of heterogeneity of sensor nodes, in terms of their energy and proposed a heterogeneous aware protocol to prolong the time interval before the death of the first node, which is crucial for many applications where the feedback from the sensor network must be reliable.

In [14], the authors have considered two types of sensor nodes to examine the performance and energy consumption of wireless sensor networks. They consider nodes that are fewer but more powerful that belong to an overlay. All the other nodes have to report to these overlay nodes, and the overlay nodes aggregate the data and send it to the BS. The drawback of this method is that there is no dynamic election of the cluster heads among the two types of nodes, and as a result nodes that are far away from the powerful nodes will die first. The authors estimate the optimal percentage of powerful nodes in the field, but this result is very difficult to use when heterogeneity is a result of operation of the sensor network and not a choice of optimal setting.

In [15], the authors have described a directed diffusion protocol where query (task) is disseminated into the network using hop-by-hop communication. When the query is traversed, the gradients (interests) are established for the result return path. Finally, the result is routed using the path based on gradients and interests.

The cluster-based routing protocols are investigated in several research studies. For example, the work in [16] shows that a 2-tier architecture is more energy efficient when hierarchical clusters are deployed at specific locations. In [17], the authors described a multi-level hierarchical clustering algorithm, where the parameters for minimum energy consumption are obtained using stochastic geometry.

Recently, in [18], the authors introduced a cluster head election method using fuzzy logic to overcome the defects of LEACH. They investigated that the network lifetime can be prolonged by using fuzzy variables in homogeneous network system.

5. Conclusion

Most recent research in wireless sensor networks considers homogeneous sensor nodes. However, these schemes perform poorly in heterogeneous environments.

The new heterogeneous clustering techniques are designed to improve the network performances. In this paper, we have proposed a new distributed clustering scheme for heterogeneous wireless sensor networks. In DCHE scheme, each sensor node independently elects itself as cluster head based on the node energy and weighted probability. Simulation results show that the DCHE scheme offers a much better performance in terms of lifetime and stability than LEACH, DEEC and Direct Transmission (DT). The energy consumption of the network is decreased in proposed as compared with existing protocol. There is still much space to improve the performance of data transmission. For future work, we will remove the assumption of single hop and design an energy efficient protocol for both inter-cluster and intra-cluster transmission.

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