Efficient Algorithms for maximizing lifetime in Wireless Sensor Networks

Ricky Mohanty, Madhumita Dash,Abhimanyu Jena, Jibanananda Mishra

***Abstract*— Minimizing energy dissipation and maximizing network lifetime are important issues in the design of routing protocols for sensor networks. Many researchers have focused only on developing energy efficient protocols for continuous-driven clustered sensor networks. Clustering is an effective technique that can greatly contribute to overall system scalability, lifetime, and energy efficiency in wireless sensor networks (WSNs). In this paper, we first completely analyzes A homogeneous sensor network consists of identical nodes, while a heterogeneous sensor network consists of two or more types of nodes (organized into hierarchical clusters). We use LEACH as the representative single hop homogeneous network, and a sensor network with two types of nodes in heterogeneous network we propose and evaluate a new distributed energy-efficient clustering scheme for heterogeneous wireless sensor networks, which is called DEEC. In DEEC, 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 epochs of being cluster-heads for nodes are different according to their initial and residual energy. The nodes with high initial and residual energy will have more chances to be the cluster-heads than the nodes with low energy. Finally, the simulation results show that DEEC achieves longer lifetime and more effective messages than current important clustering protocols in heterogeneous environments.**

***Index Terms*— Clustering, Data Aggregation, Heterogeneous environment, Energy Consumption, Lifetime, Wireless Sensor Networks.**

I. INTRODUCTION

RECENT advances in wireless communications have enabled the development of tiny, low cost, low-power, multifunctional sensor nodes in a wireless sensor network [1]. A WSN generally consists of a base station (BS) that can communicate with a number of wireless sensors via a radio link. Data is collected at the wireless sensor node, compressed, and transmitted to the BS directly or, if required, uses other wireless sensor nodes to forward data to the BS [2].

Due to limitation in the size of sensors, they can`t be equipped with large power supplies, thus small batteries are used to provide their energy.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. In WSNs, the sensor nodes are often grouped into individual disjoint sets called a cluster, clustering is used in WSNs, as it provides network scalability, resource sharing and efficient use of constrained resources that gives network topology stability and energy saving attributes. Clustering schemes offer reduced communication overheads and efficient resource allocations thus decreasing the overall energy consumption and reducing the interferences among sensor nodes. The basic idea of clustering routing is to use the information aggregation mechanism in the cluster head to reduce the amount of data transmission, thereby, reduce the energy dissipation in communication and in turn achieve the purpose of saving energy of the sensor nodes.

Data aggregation usually involves the fusion of data from multiple sensors at intermediate nodes and transmission of the aggregated data to the BS. Data aggregation can eliminate redundancy; minimize the number of transmissions and thus save energy [3, 4]. In order to support data aggregation through efficient network organization, nodes can be partitioned into a number of small groups called clusters. Each cluster has a coordinator, referred to as a cluster head, and a number of member nodes. Clustering results in a two-tier hierarchy in which cluster heads (CHs) form the higher tier while member nodes form the lower tier. Creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency [5].

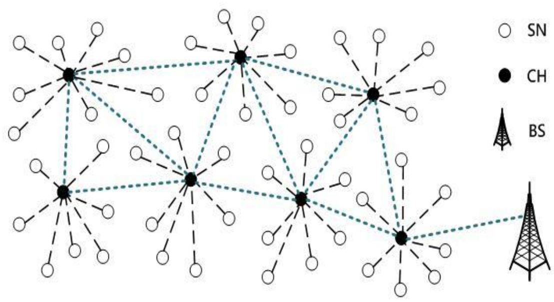

Figure 1. LEACH Protocol

In the clustering routing algorithms for wireless networks, LEACH (low-energy adaptive clustering hierarchy) is considered as the most popular routing protocol that use cluster based routing in order to minimize the energy consumption. LEACH was one of the first major improvements on conventional clustering approaches such as MTE (Minimum-Transmission-Energy) or direct-transmission which do not lead to even energy dissipation throughout a network in wireless sensor networks. In this paper, LEACH Protocol enhances the power consumption, simulation results bring out

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that our protocol outperforms LEACH protocol in terms of network life time.

In this paper, we propose and evaluate a new distributed energy-efficient clustering scheme for heterogeneous wireless sensor networks, which is called DEEC. Following the thoughts of LEACH, DEEC lets each node expend energy uniformly by rotating the cluster-head role among all nodes. In DEEC, 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 network. The round number of the rotating epoch for each node is different according to its initial and residual energy, i.e., 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. Simulations show that DEEC achieves longer network lifetime and more effective messages than other classical clustering algorithms in two-level heterogeneous environments. Moreover, DEEC is also fit for the multilevel heterogeneous networks and performs very well, while SEP only operates under the two-level heterogeneous networks. The protocols should be fit for the characteristic of heterogeneous wireless sensor networks. Currently, most of the clustering algorithms, such as LEACH [10], PEGASIS [11], and HEED [12], all assume the sensor networks are homogeneous networks. These algorithms perform poorly in heterogeneous environments.

The remainder of the paper is organized as follows. In Section 2, we briefly discuss leach protocol in the homogeneous network model. Section 3 describes the heterogeneous network model. Section 4 presents the detail of DEEC algorithm and argues the choice of its parameters. Section 5 shows the performance of DEEC by simulations and compares it with LEACH and SEP. Finally, Section 6 gives concluding remarks.

II. HIERARCHICAL-ROUTING

There are two kinds of clustering schemes. The clustering algorithms applied in homogeneous networks are called homogeneous schemes, and the clustering algorithms applied in heterogeneous networks are referred to as heterogeneous clustering schemes. It is difficult to devise an energy-efficient heterogeneous clustering scheme due to the complicated energy configure and network operation. Thus most of the current clustering algorithms are homogeneous schemes, such as LEACH. Heinzeiman developed a cluster-based routing Scheme called Low-Energy Adaptive Clustering Hierarchy (LEACH), where in each cluster, member, where in each cluster, member nodes adopt a Time Division multiple Access (TDMA) Protocol to transmit their data packets to the cluster head. After receiving data packets from all its local members, a cluster head performs data aggregation and sends the final aggregated packet to the base station under Carrier Sense Multiple Access (CSMA) protocol. To avoid Cluster heads dying quickly, LEACH rotates the roles of cluster heads among all the sensor nodes. In doing so, the energy load is distributed evenly across the network and network lifetime (in unit of data collection round) becomes much longer than the static clustering Mechanism. Compared with minimum transmission energy (MTE) routing scheme where communication distance is the only criterion for selecting low-energy routes, LEACH utilizes a more accurate Energy model and offer much better performance in terms of energy efficiency and network lifetime. The operation of LEACH is done into two steps, the setup phase and the steady state phase. In setup phase the nodes are organized into clusters and CHs are selected. These cluster heads change randomly over time in order to balance the energy of the network. This is done by choosing a random number between 0 and 1. The node is selected as a cluster head for the current round if the random number is less than the threshold value T (n), which is given by

$$T(n) = \begin{cases} \dfrac{p}{1-p\times\left(r \bmod \frac{1}{p}\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

Here G is the set of nodes that are involved in the CH election. LEACH clustering is shown in

Figure (1). In the steady state phase, the actual data is transferred to the BS. To minimize overhead the duration of the steady state phase should be longer than the duration of the setup phase. The CH node, after receiving all the data from its member nodes, performs aggregation before sending it to the BS. After a certain time period, the setup phase is restarted and new CHs is selected. Each cluster communicates using different CDMA codes to reduce interference from nodes belonging to other clusters.

Radio Signal Propagation Model

This paper deals with the first order radio frequency energy consumption model to describe energy feather of the communication channel [8].The first order radio model can be divided into free-space model and multi-path fading model according to the distance between the sending node and receiving node. The protocol assumes that the communication channel is symmetrical, the energy consumption of *l bits* message between two nodes with a distance of *d* can be shown as equations (2) and (3).

$$ETx(l,d) = \begin{cases} Eelec * l + \varepsilon fs * l * d^2 & d \le d_0 \\ Eelec * l + \varepsilon mp * l * d^4 & d > d_0 \end{cases} \quad (2)$$

$$E_{Rx}(l) = Eelec * l \quad (3)$$

Where $E_{Tx}(l, d)$ is the energy consumption in transmitting *l bits* data to a node with a distance of *d* , $E_{Rx}(l)$ is the energy consumption in receiving *l bits* data. E_{elec} equals the per bit energy consumption for transmitter and receiver circuit.ε_{mp} and ε_{fs} are the amplifier parameters of transmission corresponding to the multi-path fading model and the free-space model respectively.

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$$

d_0 is the threshold distance between multi-path fading model and the free-space model,

If $d_0 \le d$, the channel approximates free-space model, the energy dissipation in transmitter amplifier is in direct ratio to d^2 . If $d_0 > d$, the multi-path fading model will be employed and the energy dissipation is in direct ratio to d^4 .

The advantages and disadvantages of LEACH protocol

LEACH protocol has a relatively good function in energy consumption through dynamic clustering, keeps the data transmission in cluster which reduces the energy consumption by communicating directly between nodes and the base station, but there are still a lot of inadequacies. The LEACH protocol uses the mechanism of cluster-head rotation, elects cluster-head randomly, after several rounds of data transmission, the residual energy of the nodes will have a great difference, cluster-head or the nodes which are far from the base station will consume more energy in transmitting data of the same length relatively, if they are selected as cluster-heads after that, they will run out of energy and become invalid. Once the number of invalid nodes increases, it'll have a great influence in the network performance and shorten the life of the network.

Cluster member nodes select the optimal cluster-head based on the received signal intensity to join in, do not consider the distance from the node itself to the base station, either the distance between cluster-head and the base station. So normal node may chose the cluster-head that is far from base station as its optimal cluster-head, this not only is the heavy burden to the cluster-head but also increases the extra energy consumption, which is not beneficial to balance network energy consumption.

III. HETEROGENEOUS NETWORK MODEL

In this section, we describe the network model. Assume that there are N sensor nodes, which are uniformly dispersed within a M×M square region (Fig. 2). 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. Without loss of generality, we assume that the base station is located at the center of the square region. 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 transmit the aggregated data to the base station directly. To avoid the frequent change of the topology, we assume that the nodes are micro mobile or stationary as supposed in [10].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 *mN* advanced nodes equipped with initial energy of $E_0(1 + a)$ and $(1 - m)N$ normal nodes equipped with initial energy of E_0.

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

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

Therefore, the two-level heterogeneous networks have am times more energy and virtually a_m more nodes. We also consider the multi-level heterogeneous networks. 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 amax determine the value of the maximal energy. Initially, the nodes is equipped with initial energy of $E_0(1 + a_i)$, which is a_i times more energy than the lower bound E_0. 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 network.

IV. DEEC PROTOCOL

In this section, we present the detail of our DEEC protocol.DEEC uses the initial and residual energy level of the nodes to select the cluster-heads. To avoid that each node needs to know the global knowledge of the networks, DEEC estimates the ideal value of network life-time, which is use to compute the reference energy that each node should expend during a round. In DEEC, 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 network. The round number of the rotating epoch for each node is different according to its initial and residual energy, i.e., 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. Simulations show that DEEC achieves longer network lifetime and more effective messages than other classical clustering algorithms in two-level heterogeneous environments. Moreover, DEEC is also fit for the multilevel heterogeneous networks and performs well, while SEP only operates under the two-level heterogeneous networks.

A. Cluster-head selection algorithm based on residual energy

Let n_i denote the number of rounds to be a cluster head for the node s_i, and we refer to it as the rotating epoch. In homogenous networks, to guarantee that there are average $p_{opt}N$ cluster-heads every round, LEACH let each node s_i (i = 1, 2. . . N) becomes a cluster-head once every $n_i = 1/p_{opt}$ rounds. Note that all the nodes cannot own the same residual energy when the network evolves. If the rotating epoch n_i is the same for all the nodes as proposed in LEACH, the energy will be not well distributed and the low-energy nodes will die more quickly than the high-energy nodes. In our DEEC protocol, we choose different n_i based on the residual energy $E_i(r)$ of node s_i at round r.Let $p_i = 1/n_i$, which can be also regarded as average probability to be a cluster-head during n_i rounds. When nodes have the same amount of energy at each epoch, choosing the average probability p_i to be p_{opt} can ensure that there are $p_{opt}N$ cluster-heads every round and all nodes die approximately at the same time. If nodes have different amounts of energy, p_i of the nodes with more energy should be larger than p_{opt}. Let $\bar{E}(r)$ denote the average energy at round r of the network, which can be obtained by

$$\bar{E}(r) = \frac{1}{N} \sum_{i=1}^{N} E_i (r).$$

To compute $\bar{E}$ (r) by Eq. (3), each node should have the knowledge of the total energy of all nodes in the network. We will give an estimate of $\bar{E}$(r) in the latter subsection of this section. Using $\bar{E}$(r) to be the reference energy, we have

$$p_i = p_{opt}\left[1 - \frac{\bar{E}(r) - E_i(r)}{\bar{E}(r)}\right] = p_{opt}\frac{E_i(r)}{\bar{E}(r)} \qquad (4)$$

This guarantees that the average total number of cluster-heads per round of cluster-heads per round per epoch is equal to :

$$\sum_{i=1}^{N} p_i \sum_{i=1}^{N} p_{opt} \frac{E_i(r)}{\bar{E}(r)} = p_{opt} \sum_{i=1}^{N} \frac{E_i(r)}{\bar{E}(r)} = Np_{opt} \qquad (5)$$

It is the optimal cluster-head number we want to achieve. We get the probability threshold, that each node s_i use to determine whether itself to become a cluster-head in each round, as follow.

$$T(s_i) = \begin{cases} \frac{p_i}{1-p_i\times\left(r \bmod \frac{1}{p_i}\right)} & if\ s_i \in G \\ 0 & otherwise \end{cases} \quad (6)$$

Where G is the set of nodes that are eligible to be cluster heads at round r. If node s_i has not been a cluster-head during the most recent n_i rounds, we have $s_i \in G$. 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 threshold $T(s_i)$, the node s_i becomes a cluster-head during the current round.

Note the epoch n_i is the inverse of pi. From Eq. (4), n_i is chosen based on the residual energy $E_i(r)$ at round r of node s_i as follow

$$n_i = \frac{1}{p_i} = \frac{\bar{E}(r)}{p_{opt}\,E_i(r)} = n_{opt}\frac{\bar{E}(r)}{E_i(r)} \quad (7)$$

where $n_{opt} = 1/p_{opt}$ denote the reference epoch to be a cluster-head. Eq. (7) shows that the rotating epoch n_i of each node fluctuates around the reference epoch. The nodes with high residual energy take more turns to be the cluster-heads than lower ones.

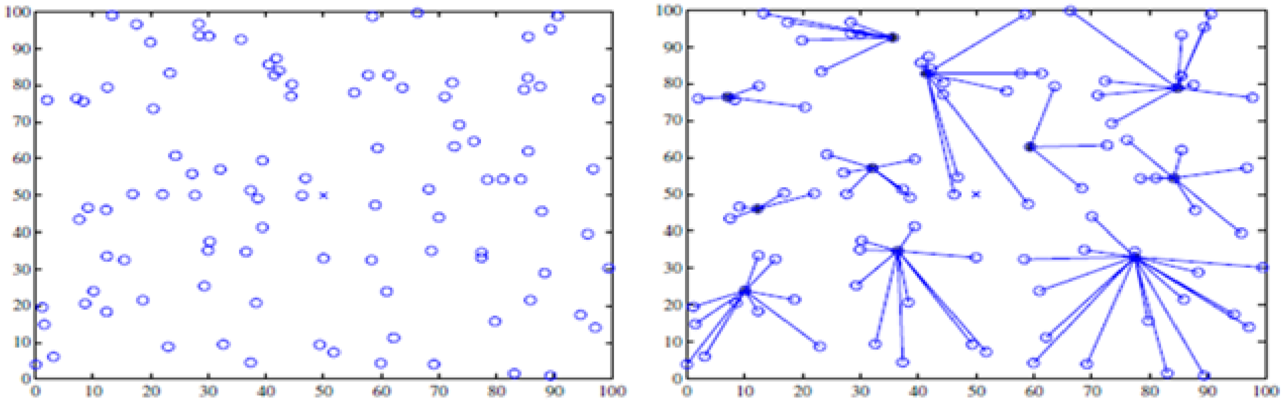

Fig 2 (Left) 100-node random network; (right) dynamic cluster structure by DEEC algorithm.

A. Coping with heterogeneous nodes

From Eq. (4), we can see that p_{opt} is the reference value of the average probability p_i, which determine the rotating epoch n_i and threshold $T(s_i)$ of node s_i. In homogenous networks, all the nodes are equipped with the same initial energy, thus nodes use the same value p_{opt} to be the reference point of pi. When the networks are heterogeneous, the reference value of each node should be different according to the initial energy. In the two-level heterogeneous networks, we replace the reference value p_{opt} with the weighted probabilities given in Eq. (8) for normal and advanced nodes [9].

$$p_{adv} = \frac{p_{opt}}{1+am}, \qquad p_{nrm} = \frac{p_{opt}(1+a)}{(1+am)}. \quad (8)$$

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+am)\bar{E}(r)} & if\ \ si\ \ is\ the\ normal\ node \\ \frac{p_{opt}(1+a)E_i(r)}{(1+am)\bar{E}(r)} & if\ \ si\ is\ the\ advanced\ node \end{cases} \quad (9)$$

Substituting Eq. (9) for p_i on (6), we can get the probability threshold used to elect the cluster-heads. Thus the threshold is correlated with the initial energy and residual energy of each node directly. This model can be easily extended to multi-level heterogeneous networks. We use the weighted probability shown in Eq. (10).

$$p(s_i) = \frac{p_{opt}N(1+a_i)}{(N+\sum_{i=1}^{N} a_i)} \quad (10)$$

$$p_i = \frac{p_{opt}N(1+a)E_i(r)}{(N+\sum_{i=1}^{N} a_i)\bar{E}(r)}. \quad (11)$$

From Eqs. (10) and (11), $I_i = (N + \sum_{i=1}^{N} a_i)/p_{opt}N(1 + a_i)$ expresses the basic rotating epoch of node s_i, and we call it reference epoch. It is different for each node with different initial energy. Note n_i = $1/p_i$, thus the rotating epoch ni of each node fluctuates around its reference epoch Ii based on the residual energy Ei(r). If $E_i(r) > \bar{E}(r)$, we have $n_i < I_i$,and vice versa. This means that the nodes with more energy will have more chances to be the cluster-heads than the nodes with less energy. Thus the energy of network is well distributed in the evolving process.

In Fig. 2, using the parameters described in Table 1, we show the value of analytical lifetime when a and m are changed. Because of the affection of the energy heterogeneity, the nodes can't die exactly at the same time. If let R of Eq. (12) be the estimating value by Eq. (13), the reference energy $\bar{E}(r)$ will be too large in the end, as we can see from Eq. (12). That is to say that the network will not have a single cluster-head and a few nodes will not die finally. The simulation results have

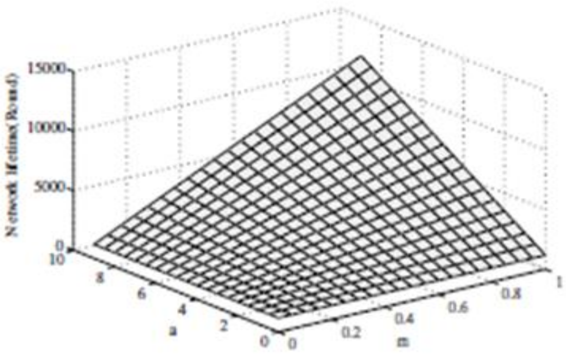

Fig. 3. Estimate of network lifetime

testified our inference (not shown due to room). Thus in the simulations of next section, we will let R be 1.5 times of the estimate value to avoid such situation. This also means that the premise of the energy of the network and nodes being uniformly distributed is not prerequisite in practical operation of DEEC.

The approximation of R is enough to get the reference energy $\bar{E}(r)$, thus DEEC can adapt well to heterogeneous environments. Initially, all the nodes need to know the total energy and lifetime of the network, which can be determined a priori. In our DEEC protocol, the base station could broadcast the total energy E_{total} 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 average probability pi by Eqs. (12) and (11). Node s_i will substitute pi into Eq. (6), 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.

V. SIMULATION RESULTS

In this section, we evaluate the performance of DEEC protocol using MATLAB. We consider a wireless sensor network with N = 100 nodes randomly distributed in a 100m-100m field. Without losing generalization, we assume the base station is in the center of the sensing region. To compare the performance of DEEC 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 1.

The protocols compared with DEEC include LEACH, SEP, and LEACH-E. In multi-level heterogeneous networks, the extended protocols of LEACH and SEP will be used. Of which LEACH is very short and nodes die at a steady rate.This is because LEACH treats all the nodes without discrimination.SEP has longer stability period than LEACH just because of discriminating nodes according to their initial energy. LEACH-E and DEEC take initial energy and residual energy into account at the same time. The results show that LEACH-E and DEEC increase 15% more rounds of stability period than SEP. Interestingly, though the number of nodes alive of DEEC seems same as LEACH-E, the messages delivered by DEEC are more than that of LEACH-E. This means that DEEC is more efficient than LEACH-E.

A. Results under two-level heterogeneous Networks

We first observe the performance of LEACH, SEP, LEACH-E and DEEC under two kinds of two-level heterogeneous networks. Fig. 3 (left) shows the results of the case with m = 0.2 and a = 3, and Fig. 3 (right) shows the results of the case with m = 0.1 and a = 5. It is obvious that the stable time of DEEC is prolonged compared to that of SEP and LEACH-E. SEP performs better than LEACH, but we can see 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.

B. Results under multi-level heterogeneous Networks

For multi-level heterogeneous networks, the initial energy of nodes are randomly distributed in [E0, 4E0]. To prevent the affection of random factors, the network is equipped with the same amount of initial energy. SEP is extended to multi-level heterogeneous environment by choosing weight probability p (s_i) in Eq. (10) for each node. In Fig. 6 (left), detail views of the behavior of LEACH, SEP, LEACH-E, and DEEC are illustrated. We observe that LEACH fails to take full

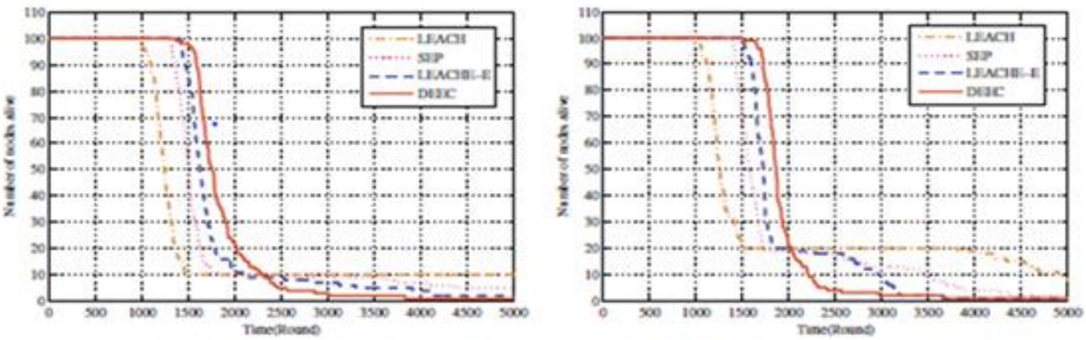

Fig.4. Number of nodes alive over time of LEACH, SEP, LEACH-E, and DEEC under two-level heterogeneous networks. (Left) When *m* = 0.2 and *a*=3. (Right) When *m* = 0.1 and *a* =5.

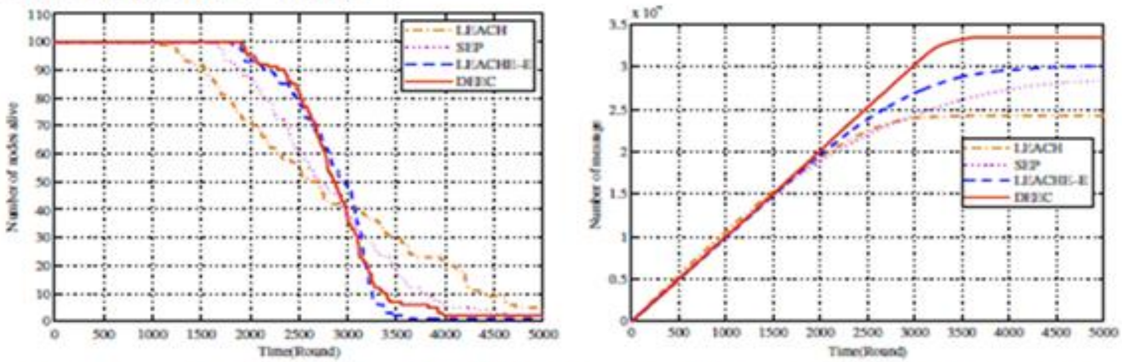

Fig.5. Performance of LEACH, SEP, LEACH-E, and DEEC under multi-level heterogeneous networks. (Left) Number of nodes alive over time (Right).Number of message received in base station over time.

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.SEP has longer stability period than LEACH just because of discriminating nodes according to their initial energy. LEACH-E and DEEC take initial energy and residual energy into account at the same time. The results show that LEACH-E and DEEC increase 15% more rounds of stability period than SEP. Interestingly, though the number of nodes alive of DEEC seems same as LEACH-E, the messages delivered by DEEC are more than that of LEACH-E. This means that DEEC is more efficient than LEACH-E.

VI. CONCLUSIONS

We describe DEEC, an energy-aware adaptive clustering protocol used in heterogeneous wireless sensor networks. In DEEC, 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, DEEC use the average energy of the network as the reference energy. Thus, DEEC does not require any global knowledge of energy at every election round. Unlike SEP and LEACH, DEEC can perform well in multi-level heterogeneous wireless sensor networks

The table (1) shows the comparison of three protocols under various performance metrics.

Table 1.Comparision table for LEACH, SEP and DEEC performance criteria LEACH SEP DEEC

performance criteria	**LEACH**	**SEP**	**DEEC**
Heterogeneity level	Not present	Two	Multilevel
Cluster Stability	Lower than SEP and DEEC	Moderate	High
Energy Efficient	Low as compare to SEP and DEEC	Moderate	High
Cluster head Selection criterion	Based on Initial and Residual Energy	Based on Initial and Residual Energy	Based on Initial , Residual and Average Energy of the network
Network Lifetime	Lower than SEP and DEEC	Moderate	Prolong Network Lifetime than SEP and LEACH

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