Analysis of Energy Efficiency and Network Lifetime of Various Clustering Protocol

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Abstract - *The clustering algorithm is a kind of basic approach used to reduce energy consumption. It can increase the scalability and lifetime of the network. Energy-efficient clustering protocols should be designed for the characteristics of heterogeneous wireless sensor networks. Here we will discuss about various Distributed Energy-Efficient Clustering (DEEC) protocols for heterogeneous sensor networks. In DEEC, the cluster-heads are selected by a probability dependent on the ratio between residual energy of each node and the average energy of the network. The nodes with high initial and residual energy will have more chances to be the cluster-heads than the nodes with low energy. The DDEEC (Developed Distributed Energy-Efficient Clustering) technique is based on changing the cluster head selection probability dynamically and with more efficiency. The EDEEC (Enhanced Distributed Energy-Efficient Clustering) technique works for three types of nodes in prolonging the lifetime and stability of the network, thus increasing the heterogeneity and energy level of the network. Last but not the least the TDEEC (Threshold Distributed Energy-Efficient Clustering) technique in which the threshold value of a node is modified on which the node decides to be a cluster head or not.*

Key Words: **Cluster Head, Base Station, Wireless Sensor Network, Residual Energy, Heterogeneous Environment, Energy-efficient**

1. INTRODUCTION

Technological developments in the field of Micro Electro Mechanical Sensors (MEMS) have enabled the development of tiny, low power, low cost sensors having limited processing, wireless communication and energy resource capabilities. Here, we will study performance of heterogeneous WSN protocols under three and multilevel heterogeneous networks. We compare performance of DEEC, DDEEC, EDEEC and TDEEC for different scenarios of three and multilevel heterogeneous WSNs. Three level heterogeneous networks comprises of normal, advanced and super nodes where the energy of super nodes is higher as compared to that of normal and advanced nodes.

We discriminate each protocol on the basis of prolonging stability period, network life time of nodes alive during rounds for numerous three level heterogeneous networks. It is found that different protocols have different efficiency for three level and multilevel heterogeneous WSNs in terms of stability period, nodes alive and network life time. DEEC and DDEEC operate well under three level heterogeneous WSNs comprising of high energy level difference between normal, advanced and super nodes in terms of stability period. However it lacks in performance as compared to EDEEC and TDEEC in terms of network lifetime. Whereas, EDEEC and TDEEC operate well under multi and three-level heterogeneous WSNs comprising of low energy level difference between normal, advanced and super nodes in terms of both stability period and network lifetime.

2. Overview of Distributed Heterogeneous Protocols

(i.) DEEC

DEEC is designed to deal with nodes of heterogeneous WSNs. For CH selection, DEEC uses initial and residual energy level of nodes. Let n_i denote the number of rounds to be a CH for node s_i. $p_{opt}N$ is the optimum number of CHs in our network during each round. A CH selection criterion in DEEC is based on energy level of nodes. As in homogeneous network, when nodes have same amount of energy during each epoch then choosing $p_i = p_{opt}$ assures that $p_{opt}N$ CHs during each round. In WSNs, nodes with high energy are more probable to become CH than nodes with low energy but the net value of CHs during each round is equal to $p_{opt}N$. $p_i$is the probability for each node s_i to become CH, so, node with high energy has larger value of p_i as compared to the p_{opt}. $\bar{E}(r)$ denotes average energy of network during round r which can be given as:

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

Probability for selecting CH in DEEC is presented as:

$$p_i = p_{opt}\left[1 - \frac{\bar{E}(r) - E_i(r)}{\bar{E}(r)}\right] = p_{opt}\frac{E_i(r)}{\bar{E}(r)} \qquad (2)$$

In DEEC the average total number of CH during each round is given as:

$$\sum_{i=1}^{N} p_i = \sum_{i=1}^{N} p_{opt}\frac{E_i(r)}{\bar{E}(r)} = p_{opt}\sum_{i=1}^{N}\frac{E_i(r)}{\bar{E}(r)} = Np_{opt} \qquad (3)$$

p_i is probability of each node to become CH in a round. Where G is the set of nodes eligible to become CH at round r. If node becomes CH in currently previous rounds then it is included in G. During each round each node chooses a random number between 0 and 1. If number is less than threshold, it is eligible to become a CH else not.

$$T(s_i) = \begin{cases} \frac{p_i}{1-p_i(r \bmod \frac{1}{p_i})} & if\ s_i \in G \\ 0 & otherwise \end{cases} \quad (4)$$

As p_{opt} is reference value of average probability p_i. In homogeneous networks, all nodes have same initial energy so they use p_{opt} to be the reference energy for probability p_i. However in heterogeneous networks, the value of p_{opt} is different according to the initial energy of the node. In two-level heterogeneous network the value of p_{opt} is given as

$$p_{adv} = \frac{p_{opt}}{1+am}, p_{nrm} = \frac{p_{opt}(1+a)}{(1+am)} \quad (5)$$

Then use the above p_{adv} and p_{nrm} instead of p_{opt} in Eq. 2 for two level heterogeneous networks as:

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+am)\bar{E}(r)} & if\ s_i\ is\ the\ normal\ node \\ \frac{p_{opt}(1+a)E_i(r)}{(1+am)\bar{E}(r)} & if\ s_i\ is\ the\ advanced\ node \end{cases} \quad (6)$$

Above version can also be expanded to multi-level heterogeneous network given below as:

$$p_{multi} = \frac{p_{opt}N(1+a_i)}{(N+\sum_{i=1}^{N} a_i)} \quad (7)$$

Above p_{multi} in Eq. 2 instead of p_{opt} to get p_i for heterogeneous node, p_i for the multilevel heterogeneous network is given as:

$$p_i = \frac{p_{opt}N(1+a)E_i(r)}{(N+\sum_{i=1}^{N} a_i)\bar{E}(r)} \quad (8)$$

In DEEC we consider the average energy E(r) of the network for any round r as:

$$\bar{E}(r) = \frac{1}{N} E_{total}(1-\frac{r}{R}) \quad (9)$$

R denotes total rounds of network lifetime and is estimated as follows:

$$R = \frac{E_{total}}{E_{round}} \quad (10)$$

E_{total} is total energy of the network where E_{round} is energy expenditure during each round.

(ii.) DDEEC

DDEEC uses same technique for approximation of average energy in the network and CH selection algorithm that is based on residual energy as incorporated in DEEC. Difference between DDEEC and DEEC is centered in expression that defines probability for normal and advanced nodes to be a CH as given in Eq. 6.

We realize that nodes with more residual energy at round r are more likely to become CH, so, in this way node having higher energy values or advanced nodes will become CH more often as compared to the nodes with lower energy or normal nodes. A point comes in a network where advanced nodes having same residual energy like normal nodes. Even though after this point DEEC continuously penalize the advanced nodes so this is not ideal method for distribution of energy because by using this method,, advanced nodes are continuously a CH and they die more rapidly than normal nodes. To avoid this unbalanced case, DDEEC makes some changes in Eq. 6 to save advanced nodes from being punished over and again. DEEC introduces threshold residual energy as:

$$Th_{REV} = E_0(1 + \frac{aE_{disNN}}{E_{disNN}-E_{disAN}}) \quad (11)$$

When energy level of advanced and normal nodes falls down to the limit of threshold residual energy then both type of nodes use same probability to become cluster head. Therefore, CH selection is balanced and more efficient. Threshold residual energy Th is given as:

$$Th_{REV} \cong (7/10)E_0 \quad (12)$$

Average probability p_i for CH selection used in DEEC is as follows:

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+am)\bar{E}(r)} & for\ Nml\ nodes, & E_i(r) > Th_{REV} \\ \frac{(1+a)p_{opt}E_i(r)}{(1+am)\bar{E}(r)} & for\ Adv\ nodes, & E_i(r) > Th_{REV} \\ c\frac{(1+a)p_{opt}E_i(r)}{(1+am)\bar{E}(r)} & for\ Adv, Nml\ nodes, & E_i(r) \leq Th_{REV} \end{cases} \quad (13)$$

(iii.) EDEEC

EDEEC uses concept of three level heterogeneous networks. It contains three types of nodes normal, advanced and super nodes based on initial energy. p_i is probability used for CH selection and p_{opt} is reference for p_i. EDEEC considers distinct p_{opt} values for normal, advanced and super nodes, so, value of p_i in EDEEC is as follows:

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+m.(a+mo.b))\bar{E}(r)} & \text{if } s_i \text{ is the normal node} \\ \frac{p_{opt}(1+a)E_i(r)}{(1+m.(a+mo.b))\bar{E}(r)} & \text{if } s_i \text{ is the advanced node} \\ \frac{p_{opt}(1+b)E_i(r)}{(1+m.(a+mo.b))\bar{E}(r)} & \text{if } s_i \text{ is the super node} \end{cases} \quad (14)$$

Threshold for CH selection for all three types of node is as follows:

$$T(s_i) = \begin{cases} \frac{p_i}{1-p_i\left(r \bmod \frac{1}{p_i}\right)} & \text{if } p_i \epsilon G' \\ \frac{p_i}{1-p_i\left(r \bmod \frac{1}{p_i}\right)} & \text{if } p_i \epsilon G'' \\ \frac{p_i}{1-p_i\left(r \bmod \frac{1}{p_i}\right)} & \text{if } p_i \epsilon G''' \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

(iv.) TDEEC

TDEEC implements same technique for selecting the CH and average energy estimation as suggested in DEEC. At each round, node decide whether to become a CH or not by choosing a random number between 0 and 1. If number is less than threshold T_s as shown in Eq. 16 then nodes decide to become a CH for the given round. In TDEEC, threshold value is adjusted and based upon that value a node decides whether to become a CH or not by introducing residual energy and average energy of that round with respect to optimum number of CHs. Threshold value proposed by TDEEC is given as follows:

$$T(s) = \begin{cases} \frac{p}{1-p.\left(r \bmod \frac{1}{p}\right)} * \frac{\text{Residual Energy of a node} * k_{opt}}{\text{Average energy of network}} & \text{if } s \in G \\ 0 & \text{otherwise} \end{cases} \quad (16)$$

3. Performance Criteria

Performance specifications that are employed in judgement of clustering protocol for heterogeneous WSNs are lifetime of heterogeneous Wireless Sensor Networks, number of nodes alive during rounds and data packets sent to BS.

Lifetime is a parameter which shows that node of each type has not yet consumed all of its energy.

Number of nodes alive is a parameter that reports number of alive nodes during each round.

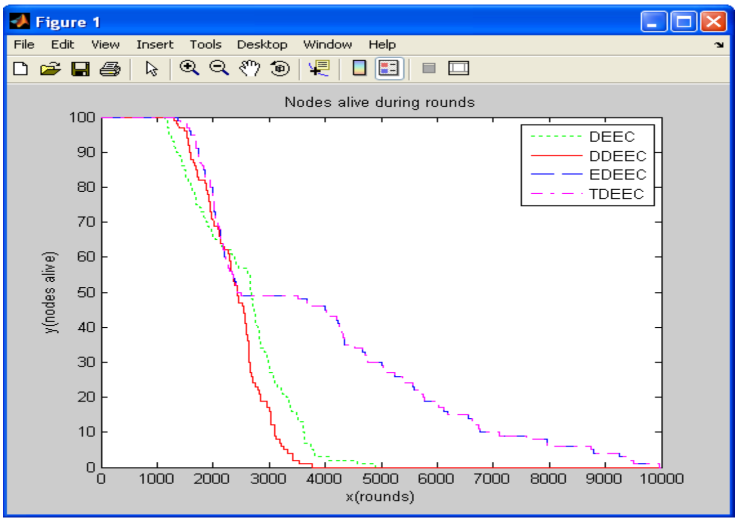
Data packets sent to the BS is the measure that how many packets are received by BS for each round.

These specifications present stability period, instability period, energy consumption, data sent to the BS, and data received by BS and lifetime of Wireless Sensor Networks. Stability period is the period from start of network until the death of first node whereas, instability period is the period from the death of the first node until the last one.

4. Comparison among Different Protocols

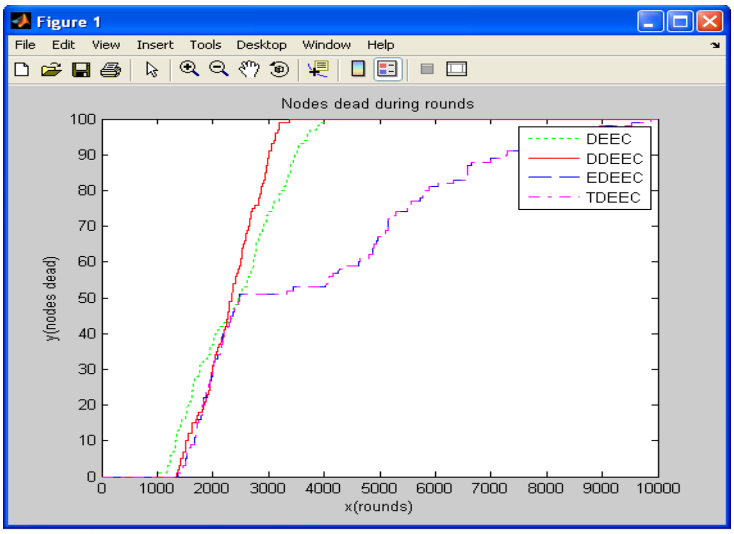
(i.) Number of Alive nodes

In this subsection is shown a comparison of the number of alive nodes in DEEC, DDEEC, EDEEC and TDEEC. The evaluated results are shown below:



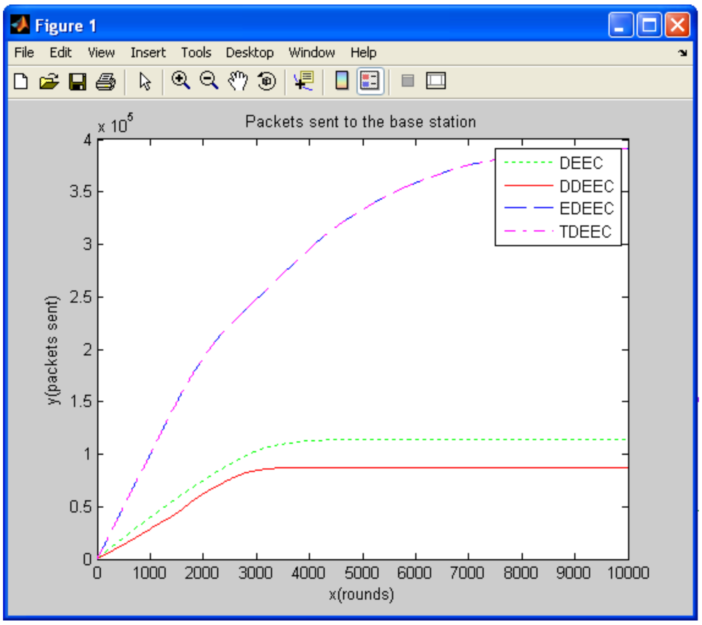
(ii.) Number of Dead Nodes

In this subsection the following figure presents a comparison of the rounds achieved by all the simulated protocols when the all node dies.



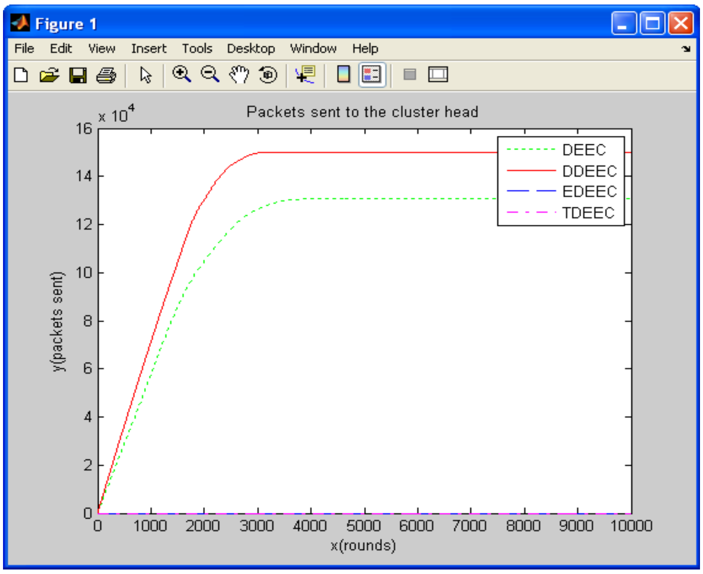
(iii.) Number of Packets Transmitted to Base Station

Besides network lifetime, another metric to judge efficiency of a routing protocol is its throughput. A base station receiving more data packets confirms the efficiency of routing protocol. Throughput depends on network lifetime in a sense but not always. Considering the simulated results as shown in below figure, we deduce that, maximum throughput is achieved by TDEEC.



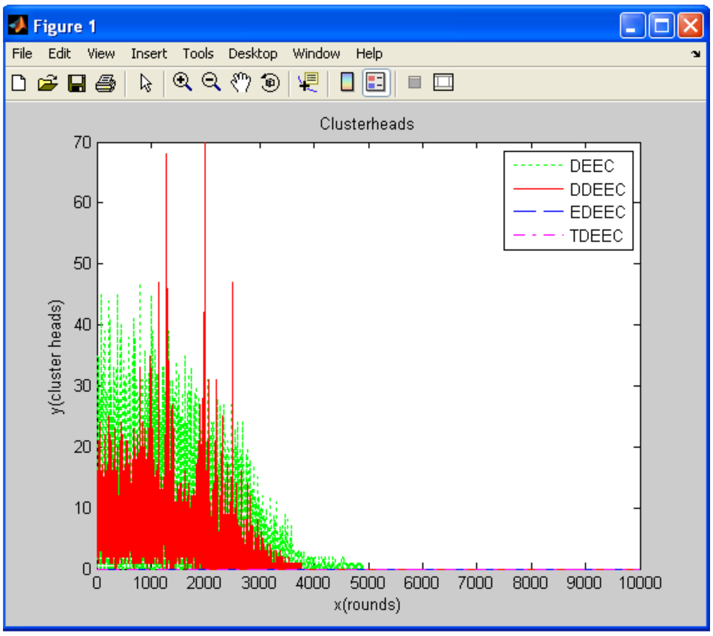
(iv.) Number of Packets Transmitted to Cluster Head

In this subsection the following figure presents a comparison of number of packets transmitted to the cluster heads node through non-cluster head nodes by all the simulated protocols. When non-cluster head nodes transmit data to the cluster head nodes then the transmission is called intra cluster communication.



(v.) Number of Cluster Heads

The following subsection presents a comparison of the total number of cluster heads present in the various protocols.



5.CONCLUSION

DEEC, an energy-aware adaptive clustering protocol is implemented 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 restraint the energy disbursement of nodes by means of adaptive approach, DEEC use the average energy of the network as the reference energy. DEEC does not require any global knowledge of energy at every election round. DDEEC is a Developed Distributed Energy-Efficient clustering for heterogeneous wireless sensor networks. 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 votes for itself as a cluster head based on its initial and residual energy and without any universal 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 refinements implemented expand better the performances of our DDEEC protocol than the others. EDEEC brings the concept of heterogeneity in the network by establishing the super nodes having energy more than normal and advanced nodes and respective probabilities. It extends the lifetime and stability of the network. TDEEC protocol upgrades stability and energy efficient property of the heterogeneous wireless sensor network and results in increase of the lifetime.

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