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TEDDEEC: Threshold enhanced developed distributed energy-efficient clustering for heterogeneous wireless sensor networks

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Abstract: In the developing trend of the Sensor City, wireless sensor networks (WSNs) are widely used in the field of information, from the field of military and national defense to the fields of medical care, industry and agriculture, urban management, environmental monitoring, and smart homes that are closely related to people. WSN comprises a vast number of arbitrarily conveyed energy-required sensor nodes. Sensor nodes can sense and send detected information to the base station (BS). Detecting and, in addition, transmitting information towards BS requires more energy. In WSNs, sparing energy and developing network lifetime are formidable difficulties. Clustering is a key method used to enhance energy utilization in WSNs. Among two types of networks, homogeneous and heterogeneous, the latter has been demonstrated to be significantly more essential in upgrading the network lifetime and making the network a great deal more energy adjusted with fitting probabilistic cluster head choice. In this paper, a novel clustering-based routing protocol called Threshold Enhanced Developed Distributed Energy Efficient Clustering scheme (TEDDEEC) for heterogeneous WSNs is proposed. This method depends on a more efficient selection of cluster heads (CH) for the rounds. Simulation is conducted for different proportions of normal and advanced nodes. Simulation results demonstrate that this proposed scheme accomplishes a longer lifetime, stability period, and more effective messages to BS than the Enhanced Developed Distributed Energy Efficient Clustering scheme (EDDEEC) in heterogeneous situations.

Keywords: Wireless sensor network (WSN), energy, clustering, threshold, normal node advanced node

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1. Introduction

In the development trend of the "Sensor City," wireless sensor networks (WSN) have been widely used in the field of information, from the field of military and national defense to the fields of medical care, industry and agriculture, urban management, environmental monitoring, and smart homes that are closely related to people.

In WSNs, every one of the nodes needs to send detected information to BS, called sink. Typically, nodes in WSNs are energy-restricted because of constrained battery assets. It is additionally unrealistic to energize or change the battery of sensor nodes in operation (Akyildiz et al., 2002). Energy efficiency in WSNs can be achieved by routing protocols. The clustering technique is utilized to minimize energy utilization (Heinzelman et al., 2000; Krishna et al., 1997; McDonald & Znati 2001; Mhatre et al., 2004). In this method, individuals from the cluster choose a CH. All nodes having a place with the same cluster send their information to CH, where CH aggregates the information and sends collected information to BS (Heinzelman et al., 2002).

Clustering is useful in achieving energy efficiency, and it ought to be conceivable in two sorts of frameworks i.e., homogenous, and heterogeneous. WSNs having nodes of the same energy level are called homogeneous WSNs. Low-Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman et al., 2000), Power-Efficient Gathering in Sensor Information networks (PEGASIS) (Lindsey et al., 2002) and Hybrid Energy-Efficient Distributed clustering (HEED) (Younis et al., 2004) are examples of cluster-based schemes which are executed for homogenous WSNs. These energy-efficient schemes perform poorly in heterogeneous WSNs. The nodes that have less energy will deplete their energy speedier than high-energy nodes because these homogenous clustering-based calculations are unfit to approach every node concerning their energy. In heterogeneous WSNs, nodes are positioned with various levels of energy. Stable Election Protocol (SEP) (Smaragdakis et al., 2004), Distributed Energy Efficient Clustering (DEEC) (Qing et al., 2006), Developed DEEC (DDEEC) (Elbhiri et al., 2010), Enhanced DEEC (EDEEC) (Saini & Sharma, 2010) and Enhanced Developed Distributed Energy Efficient Clustering plan (EDDEEC) are categories of heterogeneous WSN energy-efficient routing algorithms. SEP contains common nodes having low energy levels and advanced nodes having high energy levels. DEEC, DDEEC, EDEEC, and TDEEC (Javaid et al., 2013; Saini & Sharma, 2010) are proposed for multilevel heterogeneous frameworks and they can in like manner capacity outstandingly with two-level heterogeneous circumstances. In this paper, an energy-efficient scheme called Threshold Enhanced Developed Distributed Energy-Efficient Clustering (TEDDEEC) is proposed for heterogeneous WSNs.

This paper is organized as follows. The related work is presented in Section 2. The proposed scheme is explained in Section 3. In Section 4 simulation and results are discussed. Finally, the conclusion is given in Section 5.

2. Materials and methods

2.1. Related work

Some related research study energy-efficient schemes. In clustering scheme for homogeneous WSNs called LEACH algorithm, nodes arbitrarily select themselves to be CHs and go on these choice criteria over the whole network to disperse energy load (Heinzelman et al., 2000). An energy-efficient scheme called SEP was prescribed in which each sensor node in a heterogeneous two-level progressive network freely chooses itself as a CH considering its underlying energy near different nodes (Smaragdakis et al., 2004). In DEEC protocol proposed for heterogeneous WSNs, CH determination depends on the likelihood of the proportion of residual energy and average energy of the network (Qing et al., 2006).

The algorithm named DDEEC for heterogeneous WSN is based upon residual energy for CH determination to adjust it over the whole network (Elbhiri et al., 2010). Along these lines, for the main transmission adjusts the advanced nodes will be chosen as CH, and when their energy diminishes, these nodes will have the same CH choice likelihood as the normal nodes. The scheme called EDEEC is extended to three-level heterogeneity by including an additional measure of energy level known as supernodes (Saini & Sharma, 2010). The energy-efficient routing algorithm TDEEC, which chooses the CH from high-energy nodes enhancing energy productivity and the lifetime of the network (Saini & Sharma, 2010). An adaptive energy-efficient method called EDDEEC that progressively changes the likelihood of nodes to be converted into a CH in an adjusted and productive approach to convey level with measure of energy between sensor nodes (Javaid et al., 2013). A novel distributed energy-efficient clustering protocol called DCE for heterogeneous wireless sensor networks was proposed and evaluated based on a double-phase cluster-head election scheme (Han et al., 2017). In DCE, the procedure of cluster head election is divided into two phases. In the first phase, tentative cluster heads are elected with the probabilities which are decided by the relative levels of initial and residual energy. Then, in the second phase, the tentative cluster heads are replaced by their cluster members to form the final set of cluster heads if any member in their cluster has more residual energy. Employing two phases for cluster-head election ensures that the nodes with more energy have a higher chance of being cluster heads. An energy-efficient distributed clustering algorithm was proposed based on fuzzy approach with non-uniform distribution (EEDCF) (Zhang et al., 2017). During CHs' election, nodes' energies, nodes' degree, and neighbor nodes' residual energies are considered as the input parameters. A new Distributed Energy Efficient Clustering protocol with Enhanced Threshold (DEECET) was established by clustering sensor nodes to originate the wireless sensor network (Bhola et al., 2022). The DEECET is very dynamic, highly distributed, self-confessed and much energy efficient as compared to most of the other existing protocols.

To build stability and lifetime of heterogeneous WSNs, numerous schemes were proposed in earlier research work. Nevertheless, heterogeneous networks are of different sorts and involve different parameters. Diverse networks have distinctive heterogeneity levels, and each calculation does not work proficiently for them. Consequently, they neglect to keep up the same stability and lifetime as in earlier heterogeneous WSNs. A few calculations work proficiently in heterogeneous WSNs containing low energy distinction between normal, advanced, and supernodes, and some work effectively in networks containing high energy contrast between normal, advanced, and supernodes. So, every energy-efficient scheme in this paper is interpreted, on the premise of sorts of heterogeneous networks containing diverse heterogeneity levels furthermore different parameters on the premise of stability period, the lifetime of the network, and packets sent to the base station.

2.2. Heterogeneous WSN model

In this section, the N number of nodes placed in a square region of dimension M×M is considered. Given the energy levels, heterogeneous WSNs contain two, three, or multiple sorts of nodes. They are classified as two, three, and multi-level heterogeneous WSNs, respectively.

A. Two-level heterogeneous WSNs model

As the name implies, two-level heterogeneous WSNs contain two distinct energy levels of nodes namely normal and advanced nodes. Where E_o is the energy level of normal nodes and $E_o\ (1+a)$ is the energy level of advanced nodes containing a times more energy when contrasted with normal nodes. If N is the aggregate number of nodes, then Nm is the number of advanced nodes where m refers to the part of advanced nodes and $N(1\text{-}m)$ is the number of normal nodes. The aggregate introductory energy of the network is the total energy of normal and advanced nodes.

$$\begin{aligned} E_t &= N(1-m)E_o + Nm(1+a)\ E_o \\ &= NE_o(1-m+m+a_m) \\ &= NE_o(1+a_m) \end{aligned} \tag{1}$$

The two-level heterogeneous WSNs contain *am* times more energy when contrasted with homogeneous WSNs.

B. Three-level heterogeneous WSN model

Three-level heterogeneous WSNs contain three distinctive energy levels of nodes i.e., normal, advanced, and supernodes. Normal nodes contain the energy of E_o, the advanced nodes of portion m have a times more energy than normal nodes equivalent to $E_o(1+a)$ while super nodes of division m_o have a component of b times more energy than normal nodes, so their energy is equivalent to $E_o(1+b)$. As N is the aggregate number of nodes in the network, then Nmm_o is the total number of super nodes and $Nm(1\text{-}m_o)$ is the total number of advanced nodes. The aggregate introductory energy of three-level heterogeneous WSN is subsequently given by:

$$E_t = N(1-m)E_o + Nm(1-m_o)(1+a)\ E_o + Nm_o\ E_o\ (1+b) \tag{2}$$

$$E_t = NE_o\big(1+m(a+m_ob)\big) \tag{3}$$

The three-level heterogeneous WSNs contain $(a+m_ob)$ times more energy as compared to homogeneous WSNs.

C. Multilevel heterogeneous WSN model

If the nodes comprise numerous energy levels, then it is called a multi-level heterogeneous WSN. The underlying energy of nodes is conveyed over the close-set $[E_o, E_o(1+a_{max})]$, where E_o is the lower bound and a_{max} is the estimation of maximal energy. Initially, node S_i is furnished with starting energy of $E_o(1+a_i)$, which is a_i times more energy than the lower bound E_o. The aggregate initial energy of multi-level heterogeneous networks is given by:

$$E_t = \sum_{i=1}^{N} E_{o\,(1+a_i)} = E_o\Big(N + \sum_{i=1}^{N} a_i\Big). \tag{4}$$

At the point when contrasted with other part nodes CH nodes expend more energy. So, after a few rounds, the energy level of the considerable number of nodes gets to appear as something else when contrasted with each other. Subsequently, heterogeneity is presented in homogeneous WSNs and the networks that contain heterogeneity are more critical than homogeneous networks.

Radio dissipation model

The radio energy model describes that l bit information is transmitted over a distance d as in Heinzelman et al. (2000), Heinzelman et al. (2002), energy depleted is then given by:

$$E_{Tx}(l,d) = \{lE_{elec} + l\mathcal{E}_{fs}d^2\ , d < d_o\ \ lE_{elec} + l\mathcal{E}_{fs}d^4\ , d \geq d_o\ . \tag{5}$$

Where,

E_{elec} is the energy spent per bit of information to operate the transmitter or the receiver circuit. d is the distance between the sender and the receiver. The selection of the free space *(fs)* model and multi-path (*mp*) model is based on the distance between sender and receiver. If the distance is less than the threshold, the free space *(fs)* model is considered. Now, the total energy spent by all the nodes during a round in the network is calculated as (Heinzelman et al., 2000; Heinzelman et al., 2002):

$$E_{round} = L\left(2NE_{elec} + NE_{DA} + k\varepsilon_{mp}d_{toBS}^4 + N\varepsilon_{fs}\, d_{toCH}^2\right) \qquad (6)$$

Where, $\boldsymbol{k}$ = Total number of clusters
$\boldsymbol{E_{DA}}$= Data aggregation cost spent in CH
$\boldsymbol{d_{toBS}}$= Average distance between the CH and BS
$\boldsymbol{d_{toCH}}$= Average distance between the cluster members and the CH.

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

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}\frac{M}{d_{toBS}}} \qquad (8)$$

2.3. Overview of distributed heterogeneous protocols

A. DEEC

DEEC manages nodes of heterogeneous WSNs. DEEC utilizes the starting and residual energy levels of nodes for CH determination. Give n_i a chance to signify the number of rounds to be a CH for node s_i. $p_{opt}N$ is the ideal number of CHs in our network amid each round. CH choice criteria in DEEC depend on the energy level of nodes. As in a homogenous network, when nodes have the same measure of energy amid every time then picking $p_i = p_{opt}$ guarantees that $p_{opt}N$ CHs amid each round. In WSNs, nodes with high energy are more appropriate to end up CH than nodes with low energy however the net estimation of CHs amid each round is equivalent to $p_{opt}N$. p_i is the likelihood for every node s_i to end up CH, in this way, a node with high energy has a bigger estimation of p_i when contrasted with the p_{opt}. *E(r)* signifies the average energy of the network amid round *r* which can be given as in Qing et al. (2006):

$$\underline{E}(r) = \frac{1}{N}\sum_{i=1}^{N} \quad E_i(r). \qquad (9)$$

The probability for CH selection in DEEC can be calculated as in Qing et al. (2006):

$$p_i = p_{opt}\left[1 - \frac{\underline{E}(r) - E_i(r)}{\underline{E}(r)}\right] = p_{opt}\frac{E_i(r)}{\underline{E}(r)}. \qquad (10)$$

During each round, the average total number of CH in DEEC is given as in Qing et al. (2006):

$$\sum_{i=1}^{N} \quad p_i = \sum_{i=1}^{N} \quad p_{opt}\frac{E_i(r)}{\underline{E}(r)} = p_{opt}\sum_{i=1}^{N} \quad \frac{E_i(r)}{\underline{E}(r)} N\, p_{opt} \qquad (11)$$

$\boldsymbol{p_i}$ is the likelihood of every node to be selected as CH in a round. Where G is a set of nodes qualified to be CH at round *r*. The node will be included in *G* if it has been selected as cluster head in recent times. Amid each round, every node picks an arbitrary number somewhere around 0 and 1. The node will be selected as cluster head if the number is less than the threshold value calculated using Equation 12.

$$T(s_i) = \{\frac{p_i}{1 - p_i(rmod)\frac{1}{p_i}} \qquad if\ s_i \in$$
$$G\ 0 \qquad\qquad otherwise\,. \qquad (12)$$

As $\boldsymbol{p_{opt}}$ is reference estimation of normal likelihood $\boldsymbol{p_i}$. In homogeneous networks, all nodes have the same starting energy, so they utilize $\boldsymbol{p_{opt}}$ to be the reference energy for probability $\boldsymbol{p_i}$. However, in heterogeneous networks, the estimation of $\boldsymbol{p_{opt}}$ is diverse as per the underlying energy of the node. In a two-level heterogeneous network, the estimation of $\boldsymbol{p_{opt}}$ is given as in Qing et al. (2006):

$$p_{adv} = \frac{p_{opt}}{1+am}, p_{nrm} = \frac{p_{opt}(1+a)}{(1+am)} \qquad (13)$$

$\boldsymbol{p_{adv}}$ and $\boldsymbol{p_{nrm}}$ are used instead of $\boldsymbol{p_{opt}}$ in Equation 10 for two-level heterogeneous networks as suggested in Qing et al. (2006):

$$p_i = \{\frac{p_{opt}E_i(r)}{(1 + am)\underline{E}(r)} \;\; if\ s_i\ is\ the\ normal\ node$$
$$\frac{p_{opt}(1+a)E_i(r)}{(1+am)\underline{E}(r)} \;\; if\ s_i\ is\ the\ advanced\ node\,. \qquad (14)$$

The same model discussed above can also be extended to a multi-level heterogeneous network as given below Equation 15 as discussed in Qing et al. (2006):

$$p_{multi} = \frac{p_{opt}N(1+a_i)}{(N+\sum_{i=1}^{N} \quad a_i)}\,. \qquad (15)$$

Instead of $\boldsymbol{p_{opt}}, \boldsymbol{p_{multi}}$ will be substituted in Equation 10 to get $\boldsymbol{p_i}$ for heterogeneous node. $\boldsymbol{p_i}$ for the multilevel heterogeneous network is given by the following Equation 16 as proposed in Qing et al. (2006):

$$p_i = \frac{p_{opt}N(1+a)E_i(r)}{(N+\sum_{i=1}^{N} \quad a_i)\underline{E}(r)}\,. \qquad (16)$$

In DEEC the average energy *E(r)* of the network for any round r is estimated as projected in Saini and Sharma (2010) and given in Equation 17.

$$\underline{E}(r) = \frac{1}{N}E_{total}\left(1 - \frac{r}{R}\right). \qquad (17)$$

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

$$R = \frac{E_{total}}{E_{round}} \tag{18}$$

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

B. DDEEC

As proposed in DEEC, DDEEC utilizes the same strategy for estimation of average energy in the network and CH choice calculation depends on leftover energy as in DEEC. The contrast between DDEEC and DEEC is focused on expression. It characterizes the probability for normal and advanced nodes to be a CH (Elbhiri et al., 2010) as given in Equation 14. It is found that nodes with more leftover energy at round *r* are more likely to be selected as CH, along these lines, when contrasted with the nodes with lower energy or normal nodes, the nodes having higher energy values or advanced nodes will get selected to be CH more. A point arrives in a network where advanced nodes have the same leftover energy as normal nodes. Even though, after this point, DEEC keeps on demanding the advanced nodes this is not an ideal route for energy dissemination. Thus, advanced nodes will persistently be a CH and they pass on more rapidly than normal nodes. To keep away from this unequal case, DDEEC rolls out a few improvements in Equation 14 to spare advanced nodes from being demanded continuously. DEEC presents threshold energy as in Elbhiri et al. (2002) and given in Equation 19:

$$Th_{REV} = E_0\left(1 + \frac{aE_{disNN}}{E_{disNN} - E_{disAN}}\right). \tag{19}$$

The normal and advanced nodes use the same probability of being selected as CH when the energy level of advanced and normal nodes is drained down to the limit of threshold residual energy. So, CH determination is adjusted and more proficient. Equation 20 shows the threshold residual energy Th.

$$Th_{REV} \simeq \left(\frac{7}{10}\right)E_0 \tag{20}$$

The calculation of average probability p_i for CH selection used in DDEEC is done as given in Equation 21.

$$\begin{aligned} p_i = \{ & \frac{p_{opt}E_i(r)}{(1+am)\underline{E}(r)} for\ Nml\ nodes, \quad E_i(r) > \\ Th_{REV} & \quad \frac{(1+a)p_{opt}E_i(r)}{(1+am)\underline{E}(r)} for\ Adv\ nodes, \quad E_i(r) > \\ Th_{REV} & \quad c\frac{(1+a)p_{opt}E_i(r)}{(1+am)\underline{E}(r)}\ for\ Adv, Nml\ nodes, \quad E_i(r) \leq \\ Th_{REV} & \end{aligned} \tag{21}$$

C. DEEC

EDEEC utilizes the idea of three-level heterogeneous networks as mentioned previously. Considering initial energy, it contains three sorts of nodes: normal, advanced, and super nodes. p_i is the probability utilized for CH choice and p_{opt} is the reference for pi. EDEEC utilizes distinctive p_{opt} values for normal, advanced, and supernodes, So, the estimation of p_i in EDEEC is calculated as per Equation 22.

$$\begin{aligned} p_i = \{ & \frac{p_{opt}E_i(r)}{(1+m(a+m_o b))\underline{E}(r)}\ if\ s_i\ is\ the\ normal\ node \\ & \frac{p_{opt}(1+a)E_i(r)}{(1+m(a+m_o b))\underline{E}(r)}\ if\ s_i\ is\ the\ advanced\ node \\ & \frac{p_{opt}(1+b)E_i(r)}{(1+m(a+m_o b))\underline{E}(r)}\ if\ s_i\ is\ the\ super\ node \end{aligned} \tag{22}$$

The Threshold for CH selection for normal, advanced, and super nodes is calculated as shown Equation 23.

$$\begin{aligned} T = (s_i)\ \{ & \frac{p_i}{1 - p_i\left(rmod\frac{1}{p_i}\right)}\ if p_i \epsilon G' \\ & \frac{p_i}{1 - p_i\left(rmod\frac{1}{p_i}\right)}\ if p_i \epsilon G'' \\ & \frac{p_i}{1 - p_i\left(rmod\frac{1}{p_i}\right)}\ if p_i \epsilon G'''\ \ 0\ \ otherwise \end{aligned} \tag{23}$$

D. TDEEC

For the determination of CH and average energy estimation, TDEEC utilizes the same component as a part of DEEC. At each round by picking an irregular number somewhere around 0 and 1, nodes choose whether to become CH or not. On the off chance that number is not as much as limit *T(s)* as appeared in Equation 24 then nodes choose to become CH for the given round. In TDEEC, based upon the balanced threshold energy, a node chooses whether to become a CH or not by presenting residual energy and the average energy of that round for an ideal number of CHs (Saini & Sharma, 2010).

$$T(s) = \{\frac{p}{1 - p\left(rmod\frac{1}{p}\right)} * \frac{residual\ energy\ of\ a\ node * K_{opt}}{average\ energy\ of\ the\ network} \tag{24}$$

E. EDDEEC

The likelihood for three sorts of nodes given by EDEEC is given in Equation 22. In this equation the distinction between DEEC, DDEEC, EDEEC, and EDDEEC is summed up, which characterizes probabilities to become CH for the current round. The configuration of this expression is to appropriate energy utilization over the network productively and build the security period and lifetime of the network. Due to the repeated CH choice, after a few adjustments, some super and advanced nodes have the same residual energy level as normal nodes however EDEEC keeps on punishing advanced and super nodes. The same is the issue with DEEC, it keeps on punishing simply advanced nodes and DDEEC is successful for the two-level heterogeneous network as said already in related work. The changes prescribed in capacity are characterized by EDEEC for ascertaining probabilities of normal, advanced, and super nodes keeping in mind the end goal to stay away from the unequal case in a three-level heterogeneous network and to spare super and advanced nodes from over-punishment. These progressions depend on the absolute remaining energy level $T_{absolute}$, which is worth in which advanced and super nodes have the same energy level as that of normal nodes. The thought indicates that under $T_{absolute}$ all normal, advanced, and super nodes have the same likelihood for CH choice. The proposed probabilities for CH determination in EDDEEC are given in Equation 25.

$$\begin{aligned}
&p_i \\
&= \{\frac{p_{opt}E_i(r)}{(1+m(a+m_o b))\underline{E}(r)}\ if\ s_i\ is\ the\ normal\ node \\
&\quad if\ E_i(r) > T_{absolute} \qquad \frac{p_{opt}(1+a)E_i(r)}{(1+m(a+m_o b))\underline{E}(r)} \\
&\quad if\ s_i\ is\ the\ advanced\ node \\
&\quad if\ E_i(r) \\
&> T_{absolute} \qquad \frac{p_{opt}(1+b)E_i(r)}{(1+m(a+m_o b))\underline{E}(r)}\ if\ s_i\ is\ the\ super\ node \\
&\quad if\ E_i(r) \\
&> T_{absolute}\ \ c\,\frac{p_{opt}(1+b)E_i(r)}{(1+m(a+m_o b))\underline{E}(r)}\ if\ s_i\ is\ the\ normal, \\
&\quad advanced, super\ node \qquad if\ E_i(r) \le T_{absolute}
\end{aligned} \tag{25}$$

The value of absolute residual energy level, $T_{absolute}$ is given as:

$$T_{absolute} = zE_o \tag{26}$$

where, z∈(0,1). On the off chance that z = 0 then we have conventional EDEEC. In all actuality, advanced and super nodes may have the probability to become CH furthermore not turn into a CH in rounds *r*, and the same in the event of normal nodes. So, the precise estimation of z is not certain. Nevertheless, through various simulations utilizing random topologies, considering the first dead node in the network the nearest estimation of z is estimated by changing it for the best result and finding the best result for z =0.7. So, the value for, $T_{absolute}$ is calculated as $0.7E_0$.

2.4. Proposed work

For the determination of CH and normal energy estimation, TEDDEEC utilizes the same network as a part of EDDEEC. At each round by picking an irregular number somewhere around 0 and 1, nodes choose whether to become a CH or not. If the number is not as much as threshold *T(s)* as appeared in the Equation 27 then nodes choose to become a CH for the given round. In TEDDEEC, based upon the balanced threshold energy, a node chooses whether to become a CH or not by presenting residual energy and average energy of that round regarding the optimum number of CHs. The threshold energy value is calculated as:

$$T(s) = \{\frac{p}{1-p\left(rmod\frac{1}{p}\right)} * \frac{E_i\,(r) * K_{opt}}{\underline{E_r}}\,. \tag{27}$$

3. Simulation and results

In this section, simulation results for EDDEEC and TEDDEEC for three-level and multi-level heterogeneous WSNs are presented utilizing MATLAB. WSNs comprise of N = 100 nodes which are randomly put in a field of measurement 100m × 100m. For effortlessness, all nodes are considered either fixed or micro mobile and disregard energy loss because of collision and interference between signals of various nodes that are because of element irregular channel conditions. In this situation, BS is set at the center point of the network field. The performance metrics used for the evaluation of clustering protocols for heterogeneous WSNs are stability period, lifetime of the heterogeneous WSNs, and data packets that are successfully sent to BS. In heterogeneous WSNs, the radio parameters utilized are given in Table 1 for various protocols deployed in WSNs and assessed performance for the instance of three-level and multi-level heterogeneous WSNs.

Table 1. Simulation parameters.

Parameter	Values
Network field	100 m,100 m
Number of nodes	100
E_0(initial energy of normal nodes)	0.5J
Message size	4000 bits
E_{elec}	50nJ/bit
E_{fs}	10nJ/bit/m^2
E_{amp}	0.0013pJ/bit/m^4
EDA	5nJ/bit/signal
do (Threshold distance)	87.7m
P_{opt}	0.1
M	0.9 to 0.1
m_o	0.1 to 0.9
a	1.5
b	2.0

Figure 1a -1e shows the simulation results obtained for the values m=0.9 and m_0=0.1.

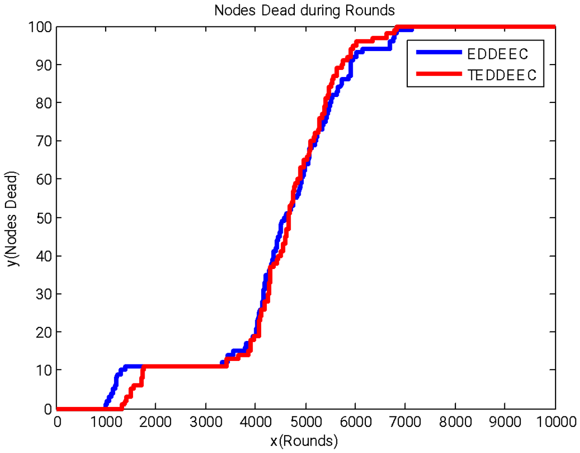

Figure 1a. Number of nodes dead over time.

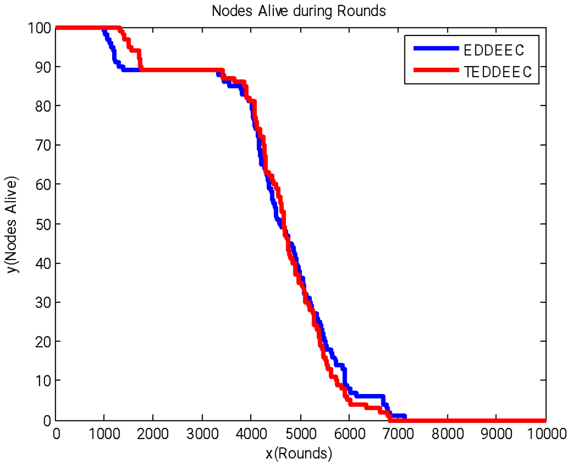

Figure 1b. Number of nodes alive over time.

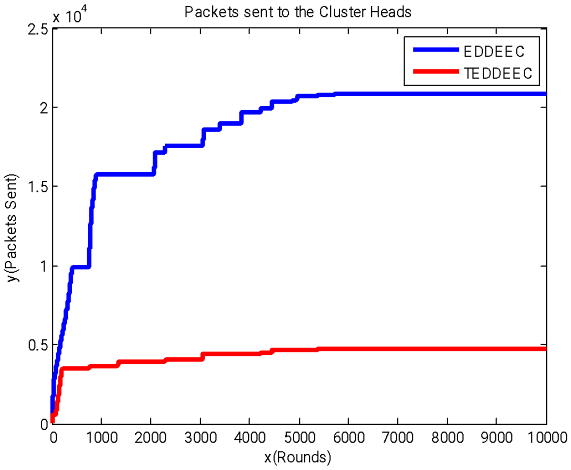

Figure 1c. Number of packets sent to cluster heads.

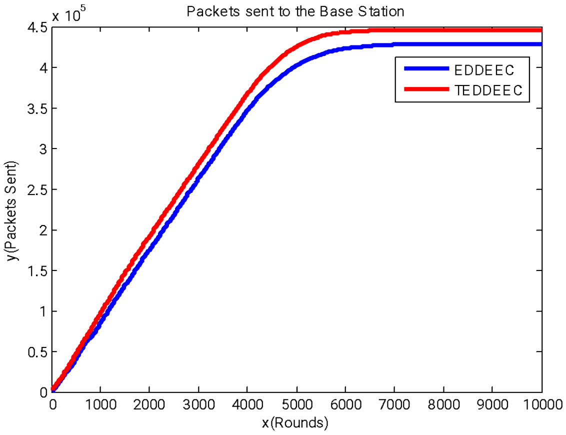

Figure 1d. Number of packets sent to base station.

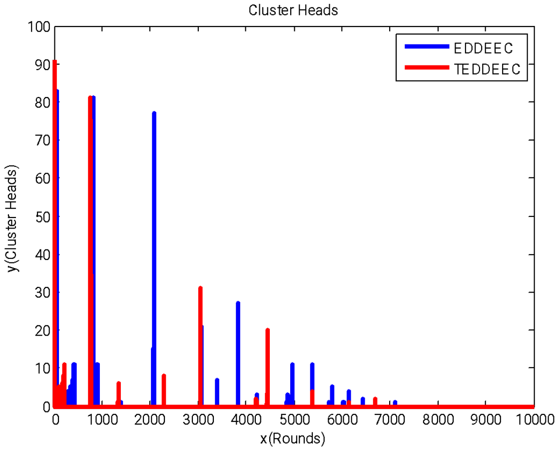

Figure 1e. Number of cluster heads during rounds.

Figure 2a - 2e shows the simulation results obtained for the values m=0.8 and m_0=0.2.

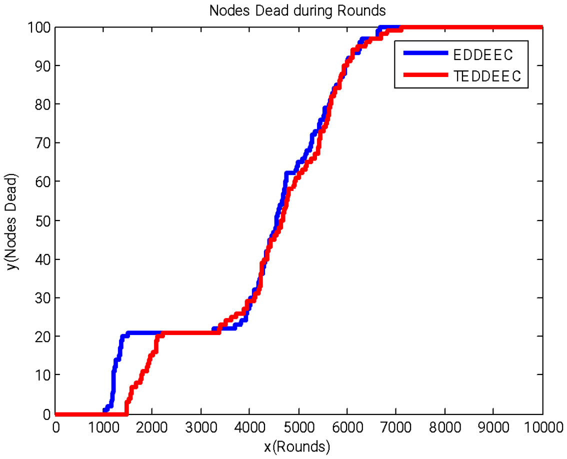

Figure 2a. Number of nodes dead over time.

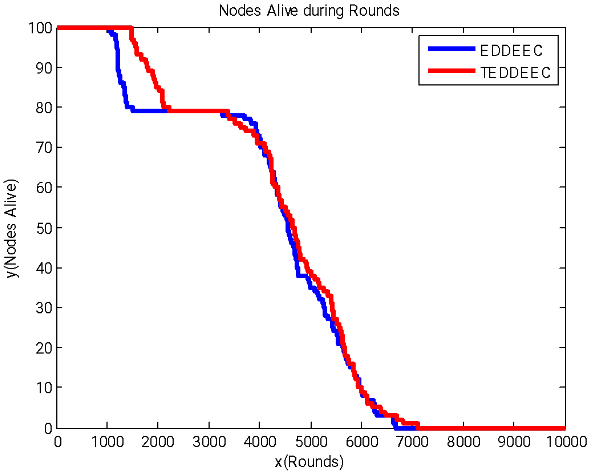

Figure 2b. Number of nodes alive over time.

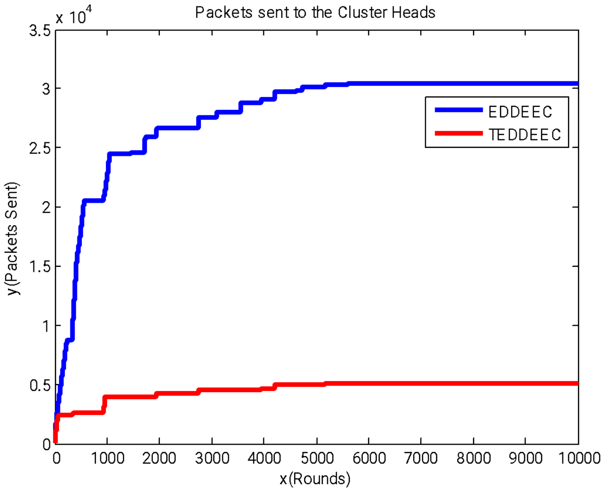

Figure 2c. Number of packets sent to cluster heads.

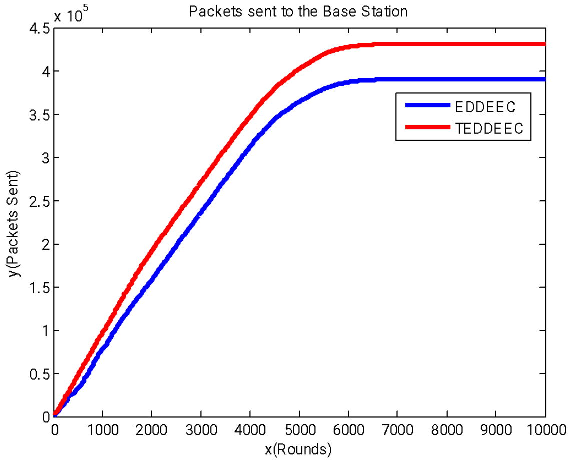

Figure 2d. Number of packets sent to base station.

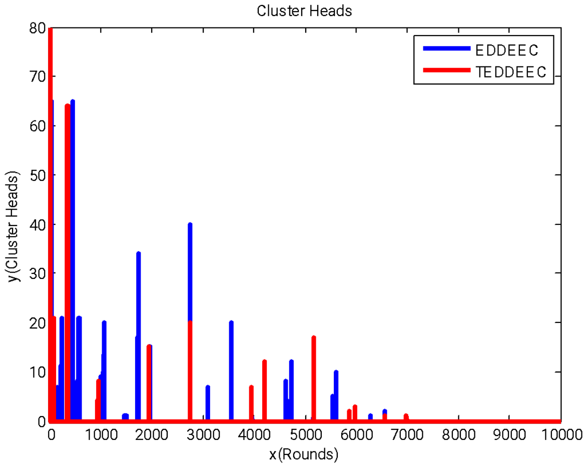

Figure 2e. Number of cluster heads during rounds.

Figure 3a - 3e shows the simulation results obtained for the values m=0.7 and m_0=0.3.

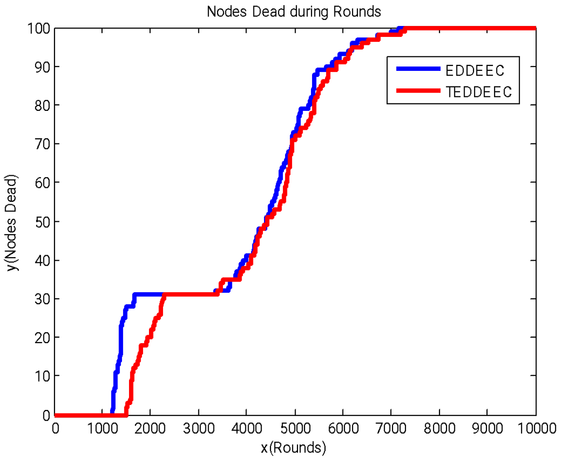

Figure 3a. Number of nodes dead over time.

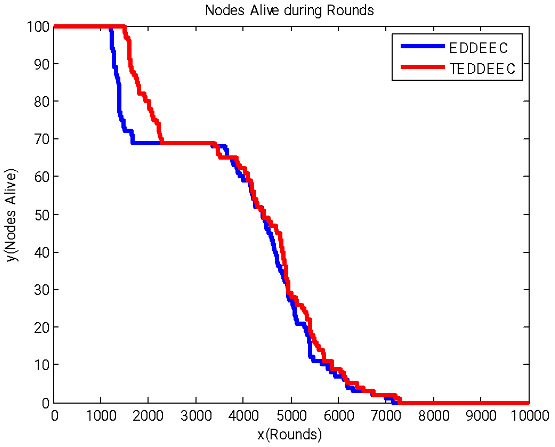

Figure 3b. Number of nodes alive over time.

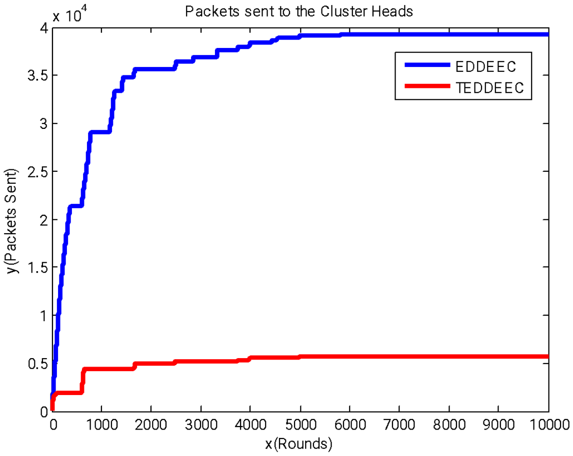

Figure 3c. Number of packets sent to cluster heads.

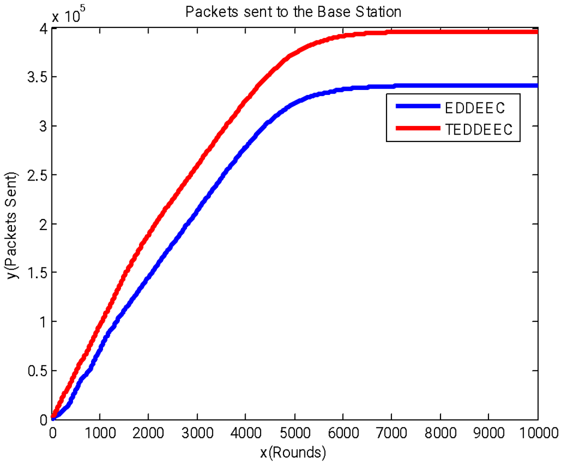

Figure 3d. Number of packets sent to base station.

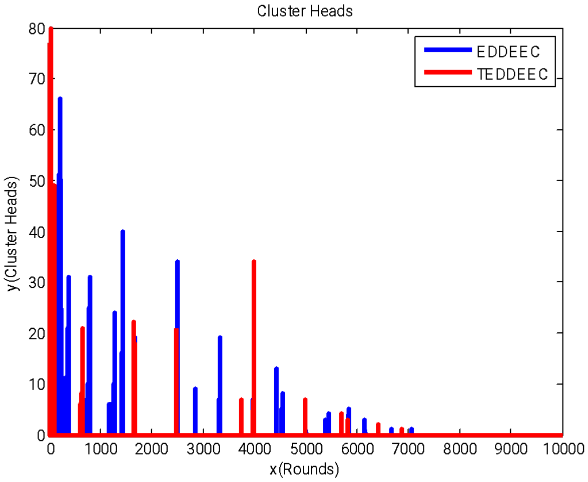

Figure 3e. Number of cluster heads during rounds.

Figure 4a - 4e shows the simulation results obtained for the values m=0.6 and m_0=0.4.

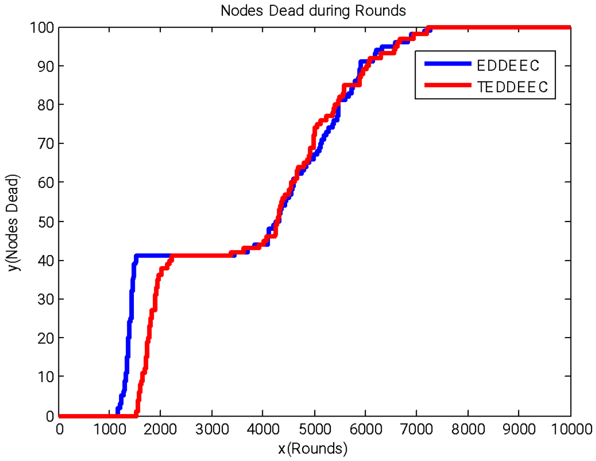

Figure 4a. Number of nodes dead over time.

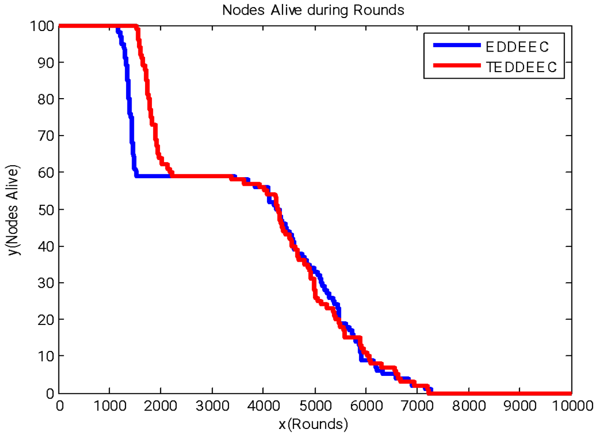

Figure 4b. Number of nodes alive over time.

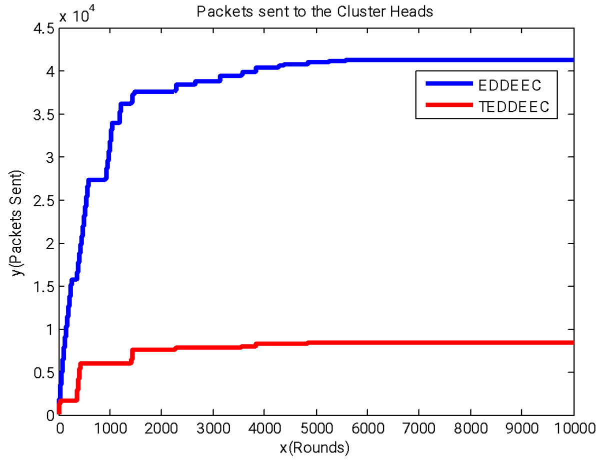

Figure 4c. Number of packets sent to cluster heads.

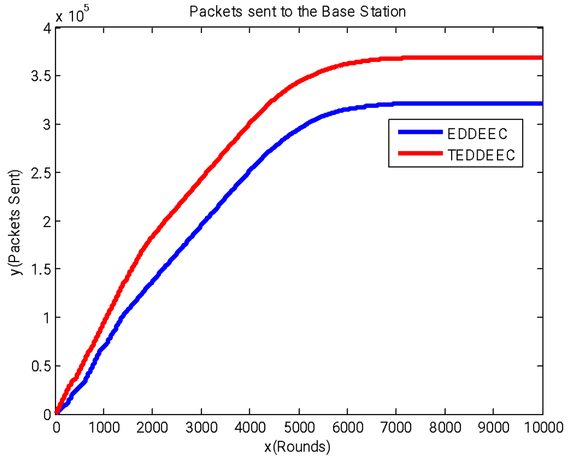

Figure 4d. Number of packets sent to base station.

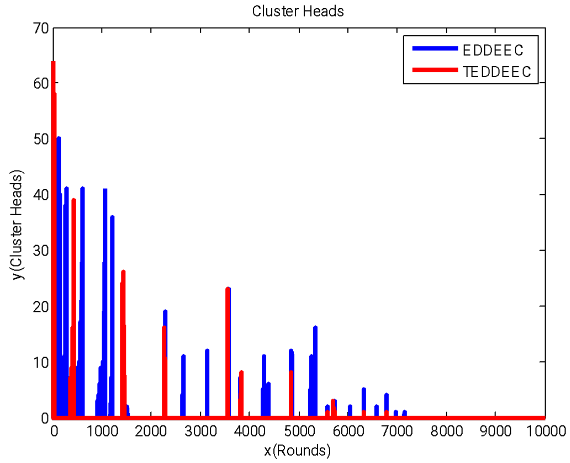

Figure 4e. Number of cluster heads during rounds.

Figure 5a - 5e shows the simulation results obtained for the values m=0.5 and m_0=0.5.

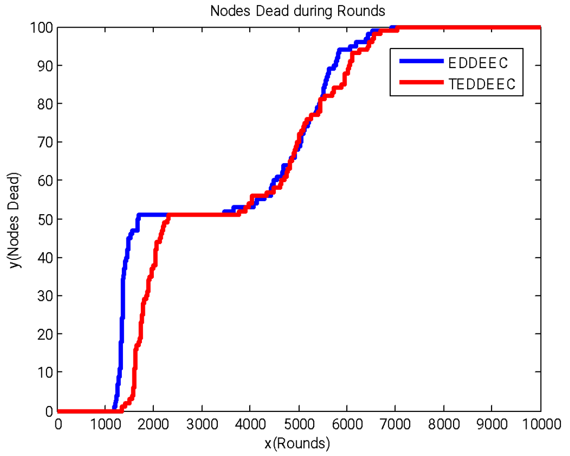

Figure 5a. Number of nodes dead over time.

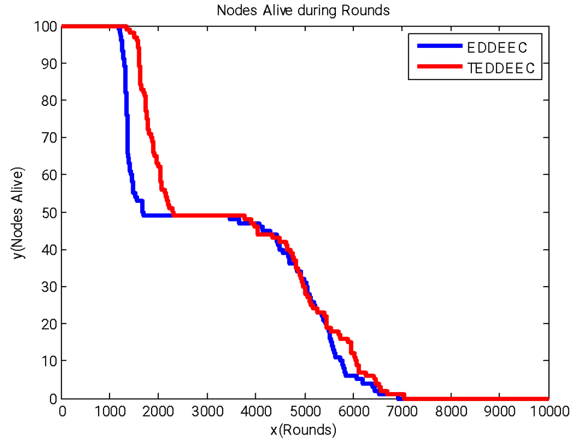

Figure 5b. Number of nodes alive over time.

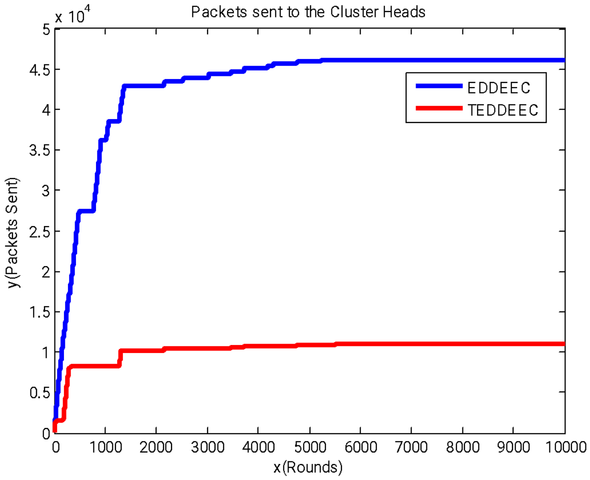

Figure 5c. Number of packets sent to cluster heads.

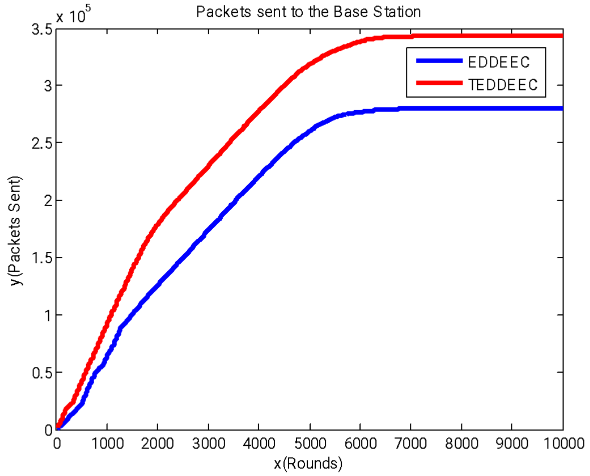

Figure 5d. Number of packets sent to base station.

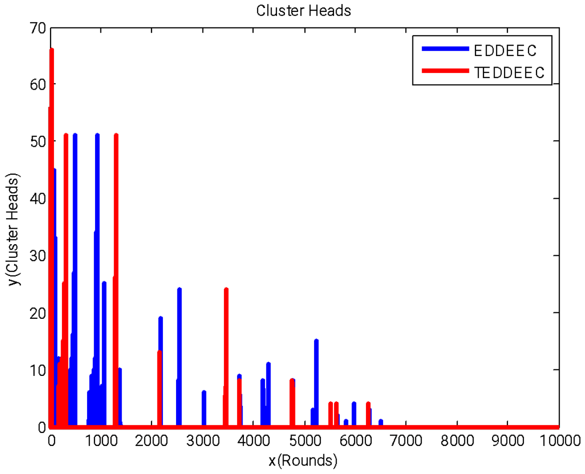

Figure 5e. Number of cluster heads during rounds.

Figure 6a - 6e shows the simulation results obtained for the values m=0.4 and m_0=0.6.

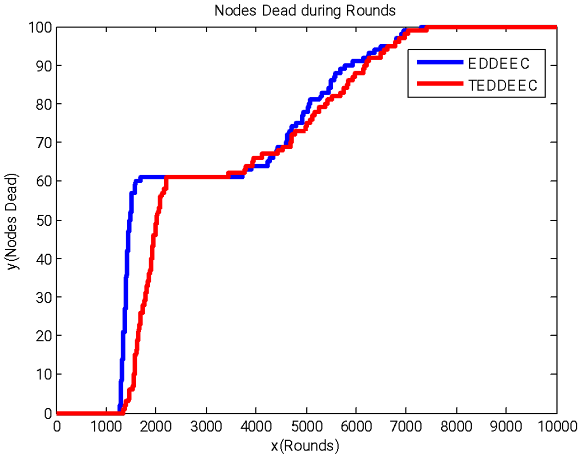

Figure 6a. Number of nodes dead over time.

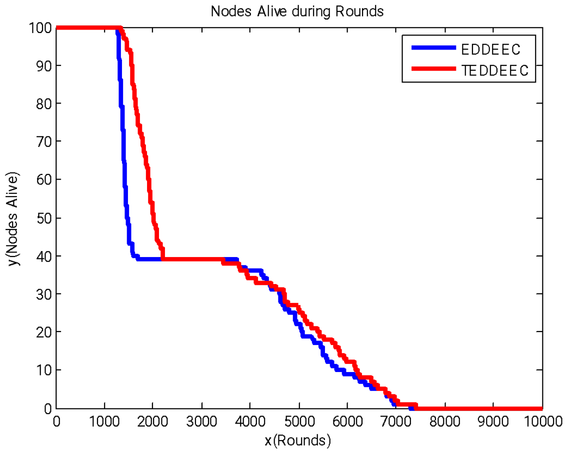

Figure 6b. Number of nodes alive over time.

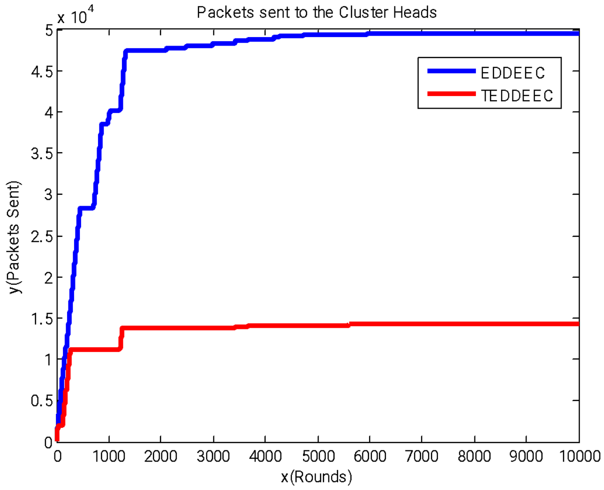

Figure 6c. Number of packets sent to cluster heads.

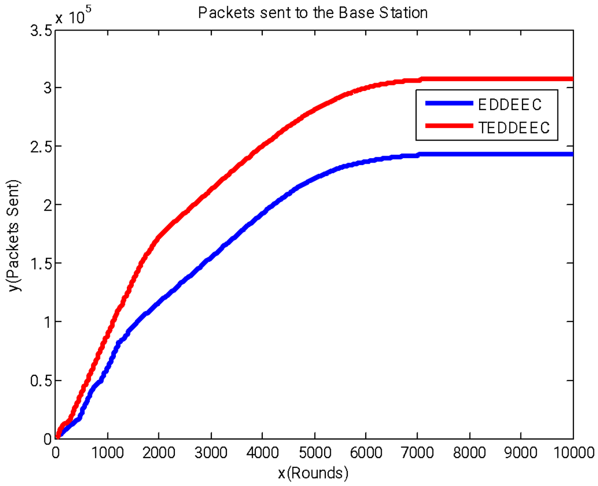

Figure 6d. Number of packets sent to base station.

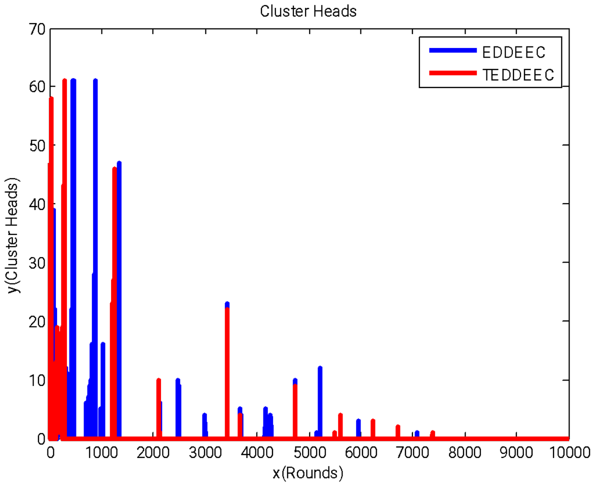

Figure 6e. Number of cluster heads during rounds.

Figure 7a - 7e shows the simulation results obtained for the values m=0.3 and m_0=0.7.

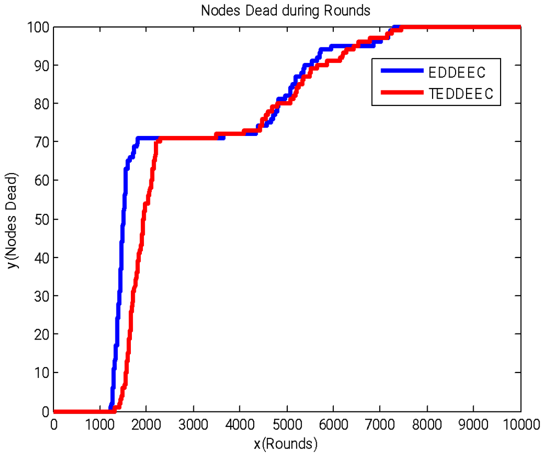

Figure 7a. Number of nodes dead over time.

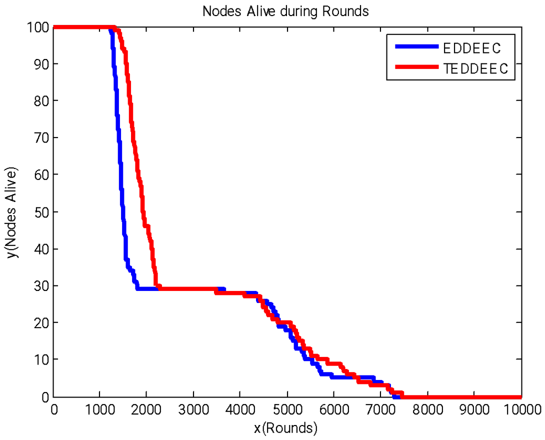

Figure 7b. Number of nodes alive over time.

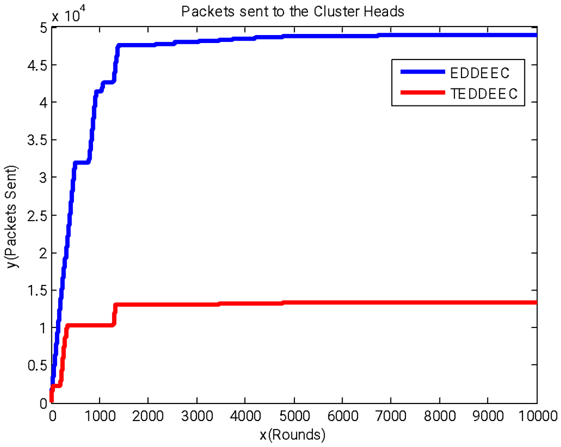

Figure 7c. Number of packets sent to cluster heads.

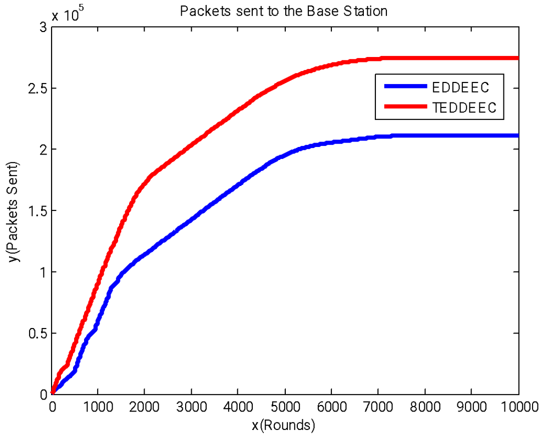

Figure 7d. Number of packets sent to base station.

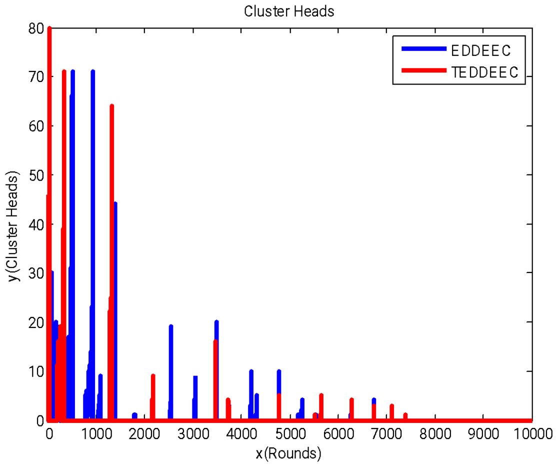

Figure 7e. Number of cluster heads during rounds.

Figure 8a - 8e shows the simulation results obtained for the values m=0.2 and m_0=0.8.

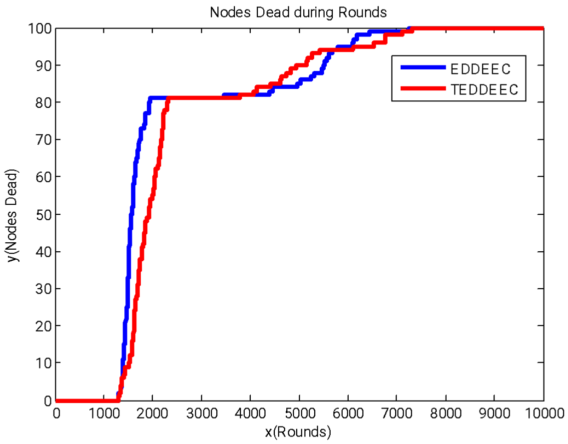

Figure 8a. Number of nodes dead over time.

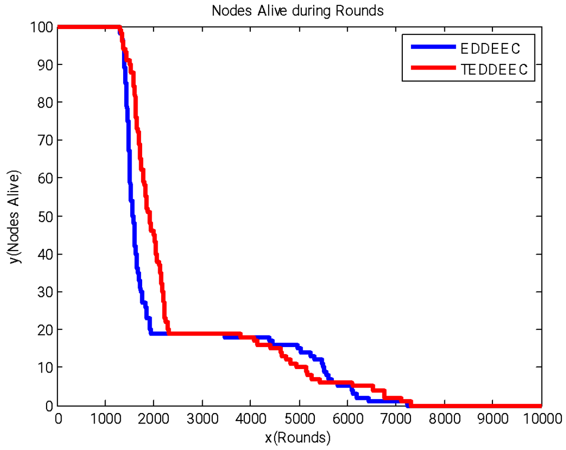

Figure 8b. Number of nodes alive over time.

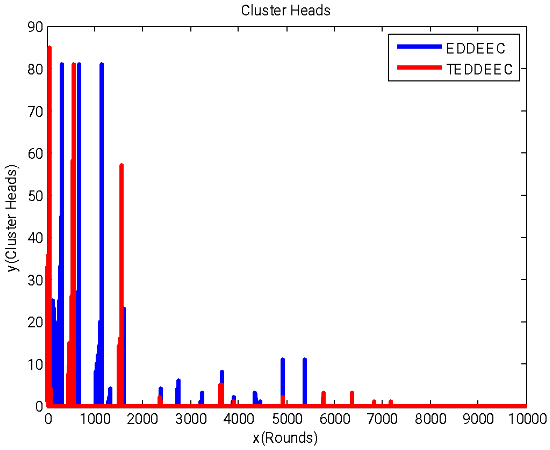

Figure 8e. Number of cluster heads during rounds.

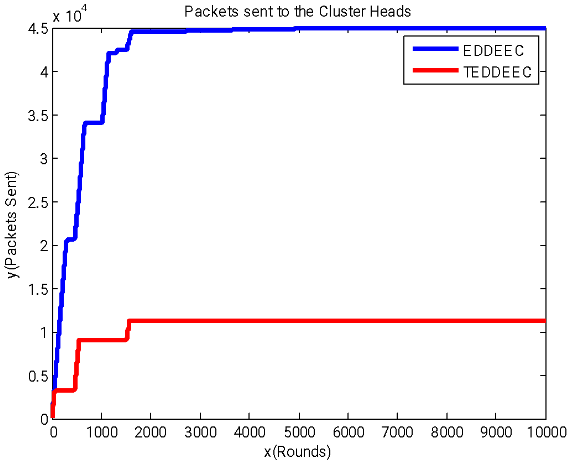

Figure 8c. Number of packets sent to cluster heads.

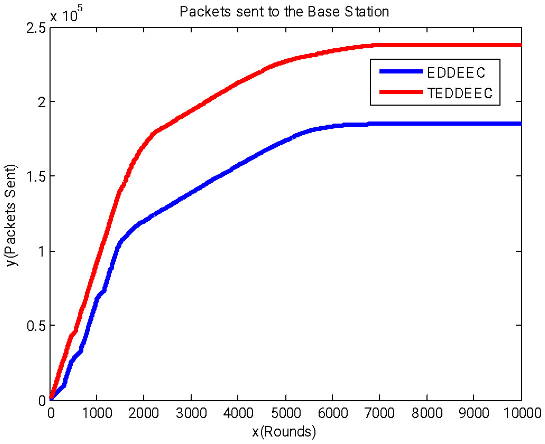

Figure 8d. Number of packets sent to base station.

Figure 9a - 9e shows the simulation results obtained for the values m=0.1 and m_0=0.9.

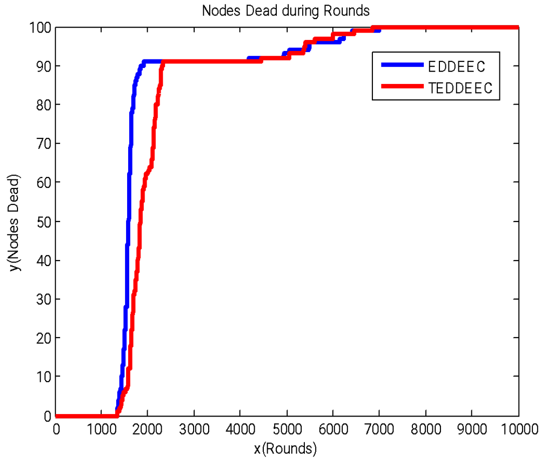

Figure 9a. Number of nodes dead over time.

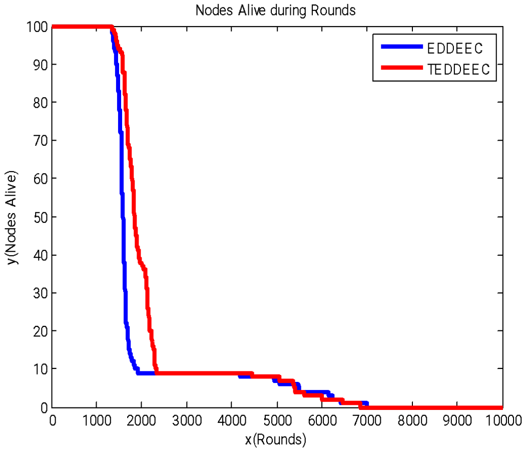

Figure 9b. Number of nodes alive over time.

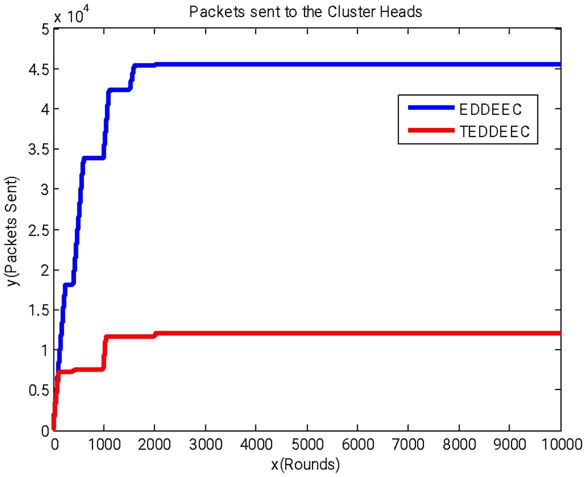

Figure 9c. Number of packets sent to cluster heads.

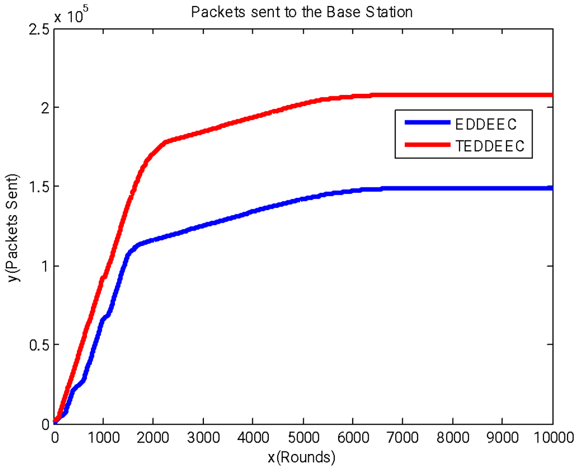

Figure 9d. Number of packets sent to base station.

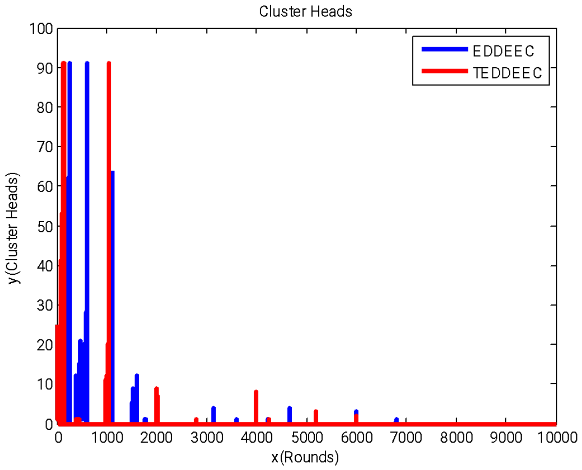

Figure 9e. Number of cluster heads during rounds.

From the above results, it is clearly observed that the proposed scheme TEDDEEC performs better when compared with EDDEEC. For m=0.7 and m_0=0.3 the first node died at 1206 and 1513 rounds respectively for EDDEEC and TEDDEEC schemes. The tenth node died at 1278 and 1616 rounds, respectively. The last node died at 7160 and 7304, respectively. The packets sent to cluster heads are 39214 and 5676, respectively. The packets sent to the base station are 340454 and 396027, respectively. Results show that TEDDEEC is most efficient when compared to EDDEEC in terms of stability period, network lifetime and packets sent to BS even in case of network containing more super and advanced nodes as compared to the normal nodes.

4. Conclusions

In this paper, the TEDDEEC protocol is proposed for WSNs. TEDDEEC is an adaptive energy-aware protocol that dynamically changes the probability of nodes becoming a CH in a balanced and efficient way to distribute an equal amount of energy between sensor nodes. Extensive simulations were performed for various proportions of normal, advanced, and super nodes to check the efficiency of the newly proposed protocol. The selected performance metrics for this analysis are stability period, network lifetime, and packets sent to BS. The simulation analysis showed better results which differentiate TEDDEEC as more efficient and dependable than EDDEEC.

Conflict of interest

The author has no conflict of interest to declare.

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References

Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: a survey. *Computer networks*, *38*(4), 393-422.
https://doi.org/10.1016/S1389-1286(01)00302-4

Elbhiri, B., Saadane, R., & Aboutajdine, D. (2010). Developed Distributed Energy-Efficient Clustering (DDEEC) for heterogeneous wireless sensor networks. In *2010 5th International symposium on I/V communications and mobile network* (pp. 1-4). IEEE.
https://doi.org/10.1109/ISVC.2010.5656252

Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. In *Proceedings of the 33rd annual Hawaii international conference on system sciences* (pp. 10-pp). IEEE.
https://doi.org/10.1109/HICSS.2000.926982

Heinzelman, W. B., Chandrakasan, A. P., & Balakrishnan, H. (2002). An application-specific protocol architecture for wireless microsensor networks. *IEEE Transactions on wireless communications*, *1*(4), 660-670.
https://doi.org/10.1109/TWC.2002.804190

Javaid, N., Qureshi, T. N., Khan, A. H., Iqbal, A., Akhtar, E., & Ishfaq, M. (2013). EDDEEC: Enhanced developed distributed energy-efficient clustering for heterogeneous wireless sensor networks. Procedia computer science, 19, 914-919.
https://doi.org/10.1016/j.procs.2013.06.125

Bhola, J., Shabaz, M., Dhiman, G., Vimal, S., Subbulakshmi, P., & Soni, S. K. (2022). Performance evaluation of multilayer clustering network using distributed energy efficient clustering with enhanced threshold protocol. *Wireless Personal Communications*, *126*(3), 2175-2189.
https://doi.org/10.1007/s11277-021-08780-x

Krishna, P., Vaidya, N. H., Chatterjee, M., & Pradhan, D. K. (1997). A cluster-based approach for routing in dynamic networks. *ACM SIGCOMM computer communication review*, *27*(2), 49-64.
https://doi.org/10.1145/263876.263885

Lindsey, S., & Raghavendra, C. S. (2002). PEGASIS: Power-Efficient Gathering in Sensor Information Networks. *Computer Systems Research Department, the Aerospace Corporation*.
https://doi.org/10.1109/AERO.2002.1035242

McDonald, A. B., & Znati, T. F. (2001). Design and performance of a distributed dynamic clustering algorithm for ad-hoc networks. In *Proceedings. 34th Annual Simulation Symposium* (pp. 27-35). IEEE.
https://doi.org/10.1109/SIMSYM.2001.922111

Mhatre, V., Rosenberg, C., Kofman, D., Mazumdar, R., Shroff, N. (2004). Design of Surveillance Sensor Grids with a Lifetime Constraint. In: Karl, H., Wolisz, A., Willig, A. (eds) Wireless Sensor Networks. EWSN 2004. Lecture Notes in Computer Science, vol 2920. Springer, Berlin, Heidelberg.
https://doi.org/10.1007/978-3-540-24606-0_18

Saini, P., & Sharma, A. K. (2010). E-DEEC-enhanced distributed energy efficient clustering scheme for heterogeneous WSN. In *2010 First international conference on parallel, distributed and grid computing (PDGC 2010)* (pp. 205-210). IEEE.
https://doi.org/10.1109/PDGC.2010.5679898

Saini, P., & Sharma, A. K. (2010). Energy efficient scheme for clustering protocol prolonging the lifetime of heterogeneous wireless sensor networks. *International Journal of computer applications*, *6*(2), 30-36.

Qing, L., Zhu, Q., & Wang, M. (2006). Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. *Computer communications*, *29*(12), 2230-2237.
https://doi.org/10.1016/j.comcom.2006.02.017

Han, R., Yang, W., Wang, Y., & You, K. (2017). DCE: A distributed energy-efficient clustering protocol for wireless sensor network based on double-phase cluster-head election. *Sensors*, *17*(5), 998.
https://doi.org/10.3390/s17050998

Smaragdakis, G., Matta, I., & Bestavros, A. (2004). *SEP: A stable election protocol for clustered heterogeneous wireless sensor networks*. Boston University Computer Science Department.
https://hdl.handle.net/2144/1548

Zhang, Y., Wang, J., Han, D., Wu, H., & Zhou, R. (2017). Fuzzy-logic based distributed energy-efficient clustering algorithm for wireless sensor networks. *Sensors*, *17*(7), 1554.
https://doi.org/10.3390/s17071554

Younis, O., & Fahmy, S. (2004). HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on mobile computing*, *3*(4), 366-379.
https://doi.org/10.1109/TMC.2004.41