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Research Article

Distributed energy efficient clustering (DEEC) protocols for enhancing energy efficiency and sensor lifespan in wireless systems networks (WSNs)

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ABSTRACT

Due to high sensing, computing and communication capabilities, the wireless sensor networks (WSNs) are widelyused in different sectors, although with numerous resource constraints such as energy, processing power, storageand transmission range etc. The present study adopted the hybrid protocol integrating homogeneous and heterogeneous clustering protocols viz. Distributed Energy Efficient Clustering-maximum threshold (DEEC-MT) as compared with the basic DEEC, balanced and centralized DEEC (BC-DEEC) protocols. These three protocols were to enhance the energy efficiency and network lifetime of WSNs at different number of nodes (100 and 200) and packet size (3000 and 4000). The implementation of DEEC-MT protocol (number of nodes=200 and packet size=4000) resulted in increased lifetime of WSN by ~19.8% over the BC-DEEC protocol. However, the corresponding increase was ~37.6% over basic DEEC protocol. At 10000 rounds, the numbers of packets sent to the base station (BS) were 9.8 x 10^5 packets for DEEC-MT, while less than 1.7 x 10^5 packets for BC-DEEC and 2.3 x 10^5 packets for DEEC protocol.The reliability of DEEC-MT protocol was considerably higher by ~24.7 and 13.8% as compared to basic DEEC and BC-DEEC protocols, respectively. The implementation of DEEC-MT protocol decreased the end-to-end delay by ~23.7%, compared with BC-DEEC protocol. These results highlight that newly proposed DEEC-MT protocol was more energy efficient and had prolonged network lifetime.

Keywords:Wireless sensor networks; Energy efficiency; DEEC protocol; Reliability; End-to-end delay

Introduction

The wireless sensor networks (WSNs) comprise small sized sensor nodes capable of transmitting data via data sensing, computation, and the wireless channels (Heinzelman et al., 2000;Vancin and Erdem, 2017). In WSNs, the sensor nodes are connected wirelessly to assemble the information from the sensing field (Thein and Thein, 2010). These sensor nodes deployed to sense the environment in different locations like pressure, temperature, sound, motion (Tilak et al., 2002). The modern WSN applications require that the entire network ought to be competent of in service unattended in ruthless environments (Al-Karaki and Kamal, 2004;Heinzelman et al., 2000), in which human login and organize neither be easily scheduled efficiently managed nor it is even feasible at all (Abbasi and Younis, 2007). These WSNs relate the physical world to the virtual by sensing the nearby surroundings and thereby converting the gathered information into a digital data-set which is then transmitted to the base station (BS) for the auxiliary processing (Lindsey and Raghavendra, 2002;Kumar and Mandoria, 2016; Thein and Thein, 2010). The WSN technology has potential for sensing and monitoring not only science and engineering, but has wide applications in the field of military (Bekmezci and Alagöz, 2009), structure health, industrial, child care, fire detection, flood detection,medical monitoring, food processing, surveillance and movement of animals, traffic control (Manjeshwar and Agarwal, 2002), home security system (Koo and Shon, 2010), health related applications andin many more fields (Manjeshwar and Agarwal, 2002; Heterogeneous et al., 2013).

The clustering of sensor nodes in WSNs has capability of balancing the load among sensor nodes(Figure 1), which help enhancing the network lifespan of sensor nodes (Lindsey and Raghavendra, 2002). The WSNs comprised the assemblage of sensor network where the size of network can vary from a few to thousands (Heinzelman et al., 2000; Kumar and Mandoria, 2016). The contemporary technology growth in the field of WSNs has been related to the sensor design, material used and relatedthoughtsof making the size smaller and compact and sensor arrays with lower cost (Mao et al., 2009; Javaid et al., 2013).

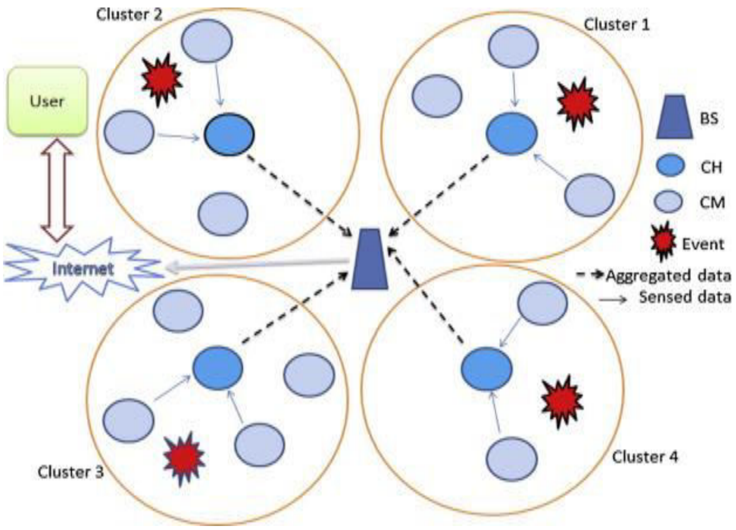


Figure 1. Clustering mechanism in wireless sensor networks (WSNs)

The major challenge for WSNs has been limited battery power at the sensor nodes (Burrell et al., 2014).Nonetheless, equally important has been the implementation of routing protocols around the work areas of the WSNswhich has capabilities of distributing the existing energy homogeneously to the entire WSN (Heinzelman et al., 2000). Over the years, several studies have been conducted to develop a robust intervention by testing different routing protocols to enhance the lifespan of the sensor network (Lindsey and Raghavendra, 2002; Kang et al., 2007; Burrell et al., 2014; Mohammad and Noorian, 2014; Aslam et al., 2016; Krishna et al., 2016). A routing algorithm with low energy adaptive clustering hierarchy (LEACH) has been implemented for homogeneous WSNs in which the sensor nodes are randomly determined as cluster heads (CHs) (Heinzelman et al., 2000).The routing algorithms had substantial space in research and the hierarchal algorithms such as LEACH to decrease energy consumption in WSNs. These routing protocols enhance the network scalability and thereby prolonging network lifetime (Mohammed and Elrahim, 2019). Kang et al., (2007) reported that LEACH protocol has been effective for energy optimization with capabilities ofequally selecting CHs. In LEACH protocol, the stability of the cluster is reduced because the irregular network causes a decrease in aggregate data efficiency (Lee et al., 2015). However, to enhance the stability of CHs, Aslam et al., (2016) proposed the improved LEACH protocol by combining it with hybrid energy efficient distributing clustering (HEED) protocol. These integrated (HEED+LEACH) protocols were implemented for 3-level heterogeneous WSNs known as central energy efficiency clustering (CEEC) with two-hop heterogeneity awareness (THCEEC) and advanced equalization-CEEC protocol (ACEEC) (Aslam et al., 2016). The implementation of CEEC and ACEEC protocols provided more network stability time (Mohammad and Noorian, 2014; Aslam et al., 2016). The DEEC protocol employed selection of CHs based on ratio of the remaining energy of the node and the average energy of the sensor network (Qing et al., 2006).

The integration of support vector in the WSNs has been suggested as efficient technology for gathering data (Mohammad and Noorian, 2014). Krishna et al., (2016) compared and evaluated centralized-LEACH (LEACH-C), LEACH and HEED routing protocols for WSNsto offers classification on behalf of kinds of models. In another study, Smaragdakis et al., (2004)implemented stable election protocol (SEP) in which each sensor node in a two-level heterogeneous WSN independently identifies itself as a CH on the basis of the first energy relative to the other sensor nodes of the WSN. The developed distributed energy efficient clustering (DDEEC)protocol has been reported to be based on the recalibration of the energy for CH (Elbhiri et al., 2010). In DDEEC, the advanced nodes are chosen as CHs in the first broadcast rounds, in which energy is reduced and these sensor nodes had the same probability of CH selection as normal sensor nodes.Saini and Sharma (2010a) proposed enhanced distributed energy efficient clustering (EDEEC) clustering protocol with 3-level heterogeneous structure that leads to enhanced energy level for super sensor nodes. The probability of CHs' selection dependsup on the remaining energy quality of the sensor nodes with the average energy of the WSN in EDDEEC protocol (Javaid et al., 2013). The probability of selection of each node to be elected as a CH has been determined towards to its energy level and to the amount of depleted energy (Saini and Sharma, 2010a, b). Therefore, the nodes with higher probability of being electedhad less delay times and the node with the smallest time delay as compared with its neighbors is chosen as CH (Saini and Sharma, 2010a). Once the clustering is performed, all nodes of each cluster are being sent to the CHsand eventually to the BS depending on residual energyaware multi-hop routing (Bozorgi et al., 2017).

The node with highest energy in a cluster is chosen as CH and the field is re-clustered depending on the selected CHs(Khan et al., 2018). Singh et al., (2017) implemented 3-level heterogeneous DEEC protocols viz. hetDEEC-1, hetDEEC-2, and hetDEEC-3, respectively and reported that DEEC-3 and hetDEEC-3 increased the network lifespan by ~154.2 and ~182. 7%, respectively by increasing the total network energy 100% with respect to the original DEEC. Basically, the DEEC protocol was developed for heterogeneous WSNsthat had 3 types of different initial energy of nodes with weighted different probability for electing CHs (Qing et al., 2006). The advanced version i.e. DDEEC had advantage that it resolves the penalizing effect of DEEC protocol (Elbhiri et al., 2010). However, EDEEC has been the extended version DEEC with normal, advance, and super node classification on the basis of node's energy (Saini and Sharma, 2010a). The TDEECprotocol, on the other side has an improvementover DEEC that it has 3 different energy nodes with modified probability function (Saini and Sharma, 2010b). With considering the aforesaid progress behind the state-of-the-art and the limited information on the use of hybrid approachof implementing Distributed energy efficient clustering with modified threshold (DEEC-MT) protocol in comparison to the existing DEEC and Balanced and Centralized Distributed energy efficient clustering (BCDEEC) protocols for energy efficiency enhancement in WSNs.

Distributed energy efficient clustering (DEEC) protocol

DEEC protocol ishighly distributed,dynamicand had extra energy from the existing protocols e.g. LowEnergy Adaptive Clustering Hierarchy (LEACH), Power Efficient Gathering in Sensor Information Systems (PEGASIS) and Hybrid Energy Efficient Distributed Clustering (HEED) etc.TheDEEC protocolsare very simple and reduce the computational overhead costs to the self-organizedWSNs (Smaragdakis et al., 2004; Li et al., 2006; Javaid et al., 2013). DEEC protocol has proved better performance in energy utilization in both heterogeneous and homogeneous networks. Itelectsthe cluster heads (CHs) on the bases of the residual energy of each sensor node. The un-regularities in the CHs' selections are decreased in DEECprotocol andbase station selects the number of CHsat \`$m$\`number of rounds in the WSN. The elected CHsidentify their role by using Carrier Sense Multiple Access (CSMA MAC)like process of LEACH protocol. However, DEEC protocolsimilar tothat of LEACH protocol had the joinrequest message containsCluster Member identity (CM-ID), Cluster Head identity (CH-ID) and the residual energy of cluster member (CM-RE), and the header treats like arequest. The residualenergy information of the cluster members (CMs) is ascribed to their correspondingCHs,therefore,is localized and could be consumed for CHs rotation in the adequate number of rounds.

In the present study, the DEEC protocol was proposed to cope with energyheterogeneity in WSNs. The DEEC protocol election ofCHswas based on the ratio between the residual energy of each node and the average network energy. The epochsof CHs for nodes were different according to the initial and the residual energies.The nodes with extra initial and remaining energy have more chances of the becoming CH against the nodes with lower energy. To ensure high energy nodes that has more chances of being elected as CH's, and the probability`$P$` to become CH is shown in Eq. 1.

$$P_i = p_{Optimum}\left[1-\frac{E(r)-E_i(r)}{E(r)}\right]= p_{Optimum}\frac{E_i(r)}{E(r)}(1)$$

Where,`$E_i(r)$` is the residual energy of node-1 at round `$r$`, `$p_{optimum}$` is the initial probability of a node to become CH in a homogeneous setup and `$E(r)$` is the estimated average total energy of the network at round `$r$`(Eq. 2-3).

$$E(r) = \frac{1}{n}E_{total}\left(1-\frac{r}{R_T}\right)(2)$$

$$R_T = \left(\frac{E_{total}}{E_{round}}\right)(3)$$

Where,`$R_T$` is the total round of the network lifetime, `$n$` is the number of nodes in the network, `$E_{total}$` and `$E_{round}$` are the total energy at the beginning of the network and the energy consumed in the network in each round, respectively.

The DEECprotocol considers thetwo and multi-level heterogeneous WSNs. The number of normal and advanced nodes in WSNs are `$N_{Normal}$`and `$N_{Advanced}$`, respectively, and the total number of nodes `$N_{total}$` in WSNs are expressed as Eq. 4.

$$N_{Total} = N_{Normal} + N_{Advanced} \qquad (4)$$

The total first energy of the normal nodes(N_{normal}) (Eq. 5) and advanced nodes ($N_{advanced}$) (Eq. 6) in theWSNs were used to estimate the total energy of the 2-level heterogeneous WSNs (Eq. 7).

$$E_{normal} = N_{normal} * E_0 \qquad (5)$$

$$E_{advanced} = N_{advanced} * E_0 a \qquad (6)$$

$$E_{total} = E_{normal} + E_{advanced} \qquad (7)$$

In a multi-level heterogeneous network model, theenergy of each sensor node (E_{total}) is randomly allocated [E_0, E_0*(1+$\alpha_{maximum}$)] ata givenenergy interval (Eq. 8).

$$E_{total} = \sum_{i=1}^{N} E_0 * (1+\alpha_i) = E_0 * (N + \sum_{n=1}^{N} \alpha_i) \qquad (8)$$

Where,`$E_0$` is lower bound of energy interval and `$\alpha_{maximum}$` determines the upper bound of the energy interval. Initially, the `$i^{th}$` node isequipped with initial energy of $E_0 * (1+\alpha_i)$, which had`$\alpha_i$`times higher energy compared to the lower bound `$E_0$` of the energy interval. All nodes had different levels of energy due to randomallocation. But, this2-level heterogeneous network model has a limitation that each node has different energy level, and therefore, the deployed sensor nodes withhigher energy levels may not be practically feasible (Mao et al., 2009). Therefore, an advanced algorithm i.e. effective data gathering algorithm(EDGA) proposed for heterogeneous WSNs (Mao et al., 2009) which considers three levels ofheterogeneity viz. normal,advanced, and super nodes has been the realistic option.The total energy for 3-level heterogeneous WSN model (E_{total}) (Eq. 9) indicates thatthe energy of an advanced node ishigher than a normal node (N_{Normal}) and the energy of a super node (N_{Super}) is higherthan an advanced node ($N_{Advanced}$).

$$E_{total} = N * E_0 * \left(1 + m * (\alpha * (1 - m_0) + m_0 * \beta)\right) \tag{9}$$

Where,`$m$` fraction of `$N$` as advanced nodes and `$m_0$` fraction of theadvanced nodes as super nodes,`$E_0$` is initial energy of a normalnode, `$\alpha$` and `$\beta$` are the energies of the advanced and super nodes are, respectively, which is `$\alpha$` and `$\beta$` times more than that of a normal node. Therefore, theenergies of each super and advanced nodes are `$E_0 * (1 + \beta)$` and`$E_0 * (1 + \alpha)$`, respectively. The weighted election probability of eachnode is used in cluster heads selection so that the heterogeneousenergy capacities are efficiently utilized.

In DEEC protocol, the averageenergy ($E_{average}$) of the network is calculated for round `$r$` using Eq. 10.

$$E_{average} = \frac{1}{N} E_{total} (1 - \frac{r}{R}) \tag{10}$$

Where, `$E_{average}$` is the average energy of the WSN, `$E_{total}$` is the total energy ofthe `$N$` nodes and `$r$` round, `$R$` is thenumber of rounds predicted according to the available energyand energy consumed at the current round `$r$` (Eq. 11).

$$R = \frac{E_{total}}{E_{round}} \tag{11}$$

At the beginning of each round, the decision as to whether ornot the nodes are CH is decided by the threshold value (Eq. 12).

$$T(k_1) = \begin{cases} \dfrac{P_i}{1 - P_{i}\left[\left(r_{mod}\frac{1}{P_i}\right]\right.} & ,if\ S_i \in G \\ 0, & otherwise \end{cases} \tag{12}$$

Where, `$p_i$` is the desired probability and varied between `0` and `1` and represents the `$i^{th}$` fraction remaining in the inverse of the `$p_i$` with `$r$`. The residual is subtracted by 1 and $T(Ki)$ is calculated. In this equation, `$G$`indicates the appropriate set of nodes,S_i is `$i^{th}$`node within the cluster. The possibilities for CH selection in the DEEC model are given in Eq. 13. Where,`$E_i(r)$` is the energy of the node, `$P_{optimum}$` is used constant probability for CH.

$$P_i = \begin{cases} \dfrac{E_i(r)P_{optimum}}{(1+\alpha)E_{average}}, if\ normal\ node \\ \dfrac{E_i(r)P_{optimum}\alpha}{(1+\alpha)E_{average}}, if\ advanced\ node \end{cases} \quad (13)$$

Balanced and Centralized Distributed energy efficient clustering (BCDEEC)protocol

BCDEEC is a self-constructed, adaptive clustering protocol that uses randomization to circulate the energy load among the sensors of the WSNs. Therefore, BCDEEC involves randomized spinning of the moreenergy CHs' position in a way that it spins among the multiple sensors to not deplete the energy of single sensor.The sensor nodes select themselves to be gateway for each round with probability (*p*) function and sends informationon its present location and level of energy to the base station. The base stationapproves that whether those nodes suit to be work as a gateway. By using advertisement message gateway, network nodes transmit their status to the sensors in the network. The nodes which are not working as a gateway select themselves to be CHs with `*p*` function and transfer information for its present location and level of energyto the base station. These CHs transmit their status to the sensors in the network by sending advertisement message. The nodes which are not working as CHs, they are waiting announcement fromCH and each sensor node determines that which cluster it needs to belong by selecting the CHs that need the less communication energy and send thejoin-request message to the selected CH, and the CH nodes wait for join-request message from rest of nodes.

When all nodes are arranged into clusters, each and everyCH designs a schedule for the cluster nodes. It allows all radio components of every node that are not working as CHs to be switched off apart from its transmitting time. When CHs complete data from the cluster nodes, the CH node aggregates based on Eq. 14-15.

To the gateway if:

$$E_{CH_{to_{base\ station}}} > E_{CH_{to_{Gateway}}} + E_{Gateway_{to_{base\ station}}} (14)$$

To the base station if:

$$E_{CH_{to_{base\ station}}} < E_{CH_{to_{Gateway}}} + E_{Gateway_{to_{base\ station}}} (15)$$

Gateway selection algorithm

All advanced sensor selects itself to work as a gateway at the starting of every round with probability function `*Pg*`, which is selectedso that the number ofgateway nodes for same round is `*Kg*`. Therefore, if there is value of `$N_{Advanced}$` in the network is `*Nm*`,with probability function `$P_g s\ (t)$` cluster node `s` will become a gateway at round `*r*` (Eq. 16).

$$P_g s\ (t) = \frac{K_g}{N*m} (16)$$

The value of `$T\,(s_{gat})$`thresholdassign for the gateway nodes is given by Eq. 17.

$$T\,(s_{gat}) = \begin{cases} \frac{P_g}{1-P_g\left(r_{mod}\frac{1}{P_g}\right)} \times \frac{E_{s_{current}}}{E_{s_{initial}}} & \\ 0 \quad Otherwise & \end{cases} \text{, if s } \mathcal{E}(17)$$

Where, `$Kg$` is the desired gateway number, `$r$`is the current round, `$Gg$`is the set of nodes which have not been gateway in `$1/Pg$` rounds, `$E_{s_{current}}$ ` is the current energy of the node and the '$E_{s_{initial}}$ ` is the initial energy of the node.

It considers that expectednumber of gateways is completely the same as the optimum number of the gateways for the sensor network kop. Every node has great probability function to become gateways, if nodesselect themselves to become a gateway; they transmit their identity and energy information to the base station. If the number of identities obtained by the base station is greater than `$Kg_{opt}$`, the base station elects the `$Kg_{opt}$` nodes with greater energy to become gateways, and rest onenot to be gateways. If the number of identities obtained by the base station is same or less than `$Kg_{opt}$`, then base station elects those nodes to become gateways.

Cluster head selection algorithm technique

The total initial energy of normal and advanced nodes is given byEq. 18-19.

E_{tot_normal} = N (1-M) E_O(18)

$E_{tot\_advanced}$= $(m\text{-}b)\ N\ (1+a)E_o$(19)

The total initial energy of network is given as a sum of total initial energy of normal and advanced nodes (Eq. 20-21).

E_{total}= E_{tot_normal} + $E_{tot\_advanced}$(20)
E_{total}= $N\ (1\text{-}m)\ E_O$ + $(m\text{-}b)\ N\ (1+a)E_O$(21)

Where,`$b$` is the fraction of whole nodes `$N$`, which are selected as gateways.

The BCDEEC protocol was implemented with the same approach for supposing the energy in the network as considered in DEEC. Since, the probability function depends on the network'saverage energyat round `$r$`, the average energy ($\bar{E}(r)$) was calculated using Eq. 22.

$\bar{E}(r) = \frac{1}{N(1-b)} E_{total}(1\text{-}\ \frac{r}{R})$ (22)

Where,`$\bar{E}(r)$`is the average energy of all nodes at round `$r$`, and`$R$` denotes the whole rounds in the network life period, and `$R$` can be calculated using Eq. 23.

$$R = \frac{E_{total}}{E_{round}} (23)$$

`$E_{round}$` is the energy dissipated in the network in a round. The total energy dissipated is given by Eq. 24.

$$E_{round} = \left[L2N(1-b)E_{doc} + N(1-b)E_{DA} + K\mathcal{E}_{amp}d_{toBS}^{4} + N(1-b)\mathcal{E}_{fs}d_{CH}^{2}\right](24)$$

Where,`k` is the number of clusters and `$d_{toCH}$`is average distance between CH and the base station and `$d_{toCH}$` is average distance between the cluster members and the CHs. Since the nodes are regularly distributed, so the average distance between the CHs was calculated using Eq. 25.

$$d_{toCH} = \frac{M}{\sqrt{2\pi K}} d_{toBS} = 0.765\frac{M}{2} \quad (25)$$

The Eq. 25 can be solvingto the derivative of `$E_{round}$` with respect to `$k$` to zero, so there are optimal number of clusters as given in Eq. 26.

$$K_{optimum} = \sqrt{\frac{N(1-b)}{2\pi}}\frac{M}{d_{toBS}^{2}}\sqrt{\frac{\mathcal{E}_{fs}}{\mathcal{E}_{amp}}}(26)$$

Distributed energy efficient clustering with modified threshold (DEEC-MT) protocol

The block diagram for DEEC-MT protocol created from existing DEEC clustering protocol has been illustrated in Figure 2.The DEEC protocol was proposed to cope with energy heterogeneity, and the election of CHs was based on the ratio between the residual energy of each node and the average network energy.

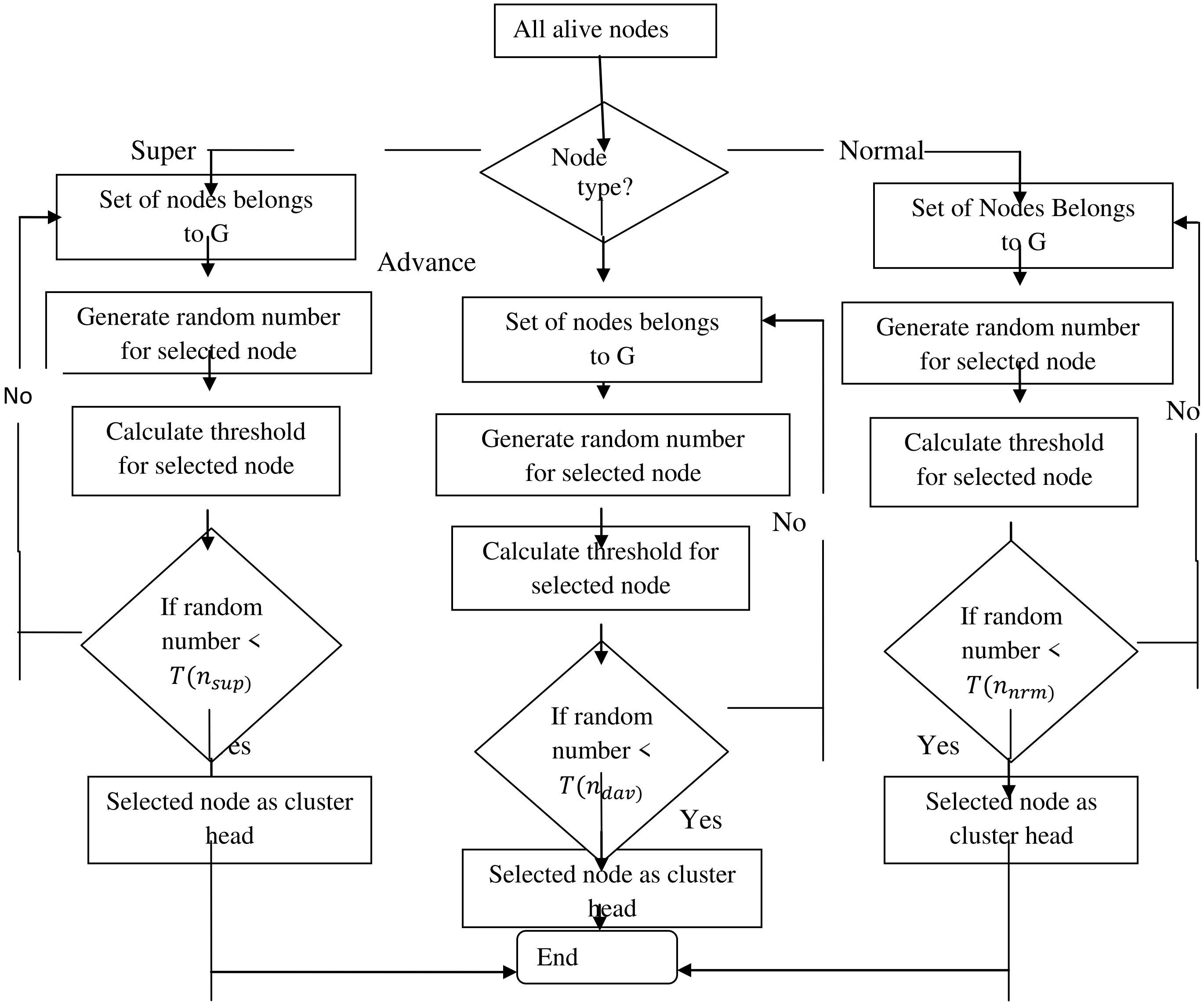


Figure 2. Flow Chart of DEEC-MT algorithm applied for enhancing energy efficiency of wireless system networks (WSNs)

The distributed energy efficient clustering protocol with modified threshold (DEEC-MT)has same system for CHs' election and averageenergy considered as designed in DEEC.The number of rounds as well as stability of network is increasedas compared to DEEC protocol.In DEEC-MT protocol, the multilevel clustering occupied three types of nodes which are assigned for describing heterogeneous environment againsttwo types of nodes defined in the BCDEEC protocol.The new type of nodes which are added in DEEC-MT are called super nodes(described in detail in Eq. 9 in previous sub-section) and contains more energy than two nodes(i.e. the advanced and normal nodes). The whole energy of network was kept similar to that for the implementation of DEEC protocol (Figure 3).

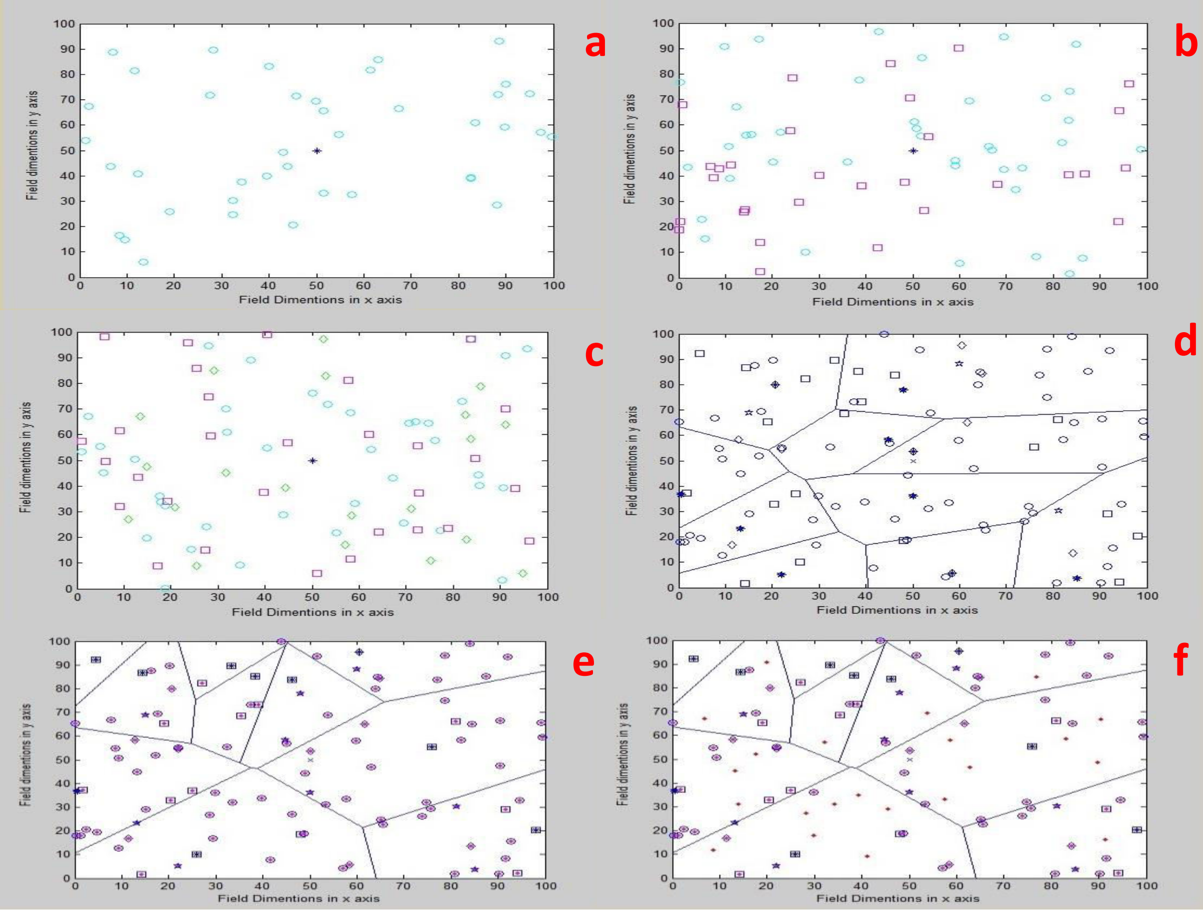


Figure 3. The deployment of normal nodes (a), advanced node (b), super nodes (c) in field, clustering of wireless signal network (WSN) (d), nodes with energy less than half remaining (e), and nodes with zero energy level (dead nodes) (f).

The energy of advanced nodes was`$\alpha$` times higher than normal nodes offraction m,equal to `Eo(1 + $\alpha$)` and the energy of super nodes has `β`times extrafrom the normal nodes with fraction mo, Eo(1 + β). If `$N$`is the total numberof nodes of the network, then `$Nm_o$` is the value of total number of supernodes and total number of advanced nodesis `$Nm\ (1-m_o)$`.The total initial energy (E_{total}) of three types heterogeneous WSNswasgiven Eq. 27-28.

$$E_{total} = N\,(1-m)E_o + Nm(1-m_o)(1+a)E_o + Nm_oE_o(1+\beta) \quad (27)$$

$$E_{total}=N\,E_o(1+m\,(\alpha+m_o\beta)) \quad (28)$$

The three types of heterogeneous WSNs consist of ($\alpha+m_o\beta$)times extra energy againsthomogeneous WSNs.DEEC-MT uses the same method for selection of CHs and averageenergy estimation as was in DEEC protocol. At every round, nodeshave two options; one to become a CH and other without selecting a random number(between 0 and 1). If value of numberis less than the threshold `$T(n)$`, the selected node become a CHfor that round `$r$`. In DEEC-MT, the modified threshold value which is based on a value a node chosen should work as aCH or not by recommendresidual energy.The threshold value determined by DEEC-MT was given In Eq. 29.

$$T(n) = \begin{cases} \frac{p}{1-p(r mod 1/p)} * \frac{E_{residual}}{E_a} * Qoptimum & if n \in G \\ 0 & else \end{cases} (29)$$

Where, `$E_{residual}$`is the residual energy of node, `*Ea*` is theaverage energy of network, `$Q_{optimum}$`is the optimal number of CHs. The proposed (DEEC-MT) protocol for clustering mode has increasedstability period of the network in heterogeneous network. IN DEEC-MT protocol, 60% of total nodes were the normal nodes. If random number (0 or 1) is less than threshold `*T(n)*`, then normal nodes decide to become a CH for the given round.Also, there were 60% of the total nodes as the advance nodes, which have fraction `*m*` times extra energy from the normal nodes (*Eo*) equal to `$Eo(1 + \alpha)$` `.There are 10% of super nodes. The super nodes of `m_o` fraction had a factor of `β`times extra energy from the normal nodes, so energies of both are equal to `$Eo(1 + \beta)$` `.

Energy model of WSNs

The energy model used in WSNs for data communication, transmission (Eqs. 30-31) and reception (Eq. 32-33) was alienated into two portions: one for data sending and others for data reception. The data sender and receiver counter parts are separated by a distance `*d*` (Smaragdakis et al., 2004). The equations for the transmission and reception of data are given as:

$$E_{trans}\,(k,d) = kE_{elec} + k\varepsilon_{efs}d^2, d < d_0 (30)$$

$$E_{trans}\,(k,d) = kE_{elec} + k\varepsilon_{amp}d^4, d \geq d_0 (31)$$

$$E_{receive}\,(k) = kE_{elec} \qquad (32)$$

$$d_0 = \sqrt{\frac{\varepsilon_{efs}}{\varepsilon_{amp}}} (33)$$

Where, `d` is the distance between receiver and transmitter, `k` denote the data bits, `$\mathcal{E}_{trans}$` is the energy required for transmission, `$\mathcal{E}_{receive}$` is the energy used in receiving the data, `$\mathcal{E}_{elec}$` is the data needed for sending the data bit, `$\mathcal{E}_{efs}$` is the amplification coefficient, and the `$\mathcal{E}_{amp}$` is the energy for amplification.

Simulation results and discussion

Implementation of DEEC and improved protocols in WSNs

A brief description of initial input parameter and their respective values used to implement DEEC, BS-DEEC and DEEC-Mt protocols has been given in Table 1. The input parameters used in the simulation process included a network area of 100 x 100 m with number of nodes (*N*=100), number of rounds (R_{max}=1000), and initial node energy (E_0=0.5 J) (Table 1). The probability (P_i) selected as CH was 0.1, and the transmission and receiving energy of nodes (E_{trans} ($d < d_0$) = 50 nJ bit^{-1}), and the energy dissipated in free space ($\mathcal{E}_{fs}$) was 10 pJ bit^{-1} m^{-1}.

Table 1. Description of selected simulation parameters and their values used in implementation of Distributed Energy Efficient Clustering (DEEC) protocol. (Acronyms: CH=cluster heads, J=Joules, nJ=nano J, pJ=pico J)

Parameter	Description	Value
X_m x Y_m	Area of the network	100 m x100m

N	Number of nodes	200
R_{max}	Number of rounds	1000
Threshold distance	Distance from centre	70m (50√2)
P	Probability selected as CH	0.1
E_0	Initial energy of the node	0.5 J
E_{trans} $(d < d_0)$	Transmission energy of node	50nJbit^{-1}
$E_{receive}$	Receiving energy of node	50nJbit^{-1}
E_{DA}	Data aggregation energy	5nJbit^{-1}message
$\mathcal{E}_{fs}$	Energy dissipation on free space	10pJbit^{-1}m^{-2}
$\mathcal{E}_{mp}$	Energy dissipation of multi-path delay	0.0013pJbit^{-1}m^{-4}
Packets	Packet size	3000 bits
$'\alpha''\beta'$ and $'\gamma'$	Threshold values	0.3333

In this study, 100 sensor nodes were randomly deployed in a square field of 100 m x 100 m, and the BS was located in the centre and was at a maximum distance of approximately 70 m (50√2) from the node. The initial node energy of E_0=0.5J was taken arbitrarily, whichdid not affectthe behavior of the simulation results. The radio dissipation model used in the present study has been detailed Elsevier (Heinzelman et al., 2002).

The simulation processimplicated 1, 2 and 3-level heterogeneity, which were incorporated, and the DEEC, BS-DEEC and DEEC-MT protocols were compared their performances. The 1-and 2-level heterogeneity the three compared protocols was same as these protocols explain an equal number of nodes and had same amount of energy. The results of existing (DEEC and BS-DEEC) were compared in terms of rounds, the WSNs' lifetime, end-to-end delay and reliability. In the present study, the parametric values (Table 1) were varied, while keeping the same amount of total network energy (E_{total}) for all three compared protocols. For 1-level heterogeneity, the sensor nodes were equipped with the same amount of energy (E_0=0.5 J initially), but for 2-level heterogeneity, 30% of the total nodes were the advanced nodes (m = 0.3), and each node was equipped with 200% higher energy, compared with the normal node (α= 2). Likewise, for 3-level heterogeneity, 12 different cases combinations for the three protocols by varying the parameter values for the DEEC protocol. The distribution of normal, advanced and the super nodes for multi-level clustering DEEC protocol varied between51-62, 26-37 and 2-23%, respectively.

Relationship between number of alive nodes and rounds

(i) For initial input parameters (number of nodes = 200, packet size=3000)

Figures 4 showed the dependence of number of alive nodes as a function of number of rounds for different protocols used viz. DEEC, BS-DEEC and proposed protocol (DEEC-MT) for initially selected input parameters (Table 1). For DEEC-MT protocol, the θ = 0.50 yielded 23 super node, 27 advanced nodes and 50 normal nodes. At θ = 0.50 and E_0=0.5 J with similar number of nodes of each type that corresponds to m = 0.52, m_0 = 0:48, α = 1.69 and β = 2.34, the respective energy for the advanced and super nodes was 1.39 J and 1.72 J. The implementation of DEEC-MT protocol has lead to considerably higher lifetime to WSNs, as a consequence of reduced rate of nodes which die slowly, compared with the basic DEEC and BS-DEEC protocols (Figure 4).

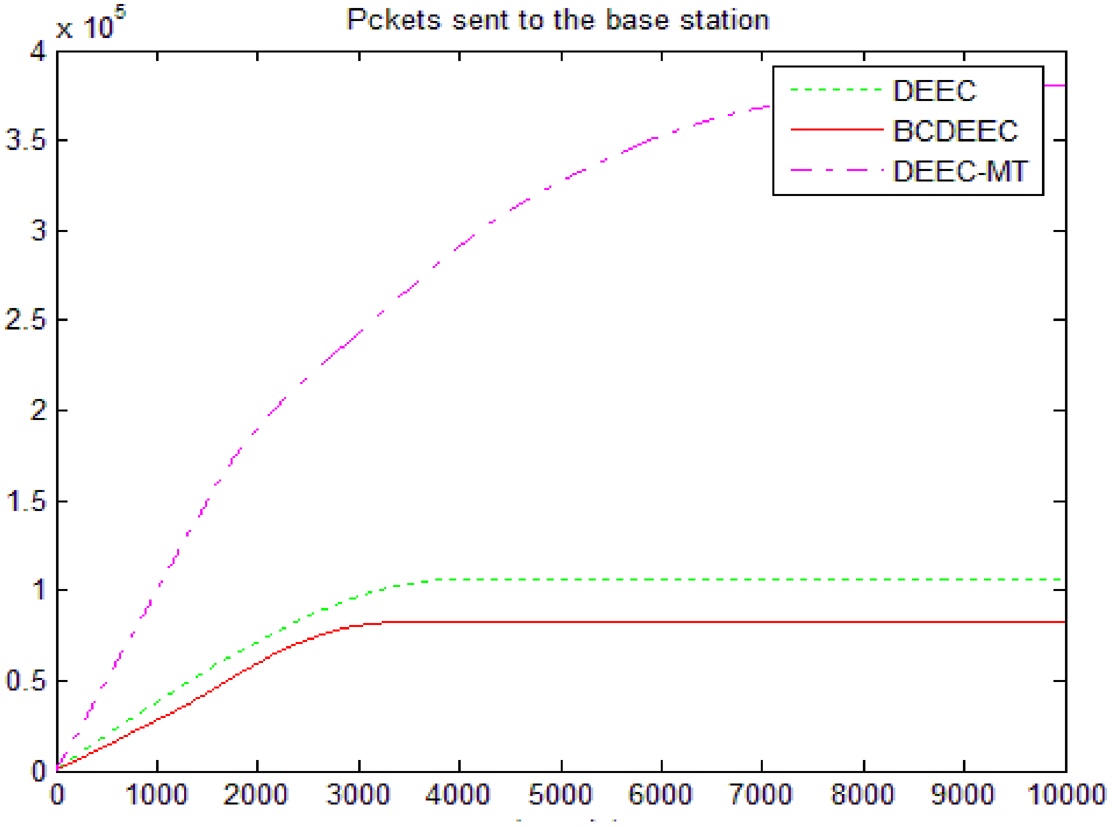


Figure 4. Relationship between the number of nodes and number of packets sent to base station (BS) for DEEC, BC-DEEC and DEEC-MT protocols for initially selected input parameters (see Table 1).

It was interested to observe that for DEEC and BS-DEEC protocols, the number of packets sent to the BS increased gradually up to 2800-3000 rounds but increased sharply for 1800-2000 rounds for DEEC-MT protocol. At 10000 rounds, the numbers of packets sent to the BS were 3.7 x 10^5packets for DEEC-MT, while less than 1 x 10^5packets for other two compared protocols. The relationship between the number of rounds and number of CHs for three protocols illustrates the dominance of CHs in the range of 0-2500 rounds (Figure 5).

The simulations carried for different input variable combinations at different energy level of nodes yielded similar results. The increase in networks' lifetime was ascribed to the fact that sensor nodes for basic DEEC and BC-DEEC protocols die much faster, compared with the DEEC-MT protocol. It was related to the death of super and advanced nodes in DEEC and BC-DEEC protocols. The total number of alive sensor nodes as a function of number of rounds has been shown in Figure 6.

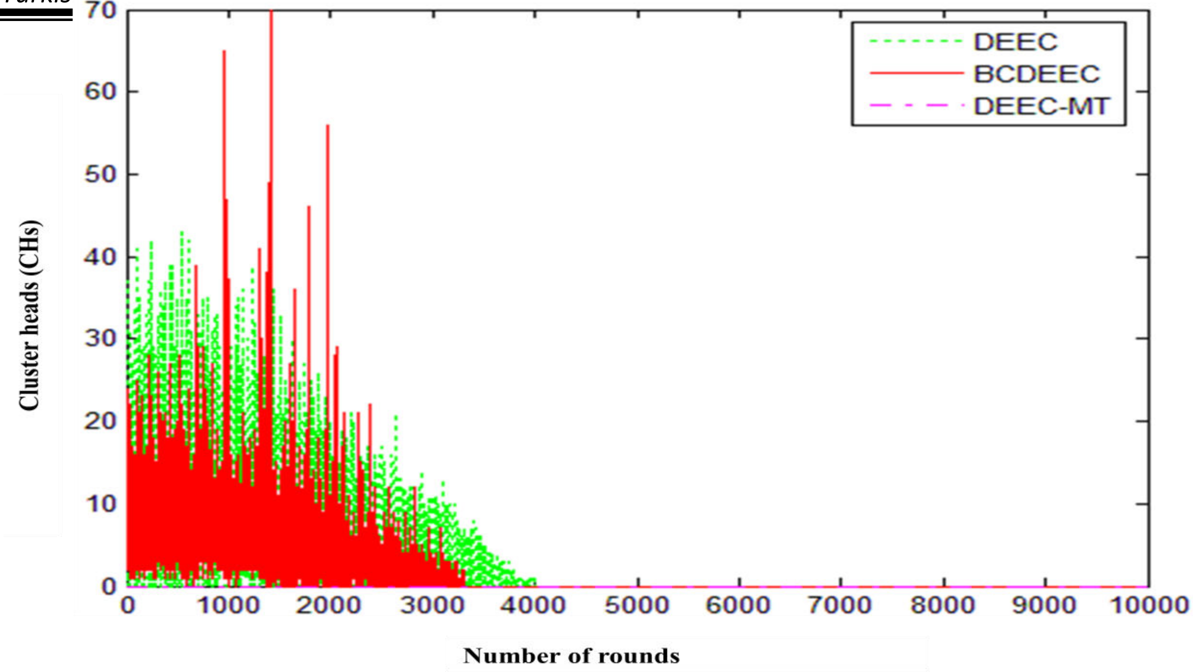
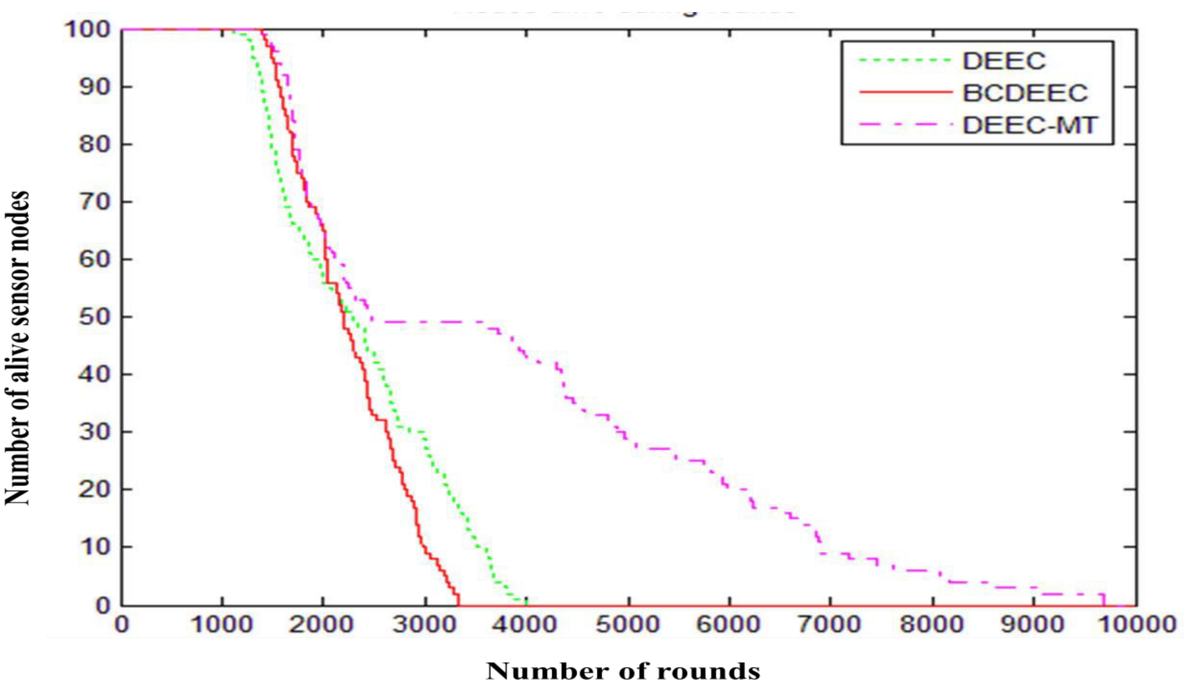


Figure 5. Relationship between the number of nodes and cluster heads (CHs) for DEEC-MT with respect to DEEC and BC-DEEC protocols for initially selected input parameters (see Table 1)



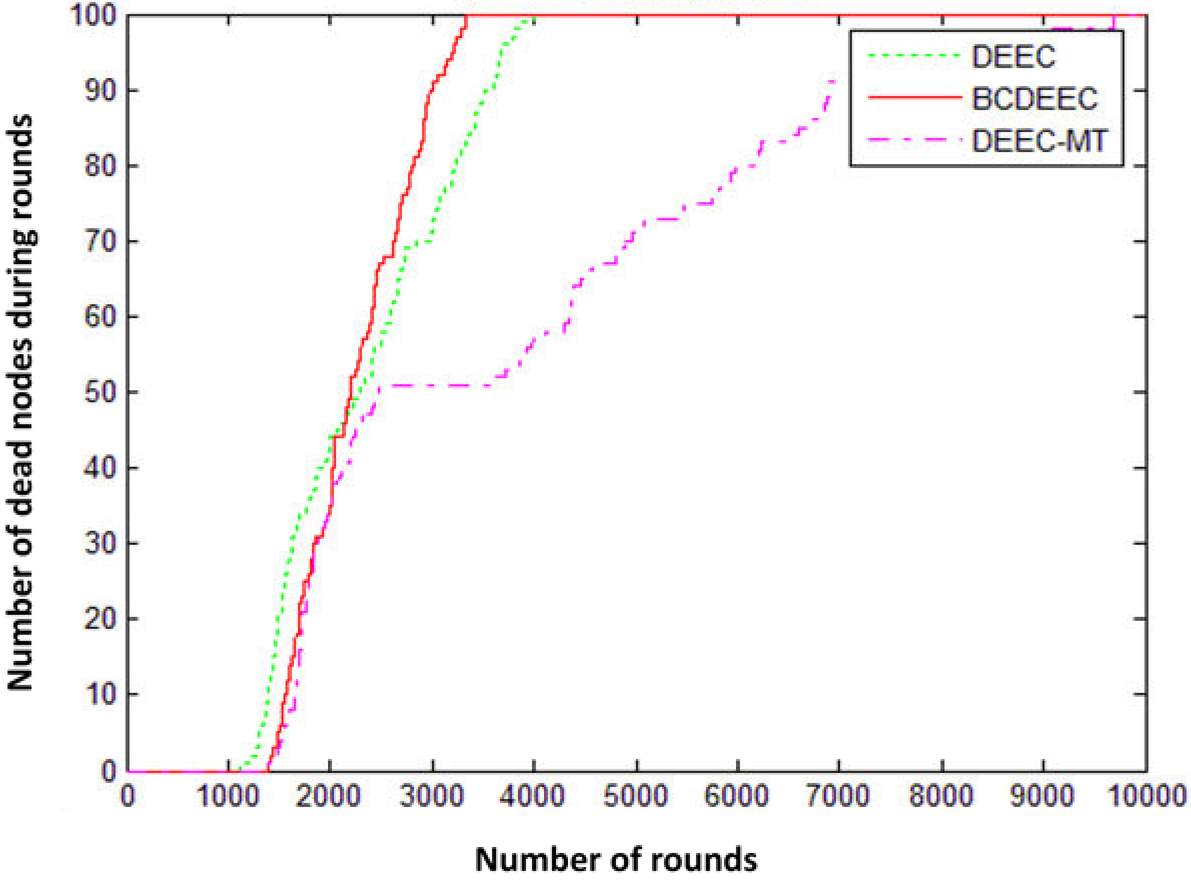


Figure 6. Relationship between the number of alive sensor nodes and the number of rounds at m = 0.50, m_0 = 0.40, α = 2.32, β = 1.50 and θ = 3.00 for DEEC-MT with respect to DEEC and BC-DEEC protocols for initially selected input parameters (see Table 1).

Figure 7. Relationship between the number of dead nodes during sounds and the number of rounds for DEEC-MT with respect to DEEC and BC-DEEC protocols for initially selected input parameters (see Table 1).

The number of alive sensor nodes did not vary much for DEEC and BC-DEEC protocols, while varied largely for DEEC-MT protocol. There was inverse relationship for number of dead nodes formed during data transmission as a function of number of rounds (Figure 7).The stability of network assessed in terms of number of rounds till first node died was 1032 for basic DEEC protocol, as compared with 1298 and 1400 for BC-DEEC and DEEC-MT protocols. Similarly, the number of rounds till network survived was 2800 and 4300 for DEEC and BC-DEEC protocols, which were ~89.3 and 55.5% lower compared to the proposed DEEC-MT protocol (Table 2).

Table 2. Comparative evaluation of results obtained with initially selected input parameters for existing protocols viz. Distributed Energy Efficient Clustering (DEEC) and Balanced and Centralized-Distributed Energy Efficient Clustering (BC-DEEC) with the proposed Distributed Energy Efficient Clustering-Maximum Threshold (DEEC-MT) protocol (at $m = 1$, $m_0 = 0.9$, $\alpha = 2$ and β=4 and number of nodes = 200)

Particular	**DEEC**	**BC-DEEC**	**DEEC-MT**
Number of rounds till first node dead	1032	1298	1400
Number of rounds till network survived	2800	4300	9667
Number of rounds till rate of packets sends to BS is stable	--	--	10000

(i) For modified input parameters (number of nodes = 100, packet size=3000)

Figure 8illustrates the relationship between the number of packets sent to the BS and number of rounds for DEEC, BS-DEEC and DEEC-MT protocol for modified input parameters (Table 3).

Table 3. Description of selected simulation parameters and their values used in implementation of Distributed Energy Efficient Clustering (DEEC) protocol. (Acronyms: CH=cluster heads, J=Joules, nJ=nano J, pJ=pico J)

Parameter	**Description**	**Value**
X_m x Y_m	Area of the network	100 m x100m
N	Number of nodes	100
R_{max}	Number of rounds	1000
Threshold distance	Distance from centre	70m (50√2)
P	Probability selected as CH	0.1
E_0	Initial energy of the node	0.5 J
E_{trans} ($d < d_0$)	Transmission energy of node	50nJbit^{-1}
$E_{receive}$	Receiving energy of node	50nJbit^{-1}
E_{DA}	Data aggregation energy	5nJbit^{-1}message
$\mathcal{E}_{fs}$	Energy dissipation on free space	10pJbit^{-1}m^{-2}
$\mathcal{E}_{mp}$	Energy dissipation of multi-path delay	0.0013pJbit^{-1}m^{-4}
Packets	Packet size	3000 bits
′□″□′ □□□ ′□′	Threshold values	0.3333

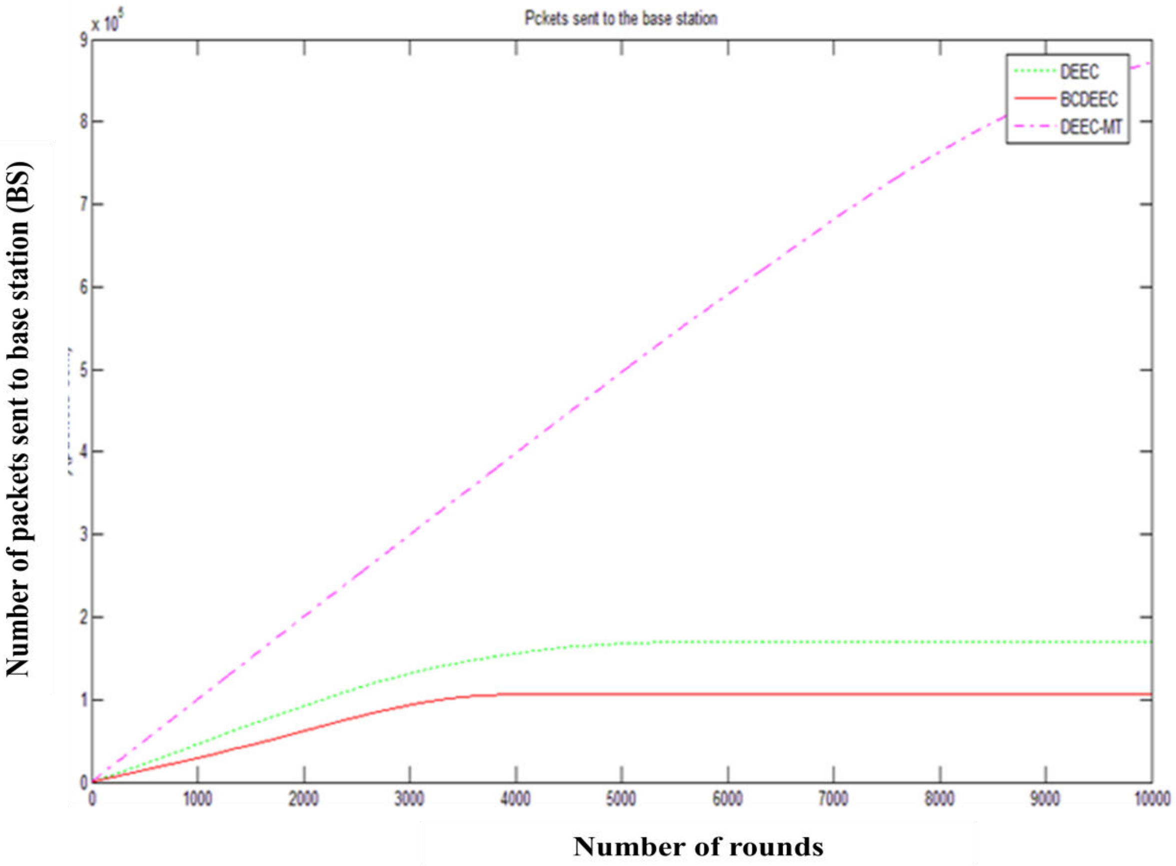


Figure 8. Relationship between the number of nodes and number of packets sent to base station (BS) for DEEC, BC-DEEC and DEEC-MT protocols for modified input parameters (see Table 3).

For DEEC-MT protocol, the θ = 0.50 yielded 22 super node, 28 advanced nodes and 50 normal nodes. At θ = 0.50 and E_0=0.5 J with similar number of nodes of each type that corresponds to m = 0.51, m_0 = 0:47, □ = 1.72 and β = 2.56, the respective energy for the advanced and super nodes was 1.43 J and 1.74 J.DEEC-MT protocol increased lifetime to WSNs as compared with the basic DEEC and BS-DEEC protocols.At 10000 rounds, the numbers of packets sent to the BS were 8.6 x 10^5 packets for DEEC-MT, while less than 1 x 10^5 packets for BC-DEEC and 1.7 x 10^5 packets for DEEC protocol. The relationship between the number of rounds and number of CHs for three protocols illustrates the dominance of CHs in the range of 0-4200 rounds for BC-DEEC and 0-6000 for basic DEEC protocols (Figure 9). The total number of alive sensor nodes as a function of number of rounds has been shown in Figure 10.

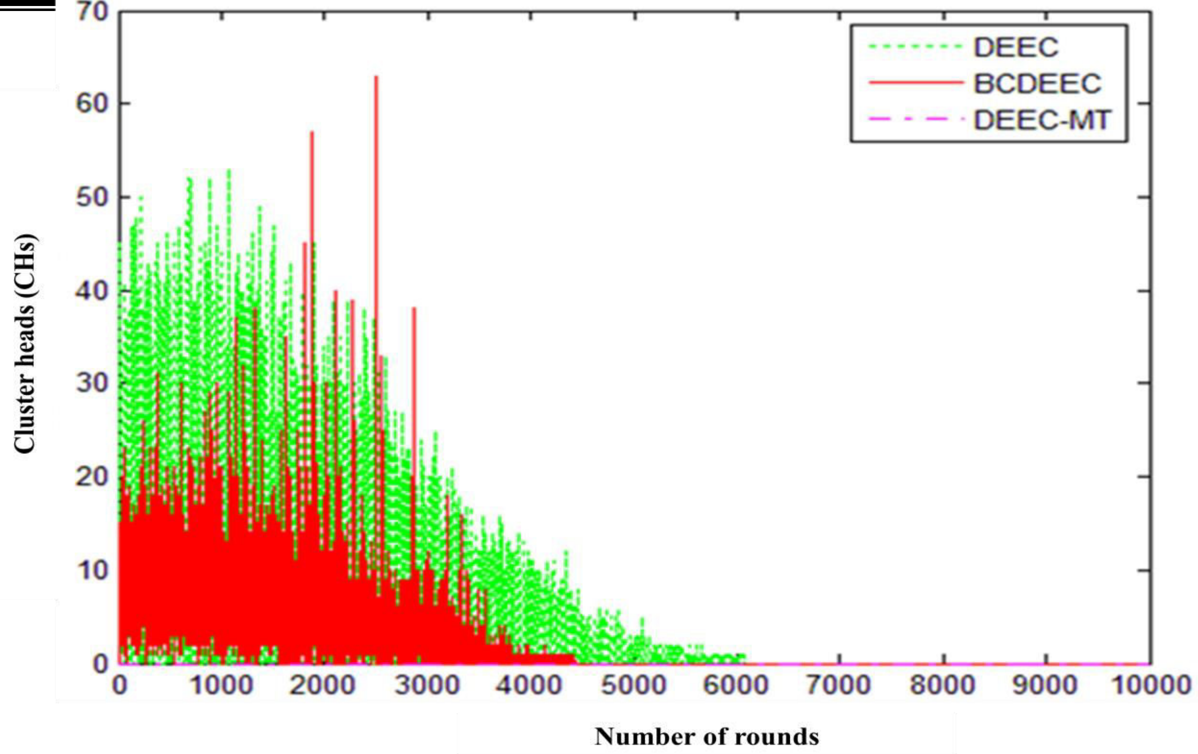


Figure 9. Relationship between the number of nodes and cluster heads (CHs) for DEEC, BC-DEEC and DEEC-MT protocols for modified input parameters (see Table 3).

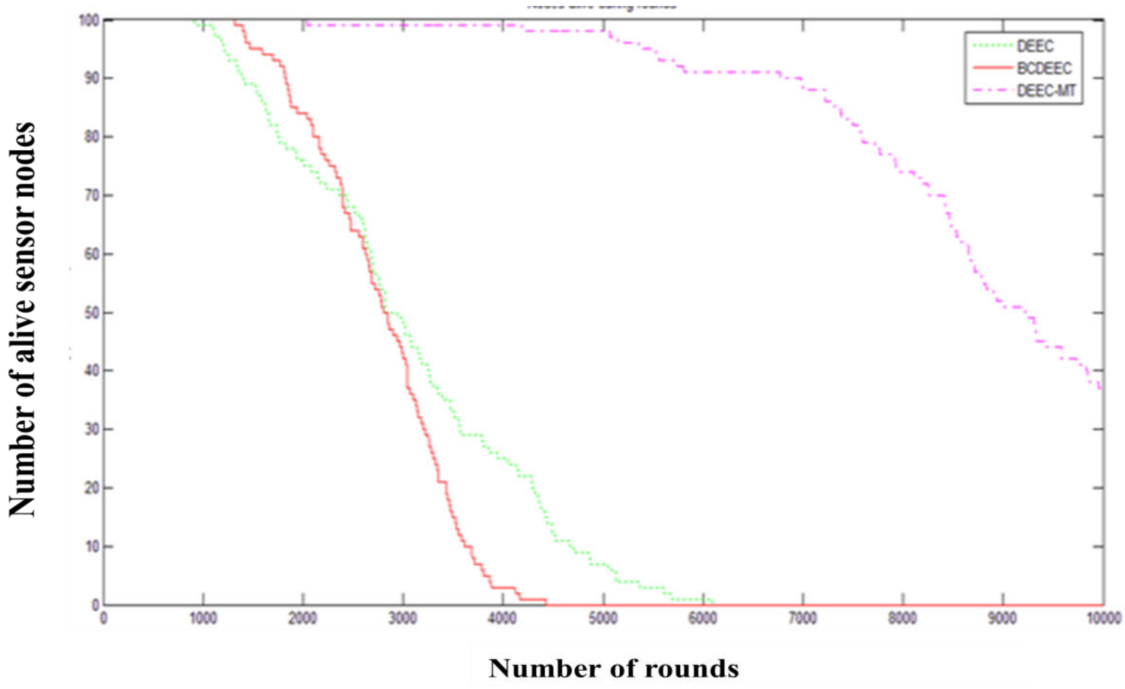


Figure 10. Relationship between the number of alive sensor nodes and the number of rounds at m = 0.51, $m_0 = 0.47$, □ = 1.72, $\beta = 2.56$ and $\theta = 3.00$ for DEEC-MT with respect to DEEC and BC-DEEC protocols for modified parameters (see Table 3).

The number of alive sensor nodes did not vary much for DEEC and BC-DEEC protocols, while varied largely for DEEC-MT protocol. There was inverse relationship for number of dead nodes formed during data transmission as a function of number of rounds (Figure 11). The stability of network for the modified input parameters till first node died was 1300 for basic DEEC protocol, as compared with 1832 and 1988 for BC-DEEC and DEEC-MT protocols. Similarly, the number of rounds till network survived was 2800 and 4300 for DEEC and BC-DEEC protocols, which were ~71.6 and 56.4% lower compared to the proposed DEEC-MT protocol (Table 4).

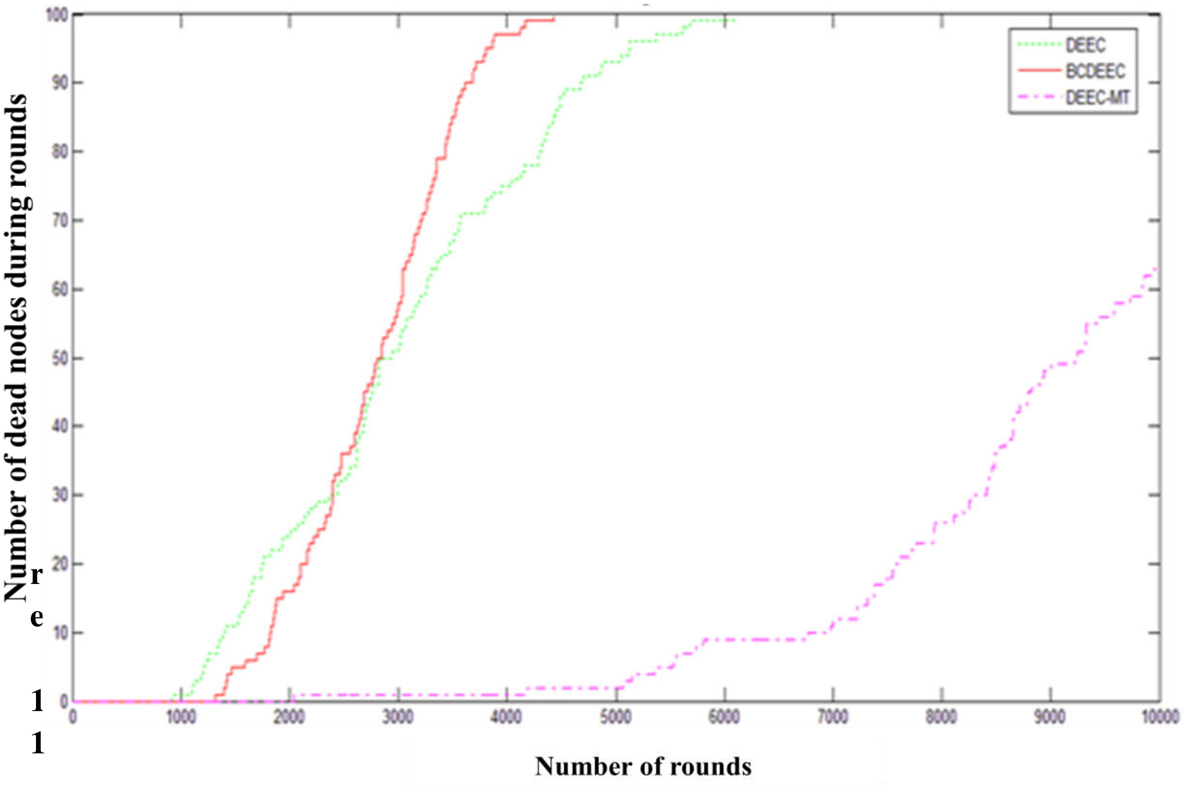


Figure 11. Relationship between the number of dead nodes during sounds and the number of rounds for DEEC-MT with respect to DEEC and BC-DEEC protocols for modified input parameters (see Table 3).

Table 4. Comparative evaluation of results obtained with initially selected input parameters for existing protocols viz. Distributed Energy Efficient Clustering (DEEC) and Balanced and Centralized-Distributed Energy Efficient Clustering (BC-DEEC) with the proposed Distributed Energy Efficient Clustering-Maximum Threshold (DEEC-MT) protocol (at $m = 1$, $m_0 = 0.9$, □ = 2 and β=4 and number of nodes = 100)

Particular	DEEC	BC-DEEC	DEEC-MT
Number of rounds till first node dead	1300	1832	1988
Number of rounds till network survived	2800	4300	9855
Number of rounds till rate of packets sends to BS is stable	-	-	10000

(i) For modified input parameters (number of nodes = 200, packet size=4000)

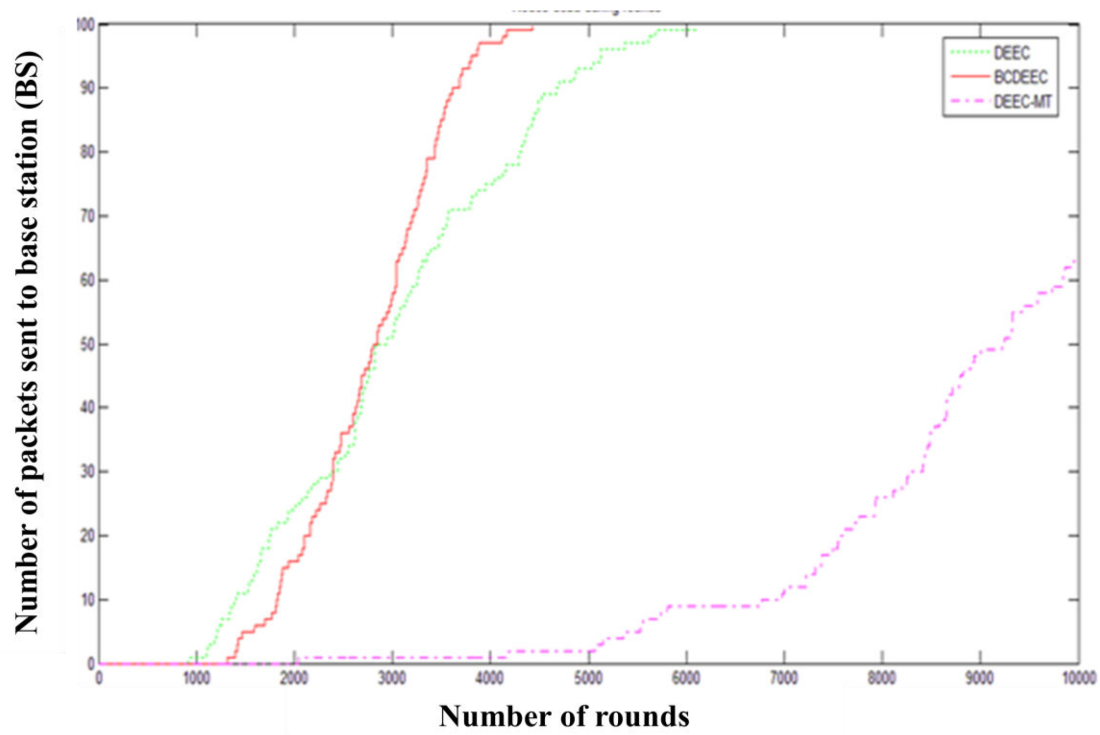


Figure 12. Relationship between the number of nodes and number of packets sent to base station (BS) for DEEC, BC-DEEC and DEEC-MT protocols for modified input parameters (see Table 5).

The WSN's were simulated for 200 nodes and 4000 packets size. Figure 12 illustrates the relationship between the number of packets sent to the BS and number of rounds for DEEC, BS-DEEC and DEEC-MT protocol for modified input parameters (see Table 5).

Table 5. Description of modified simulation parameters and their values used in implementation of Distributed Energy Efficient Clustering (DEEC) protocols. (Acronyms: CH=cluster heads, J=Joules, nJ=nano J, pJ=pico J)

Parameter	**Description**	**Value**
X_m x Y_m	Area of the network	100 m x100m
N	Number of nodes	200
R_{max}	Number of rounds	1000
Threshold distance	Distance from centre	70m (50√2)
P	Probability selected as CH	0.1
E_0	Initial energy of the node	0.5 J
E_{trans} $(d < d_0)$	Transmission energy of node	$50nJbit^{-1}$
$E_{receive}$	Receiving energy of node	$50nJbit^{-1}$
E_{DA}	Data aggregation energy	$5nJbit^{-1}$message
$\mathcal{E}_{fs}$	Energy dissipation on free space	$10pJbit^{-1}m^{-2}$
$\mathcal{E}_{mp}$	Energy dissipation of multi-path delay	$0.0013pJbit^{-1}m^{-4}$
Packets	Packet size	4000 bits
′□″□′ □□□ ′□′	Threshold values	0.3333

For DEEC-MT protocol, the $\theta = 0.50$ yielded 24 super node, 26 advanced nodes and 50 normal nodes (Table 6). At $\theta = 0.50$ and E_0=0.5 J with similar number of nodes of each type that corresponds to $m = 0.52$, $m_0 = 0.48$, □ = 1.71 and $\beta = 2.38$, the respective energy for the advanced and super nodes was 1.62 J and 1.33 J. The implementation of DEEC-MT protocol increased lifetime to WSNs as compared with the basic DEEC and BS-DEEC protocols. The total number of alive sensor nodes as a function of number of rounds revealed that the number of alive sensor nodes decreased as the number of rounds was increased (Figure 13). At 10000 rounds, the numbers of packets sent to the BS were 9.8×10^5 packets for DEEC-MT, while less than 1.7×10^5 packets for BC-DEEC and 2.3×10^5 packets for DEEC protocol. The number of alive sensor nodes did not vary much for DEEC and BC-DEEC protocols, while varied largely for DEEC-MT protocol. It was interesting to note that even at 10000 rounds, there were 13 alive sensor nodes for data transmission to the BS. There was inverse relationship for number of dead nodes formed during data transmission as a function of number of rounds (Figure 14).

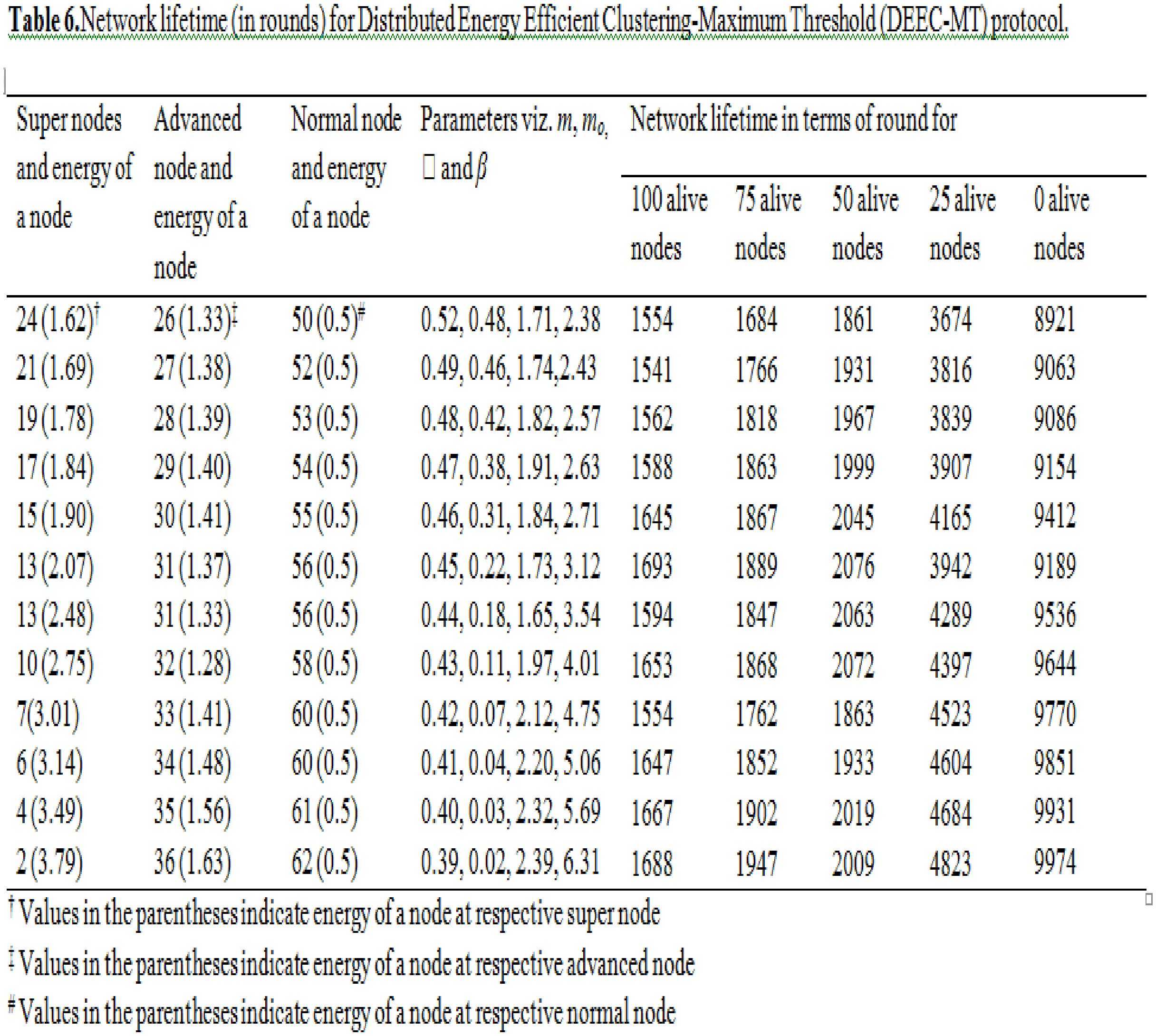


Table 6. Network lifetime (in rounds) for Distributed Energy Efficient Clustering-Maximum Threshold (DEEC-MT) protocol.

Super nodes and energy of a node	Advanced node and energy of a node	Normal node and energy of a node	Parameters viz. m, $m_{0,}$ □ and β	Network lifetime in terms of round for				
				100 alive nodes	75 alive nodes	50 alive nodes	25 alive nodes	0 alive nodes
24 (1.62)[†]	26 (1.33)[‡]	50 (0.5)[#]	0.52, 0.48, 1.71, 2.38	1554	1684	1861	3674	8921
21 (1.69)	27 (1.38)	52 (0.5)	0.49, 0.46, 1.74,2.43	1541	1766	1931	3816	9063
19 (1.78)	28 (1.39)	53 (0.5)	0.48, 0.42, 1.82, 2.57	1562	1818	1967	3839	9086
17 (1.84)	29 (1.40)	54 (0.5)	0.47, 0.38, 1.91, 2.63	1588	1863	1999	3907	9154
15 (1.90)	30 (1.41)	55 (0.5)	0.46, 0.31, 1.84, 2.71	1645	1867	2045	4165	9412
13 (2.07)	31 (1.37)	56 (0.5)	0.45, 0.22, 1.73, 3.12	1693	1889	2076	3942	9189
13 (2.48)	31 (1.33)	56 (0.5)	0.44, 0.18, 1.65, 3.54	1594	1847	2063	4289	9536
10 (2.75)	32 (1.28)	58 (0.5)	0.43, 0.11, 1.97, 4.01	1653	1868	2072	4397	9644
7(3.01)	33 (1.41)	60 (0.5)	0.42, 0.07, 2.12, 4.75	1554	1762	1863	4523	9770
6 (3.14)	34 (1.48)	60 (0.5)	0.41, 0.04, 2.20, 5.06	1647	1852	1933	4604	9851
4 (3.49)	35 (1.56)	61 (0.5)	0.40, 0.03, 2.32, 5.69	1667	1902	2019	4684	9931
2 (3.79)	36 (1.63)	62 (0.5)	0.39, 0.02, 2.39, 6.31	1688	1947	2009	4823	9974

[†] Values in the parentheses indicate energy of a node at respective super node

[‡] Values in the parentheses indicate energy of a node at respective advanced node

[#] Values in the parentheses indicate energy of a node at respective normal node

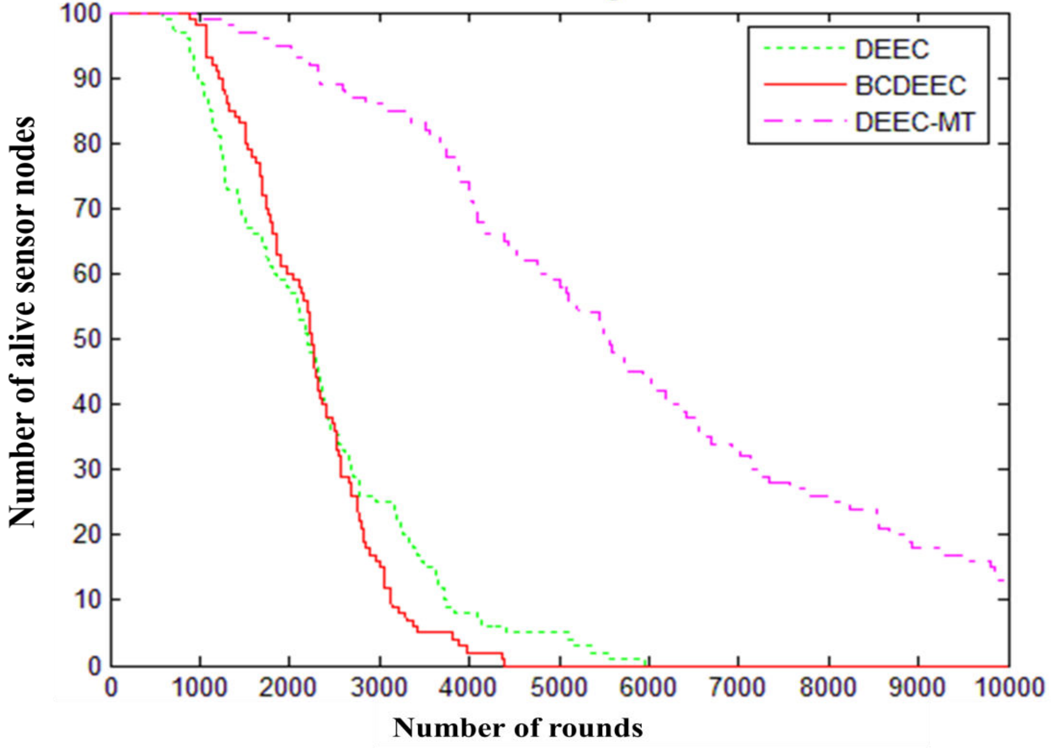


Figure 13. Relationship between the number of alive sensor nodes and the number of rounds at m = 0.52, m_0 = 0.48, □ = 1.71, β = 2.38 and θ = 3.00 for DEEC-MT with respect to DEEC and BC-DEEC protocols for modified parameters (see Table 5).

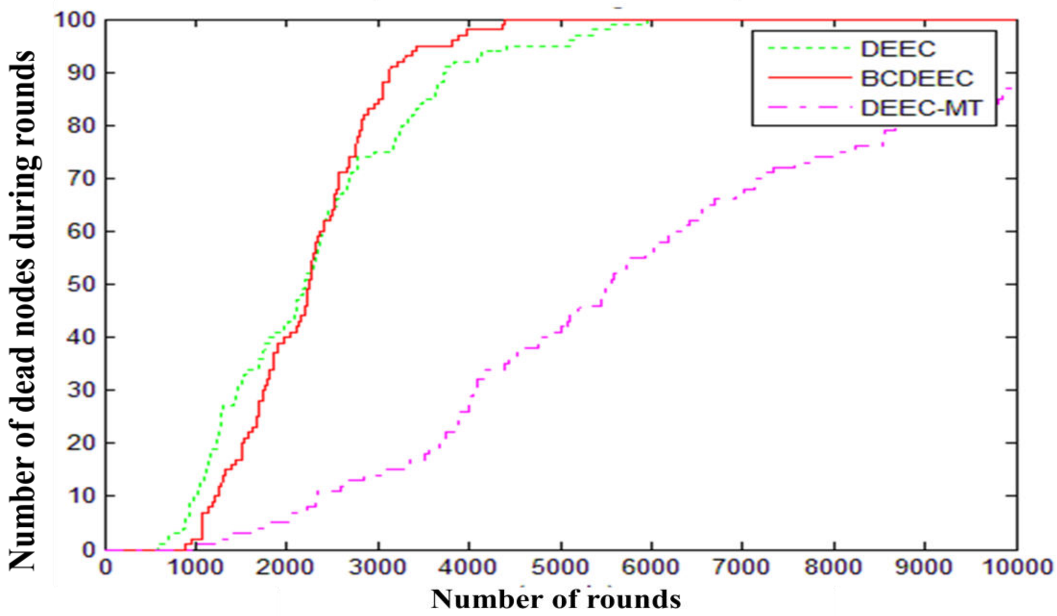


Figure 14. Relationship between the number of nodes and number of packets sent to base station (BS) for DEEC, BC-DEEC and DEEC-MT protocols for modified input parameters (see Table 5).

The stability of network for the modified input parameters till first node died was 539 for basic DEEC protocol, as compared with 634 and 887 for BC-DEEC and DEEC-MT protocols.

Similarly, the number of rounds till network survived was 5425 and 7400 for DEEC and BC-DEEC protocols, which were ~42.5 and 21.6% lower compared to the proposed DEEC-MT protocol (Table 7).

Table 7. Comparative evaluation of results obtained with modified input parameters (see table 5) for existing protocols viz. Distributed Energy Efficient Clustering (DEEC) and Balanced and Centralized-Distributed Energy Efficient Clustering (BC-DEEC) with the proposed Distributed Energy Efficient Clustering (DEEC)-Maximum Threshold (DEEC-MT) protocol.

Particular	**DEEC**	**BC-DEEC**	**DEEC-MT**
Number of rounds till first node dead	539	634	887
Number of rounds till network survived	5425	7400	9437
Number of rounds till rate of packets sends to BS is stable	-	-	10000

Table 8. Network lifetime (in rounds) for Distributed Energy Efficient Clustering (DEEC), Balanced and Centralized-DEEC (BC-DEEC) and Distributed Energy Efficient Clustering-Maximum Threshold (DEEC-MT) protocols by deploying 100 normal nodes with initial energy of E_0 = 0.5 joules (J).

Number of alive nodes	Network lifetime (in rounds)		
	DEEC	BC-DEEC	DEEC-MT
0	1241	1758	2268
25	1118	1547	1941
50	1032	1454	1753
75	994	1204	1544
100	882	1108	1223

Simulations of network lifetime

For 1-and 2-level heterogeneity, the WSNs' lifetime was premeditated in terms of rounds considering an equal number of nodes (i.e., 100 nodes) and the same amount of total network energy (E_{total}= 100 J). The results revealed that at different number of alive nodes (0-100 nodes; interval of 25 nodes) for DEEC protocol, the network lifetime varied between 842-1241 rounds, as compared with 1108-1758 rounds for BC-DEEC protocol, and 1223-2268 rounds for DEEC-MT protocols (Table 8). Average across the number of alive nodes (0-100 nodes), the network lifetime for BC-DEEC and DEEC-MT protocols increased by ~34.3 and 65.7%, respectively. However, as compared with BC-DEEC protocol, the implementation of proposed DEEC-MT protocol results to additional enhancement of network lifetime ~23.4%. Regardless of the protocol implemented for enhancing the networks' lifetime, there was an apparent converse trend observed for network lifetime and the number of rounds.

Reliability, packets overhead and Lifespan of WSNs

The reliability of DEEC-MT protocol was considerably higher by ~24.7 and 13.8% as compared to basic DEEC and BC-DEEC protocols, respectively.These results showed that DEEC-MT protocol deployed only 63 packet overheads, which were respectively 15 and 8 packets less compared with DEEC and BC-DEEC protocols. The delay of 73 packets with DEEC-MT protocol was considerably lower than the DEEC (81 packets) and BC-DEEC (78 packets) protocols. The average lifespan was increased by ~19.8% with the implementation of DEEC-MT, compared with the BC-DEEC protocol. As compared with the DEEC, the implementation of DEEC-MT protocol resulted in ~37.6% increase in lifespan of the WSN. The comparison of DEEC-MT and LEACH-CS showed that proposed protocol (DEEC-MT) enhanced the WSNs' lifespan by ~13.9%.

End-to-end delay

The end-to-end delay (in seconds) was averaged across the network lifetime to determine the mean end-to-end delay in the network. The relationship between the number of nodes and end to end delay for DEEC, BC-DEEC and the proposed protocol (DEEC-MT) shows a gradual increase in delay (in seconds) with the increase in number of nodes. These results revealed that DEEC-MT protocol resulted in a mean decrease in end-to-end delay by ~23.7%, compared with BC-DEEC protocol. However, the mean decrease in delay with DEEC-MT protocol was ~37.8% than the basic DEEC protocol. At the largest number of nodes (nodes = 10000), the delay with DEEC-MT protocol was lower by ~18.4 seconds (~33.4%), compared with the implementation of DEEC protocol. However, as compared with BC-DEEC, the delay of 13 seconds (~24.7%) was observed with the implementation DEEC-MT protocol.

Conclusions

These results revealed that energy heterogeneity with the implementation of newly proposed protocol (DEEC-MT) helps enhancing the WSNs' energy efficiency, while increasing the network lifetime. The rate of energy dissipation was much slower with the implementation of DEEC-MT) protocol, compared with the basic DEEC and BC-DEEC protocols.The reliability of DEEC-MT protocol was higher by ~24.7 and ~13.8% as compared to basic DEEC and BC-DEEC protocols, respectively. Results revealed that DEEC-MT protocol decreased the end-to-end delay by ~23.7%, compared with BC-DEEC protocol. Therefore, these results highlight that proposed protocol uses network energy much efficiently and help enhancing the network lifetime.

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