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Threshold Adaptive Balanced Energy Efficient Network Integrated Super Heterogeneous Protocol for WSNs

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Abstract : Wireless sensor networks (WSNs) consists of large number of sensor nodes scattered inside a region, these sensor nodes sense data and then transmit it towards the base station (BS). Since both sensing and transmitting towards the base station utilizes high energy amount so it leads to a finite network lifetime. So, in WSNs energy conservation and extending lifetime of the network are the major issues. Thus, clustering techniques are used to optimize energy consumption and furthermore lifetime and stability of the network can be increased with the induction of heterogeneity in the WSN. Since cluster head requires more energy than other nodes because they have to perform both inter-cluster and intra-cluster communication, the cluster head must be selected in an efficient manner such that balanced energy consumption takes place in the network. Hence, we propose a modified algorithm of "Balanced Energy Efficient Network Integrated Super Heterogeneous Protocol for Wireless Sensor Networks (BEENISH)" called "Threshold Adaptive Balanced Energy Efficient Network Integrated Super Heterogeneous Clustering Protocol for WSNs (T-BEENISH)". In the proposed protocol, the threshold equation for the cluster head selection is modified so that better election of cluster head can take place among nodes having different energy levels in heterogeneous wireless sensor networks. It aims at prolonging the network lifetime, stability period and throughput of the sensor networks.

Keywords : Heterogeneity Efficient Routing Protocols, Wireless Sensor Networks, BEENISH, T-BEENISH

1. INTRODUCTION

Wireless sensor networks consist of a large number of sensor nodes randomly deployed inside a region. WSNs are widely used in a number of applications such as security, battlefield surveillance, and environment and object monitoring, etc. In WSN, the sensor nodes since the data and send it towards the base station (sink). The query is sent by the sink to the sensor nodes inside the sensing region, the sensors nodes coordinates to accomplish the task of sensing and sends the sensed data to the sink and the sink serves as a gateway to the outside networks. Various clustering algorithms are present in a context which efficiently distributes the load over the network and thus increases the network lifetime. Here, sensor nodes are organized into clusters, the nodes having low energy serves as cluster members while nodes having higher energy serve as cluster head.

Low-Energy Adaptive Clustering Hierarchy (LEACH), Power Efficient Gathering in Sensor Information Systems (PEGASIS) and Hybrid Energy-Efficient Distributed Clustering (HEED) are examples of homogeneous cluster based protocols. These algorithms perform poorly in heterogeneous WSNs. Nodes having less energy will expire faster than high energy nodes because these homogeneous clustering based protocols are incapable to treat every node with respect to energy.

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Stable Election Protocol (SEP), Distributed Energy Efficient Clustering (DEEC), Enhanced DEEC (EDEEC), Developed DEEC (DDEEC), Enhanced Developed DEEC (EDDEEC), Threshold DEEC (TDEEC), Stochastic DEEC (SDEEC), Threshold Adaptive DEEC (TADEEC) and Balanced Energy Efficient Network Integrated Super Heterogeneous (BEENISH) protocol are the examples of heterogeneous wireless sensor networks (HWSNs).

The rest of the paper is organized as follows: Section 2 describes related work. Section 3 describes the properties and assumptions of the network. Section 4 describes proposed protocol T-BEENISH. In Section 5, results of simulation are discussed and in Section 6, the conclusion of the work is given.

2. RELATED WORK

Qing, L.et al. [2] proposed a Distributed Energy-Efficient Clustering Algorithm (DEEC) in 2006. This algorithm is based on the idea of selecting the cluster heads on the basis of the probability of the ratio between the residual energy of each node and the average energy of the network. The chances for becoming the cluster heads are more for the nodes having high initial energy and residual energy. This method increases the network lifetime and stability period in multi-level heterogeneous wireless sensor networks.

Elbhiri, B.et al. [3] proposed a Developed Distributed Energy-Efficient Clustering (DDEEC) Algorithm in 2010. This algorithm is based on the idea that at some moment, it is possible that the advanced nodes have the same residual energy as that of normal nodes and according to DEEC algorithm the advanced nodes will be continuously punished to become the cluster heads. In this way the energy of the advanced nodes keeps on depleting and dies. DDEEC introduce a change in the probability equation based on the threshold residual energy value given by equation 1.

$$ThREV = Eo\left(1+\frac{aE_{disNN}}{E_{disNN}-E_{disAN}}\right)$$

The equation (1) gives the theoretical value under which all nodes (normal and advanced) have the same probability to become the cluster head. Thus it gives a balanced cluster head election probability. This development on DEEC protocol *i.e.* DDEEC performs better than SEP and DEEC in account of network lifetime and stability period.

Saini, P.et al. [4] proposed an Enhanced Distributed Energy-Efficient Clustering (EDEEC) Algorithm in 2010. This algorithm increases the heterogeneity and energy level of the network. This algorithm follows the concept of DEEC in which cluster head is elected on the basis of ratio of residual energy and average energy of the network by extending it up to three level of heterogeneity by adding nodes having energy more than that of normal and advanced nodes called super nodes. This enhancement of DEEC *i.e.* EDEEC results in better performance than SEP in terms of number of alive nodes, network remaining energy and data packets received at the base station.

Saini.P.et al. [5] proposed a Threshold Distributed Energy Efficient Clustering Protocol (TDEEC) in 2010. In this protocol the threshold value of a node on which decision of cluster-head selection is made is modified. The strategy is same as per that of DEEC, the difference lies in the threshold equation. In TDEEC, the value of the threshold is adjusted by taking in account the ratio of residual energy of a node and average energy of the network with respect to that round to the optimum number of cluster heads (K_{opt}). This improvement results in better stability and energy efficiency thus increasing the network lifetime.

Javaid.N.et al. [6] proposed an EDDEEC (Enhanced Developed Distributed Energy Efficient Clustering Algorithm) in 2013. This protocol is based on the assumption made in DDEEC algorithm. As DEEC continues to punish advanced nodes to become cluster heads due to which they are over penalized and dies quickly, this drawback is overcome by DDEEC by introducing the factor of threshold residual value but it only accounts for two-level energy heterogeneity. In EDEEC there are three types of nodes- normal, advanced and super-nodes , same problem of cluster head selection arises in this at the moment when the energy of advanced and super nodes depletes and their residual energies comes in the range of normal nodes. It continues to over-penalized advance and super-nodes. This protocol overcomes this problem by introducing changes in the function of probabilities to elect cluster head. The changes are made by introducing a factor $T_{absolute}$ (absolute residual energy). At this value all the three nodes- normal, advance and super nodes have same energy level and same probability for CH selection. It provides better stability, network lifetime and more effective messages to base station than DEEC, DDEEC and EDEEC.

Qureshi.T.N.et.al [7] proposed a balanced energy efficient network integrated super heterogeneous protocol (BEENISH) in 2013. This protocol increases the heterogeneity in network upto four level. The basic idea is same as that of the DEEC whereas DEEC uses two types of nodes-normal and advanced nodes. In BEENISH four types of nodes are used-normal, advanced, super and ultra-super nodes. The idea of cluster head selection is same as that of DEEC *i.e.* taking account of residual energy and average energy of the network. Thus, the ultra-super nodes have more chances to be elected as cluster-heads. This extension for WSN containing four level heterogeneity provides better results than DEEC, DDEEC and EDEEC in terms of first and last node die.

3. ASSUMPTIONS AND PROPERTIES OF THE NETWORK

The assumptions and properties of the network and sensor nodes are as follows :

- Sensor nodes are uniformly randomly deployed in the network.
- There is one base station which is present in the center of the sensing field.
- Nodes always have the data to send to the base station.
- Sensor nodes are immobile.
- Sensor nodes have heterogeneity in terms of energy *i.e.* different energy levels.

4. PROPOSED PROTOCOL

The radio energy model described in [1, 8] is used in our proposed protocol. Energy model describes that l-bit message is transmitted over a distance d as shown below.

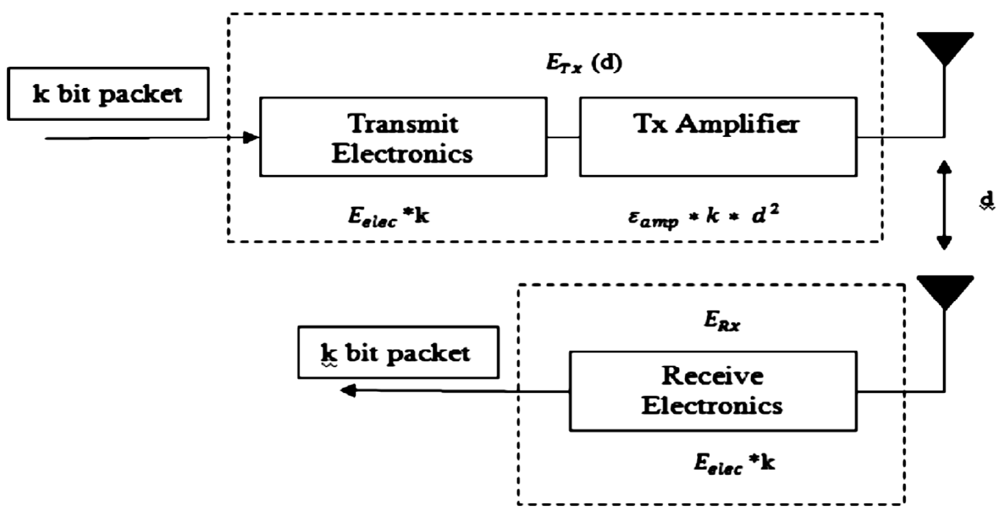

Fig. 1. Radio Energy Dissipation Model.

$$E_{Tx}(1, d) = \begin{cases} 1E_{elec} + 1\varepsilon_{fs} d^2, & d < d_0 \\ 1E_{elec} + 1\varepsilon_{mp} d^4, & d \geq d_0 \end{cases} \quad (2)$$

where E_{elec} is energy used per bit to run transmitter or receiver circuit. Free space (f_s) model is used if distance is less than threshold d_0 otherwise multi path (mp) model is used. Now, total energy dissipated in the network during a round is given below,

$$E_{round} = L(2NE_{elec} + NE_{DA} + k\varepsilon_{mp}\, d^4_{toBS} + N\varepsilon_{fs} d^2_{toCH})$$

where, k = number of clusters,

E_{DA} = Data aggregation cost expended in CH

d_{toBS} = Average distance between CH and BS

d_{toCH} = Average distance between cluster members and CH

Assuming all nodes are uniformly distributed over network, d_{toBS} and d_{toCH} can be calculated as following,

$$d_{\text{toCH}} = \frac{\mathrm{M}}{\sqrt{2\pi k}},\ d_{\text{toBS}} = 0.765\frac{\mathrm{M}}{2} \tag{4}$$

By finding the derivative of with respect to k to zero, we get the optimal number clusters as,

$$k_{\text{opt}} = \frac{\sqrt{\mathrm{N}}}{\sqrt{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}\frac{\mathrm{M}}{d^{\mathrm{t}}_{\text{toBS}}} \tag{5}$$

T-BEENISH implements the same idea of probabilities for CH selection based on initial, remaining and average energy of the network as supposed in DEEC.

The average energy of the round can be calculated as:

$$\overline{\mathrm{E}}(r) = \frac{1}{\mathrm{N}}\mathrm{E}_{\text{total}}\left(1\frac{r}{\mathrm{R}}\right) \tag{6}$$

R denotes total rounds during network lifetime and can be estimated as;

$$\mathrm{R} = \frac{\mathrm{E}_{\text{total}}}{\mathrm{E}_{\text{round}}} \tag{7}$$

Traditionally as per LEACH, cluster head selection is broken into rounds. At each round node decides whether to become a cluster head or not based on the threshold calculated. Each node n chooses a random number between 0 and 1. If the number is less than a threshold T(n), the node becomes a cluster-head for the current round. The threshold is set as following,

$$\mathrm{T}(s) = \begin{cases} \dfrac{p}{1 - p*\left(r \bmod \dfrac{1}{p}\right)} & \text{if } s \in \mathrm{G} \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

Here p, r and G represent the desired percentage of cluster heads, the current round, and the set of nodes that have not been cluster heads in the last 1/p rounds. Using this threshold, each node will be a cluster head just once at some point within 1/p rounds.

In real time scenarios, WSN have more than two or three energy levels of nodes. In WSN due to random cluster head selection large range of energy levels exists. So, as much more energy levels we quantize and define different probability for every energy level will leads to much better results and energy efficiency. So in BEENISH concept of four level heterogeneity is introduced and the nodes are characterized as normal, advanced, super and ultra-super as given in [7]. The probability of four types of nodes given by BEENISH is given below:

$$p_i = \begin{cases} \dfrac{\mathrm{P}_{\text{opt}}\mathrm{E}_i(r)}{(1+m(a+mo(-a+b+m_1(-b+u))))\overline{\mathrm{E}}(r)} & \text{normal node} \\ \dfrac{\mathrm{P}_{\text{opt}}(1+a)\mathrm{E}_i(r)}{(1+m(a+mo(-a+b+m_1(-b+u))))\overline{\mathrm{E}}(r)} & \text{advanced node} \\ \dfrac{\mathrm{P}_{\text{opt}}(1+b)\mathrm{E}_i(r)}{(1+m(a+mo(-a+b+m_1(-b+u))))\overline{\mathrm{E}}(r)} & \text{super node} \\ \dfrac{\mathrm{P}_{\text{opt}}(1+u)\mathrm{E}_i(r)}{(1+m(a+mo(-a+b+m_1(-b+u))))\overline{\mathrm{E}}(r)} & \text{ultra super node} \end{cases} \tag{9}$$

The difference between the T-BEENISH and other heterogeneous protocols BEENISH and EDEEC lies in the cluster head selection. In order to keep the sensor network alive for much longer duration there has to be efficient cluster head selection. Since cluster heads require more energy than the other nodes because they have to perform both inter-cluster and intra-cluster communication, the role of cluster head must be rotated among the all nodes in an efficient manner. In existing BEENISH the cluster head is selected randomly which results in unbalanced energy consumption and inefficient cluster head selection. The threshold equation for cluster head selection is same for all nodes. Since nodes present in BEENISH are heterogeneous, so threshold must be adjusted in order to adapt for different energy levels. In proposed T-BEENISH the threshold is modified and set as:

$$T(S_i) = \frac{P_i}{1 - P_i * \left(r \bmod \frac{1}{P_i}\right)} \left[\frac{E_i}{Me(i)} + \left(r_s \operatorname{div} \frac{1}{P_i}\right)\left(1 - \frac{E_i}{M_e(i)}\right)\right] \text{if } S_i \in G \tag{10}$$

where threshold is set differently and dependent on P_i that has been set according to the four level heterogeneity and $M_e(i)$ which is classified according to the level of the node- normal, advance, super and ultra-super. Here r_s is the number of rounds in which node has not been cluster head. $M_1(i)$, $M_2(i)$, $M_3(i)$, $M_4(i)$ are the initial energies of normal, advanced, super and ultra super nodes respectively. This threshold is set differently for each set of nodes. When node becomes cluster head r_s is set to 0.

When r_s reaches 1/Pi the threshold $T(S_i)$ is reset to the value it had before the inclusion of the remaining energy. So, the chance of node to become cluster head increases because of different sets of threshold. Thus, we ensure that data is transmitted to the base station as long as nodes are alive.The probabilities for four types of nodes in T-BEENISH are as follows:

$$P_i = \begin{cases} \frac{P_{opt} M_1(i)}{(1 + m(a + mo(-a + b + m_1(-b + u))))\bar{E}(r)} & \text{if } S_i \text{ is the normal} \\ \frac{P_{opt}(1 + a) M_2(i)}{(1 + m(a + mo(-a + b + m_1(-b + u))))\bar{E}(r)} & \text{if } S_i \text{ is the advanced} \\ \frac{P_{opt}(1 + b) M_3(i)}{(1 + m(a + mo(-a + b + m_1(-b + u))))\bar{E}(r)} & \text{if } S_i \text{ is the super node} \\ \frac{P_{opt}(1 + u) M_4(i)}{(1 + m(a + mo(-a + b + m_1(-b + u))))\bar{E}(r)} & \text{if } S_i \text{ is the ultra super} \end{cases} \tag{11}$$

Threshold is calculated for CH selection of normal, advanced, super and ultra-super nodes by putting above values in equation below,The equation (12) represents the classification of $T(S_i)$ for different energy levels where G’ , G”, G’”, G”” are the sets of normal nodes, advanced nodes, super nodes and ultra-super nodes respectively. This classification is necessary because in existing BEENISH among all the nodes (normal, advance, super and ultra-super) the cluster head is selected at random, each node randomly selects a number between 0 and 1 and if the number is less than the threshold $T(s)$, it becomes the cluster head for the current round. Now classification of threshold equation for different energy levels will help in setting different thresholds for distinct level nodes, this will further improves the cluster head selection in more efficient way.

$$T(S_i) = \begin{cases} \dfrac{Pi}{1 - Pi*\left(r \bmod \dfrac{1}{Pi}\right)}\left[\dfrac{E_i}{M_1(i)} + \left(r_s \text{ div } \dfrac{1}{Pi}\right)\left(1 - \dfrac{E_i}{M_1(i)}\right)\right] \text{if } S_i \text{ € G' is normal node} \\ \dfrac{Pi}{1 - Pi*\left(r \bmod \dfrac{1}{Pi}\right)}\left[\dfrac{E_i}{M_2(i)} + \left(r_s \text{ div } \dfrac{1}{Pi}\right)\left(1 - \dfrac{E_i}{M_2(i)}\right)\right] \text{if } S_i \text{ € G'' is advanced node} \\ \dfrac{Pi}{1 - Pi*\left(r \bmod \dfrac{1}{Pi}\right)}\left[\dfrac{E_i}{M_3(i)} + \left(r_s \text{ div } \dfrac{1}{Pi}\right)\left(1 - \dfrac{E_i}{M_3(i)}\right)\right] \text{if } S_i \text{ € G''' is super node} \\ \dfrac{Pi}{1 - Pi*\left(r \bmod \dfrac{1}{Pi}\right)}\left[\dfrac{E_i}{M_4(i)} + \left(r_s \text{ div } \dfrac{1}{Pi}\right)\left(1 - \dfrac{E_i}{M_4(i)}\right)\right] \text{if } S_i \text{ € G'''' is ultra node} \end{cases} \quad (12)$$

5. SIMULATION RESULTS

The proposed work is implemented using MATLAB simulator. Using MATLAB, the sensor field of 100mX100m is designed, the base station is placed in the centre of the network at the position (50, 50) and four types of nodes are randomly deployed with different initial energy thus resulting in heterogeneous sensor network. The network consists of 50 normal nodes, 35 advanced nodes, 12 super nodes and 3 ultra-super nodes.

Table 1. Simulation Parameters.

Parameters	***Values***
Area of network	100 x 100
Number of nodes	100
Length of data packet, L	4000 bits
Energy consumption of electronic emission, E_{Tx}	50nJ/bit
Energy consumption of electronic receiver, E_{RX}	50nJ/bit
Amplifier parameter of transmitting at close range, $\in_{fs}$	10pJ/bit/
Amplifier parameter of transmitting at long range, $\in_{mp}$	0.0013pJ/bit/
Energy consumption of data aggregation, E_{DA}	5nJ/bit/signal
The proportion of cluster heads, P_{opt}	10%
Initial energy of sensor nodes, E_0	0.5J
Threshold distance, d_0	87m

For simplicity, assumptions are made that all nodes are fixed and energy loss due to signal collision and interference between signals of different nodes due to dynamic random channel conditions are ignored. Protocols compared with T-BEENISH include BEENISH and EDEEC. The parameters are taken as; $m = 0.5$, $m_0 = 0.3$, $m_1 = 0.2$, $a = 1.5$, $b = 2.0$ and $u = 2.5$, containing 50 normal nodes having E_0 energy, 35 advanced nodes having 1.5 times more energy than normal nodes, 12 super nodes containing 2 times more energy than normal nodes and 3 ultra-super nodes containing 2.5 times more energy than normal nodes. Figure 2. represents the random deployment of nodes having four different levels of energy in the network. Figure 3. represents the comparison between the proposed protocol T-BEENISH with existing heterogeneous protocols BEENISH and EDEEC in terms of alive nodes during network lifetime and in figure 4. comparison in terms of packets sent to base station is given. It clearly shows that the stability period and lifetime of the T-BEENISH is longer as compared to other heterogeneous protocols.

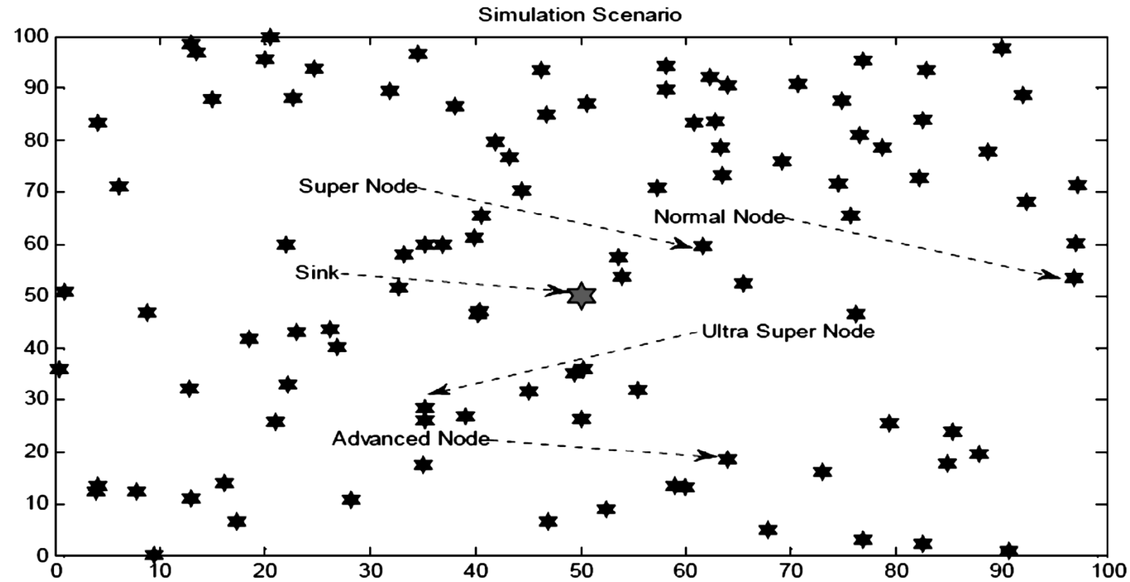

Fig. 2. Wireless sensor network with four level heterogeneity.

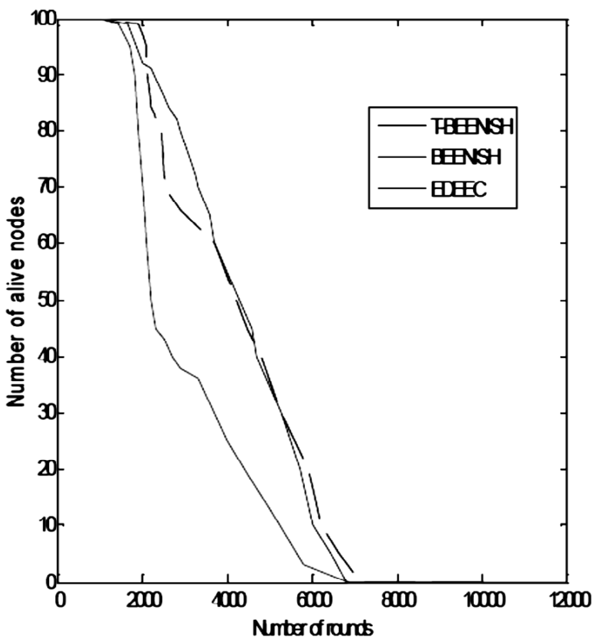

Fig. 3. Alive nodes during network lifetime

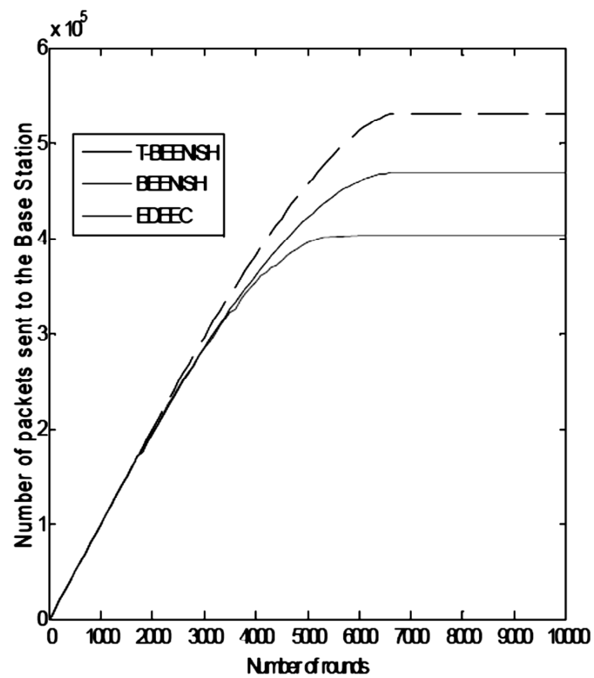

Fig. 4. Packets sent to Base Station

T-BEENISH shows 34 % improvement from EDEEC and 15% from BEENISH for first node dies (FND). It shows 5% improvement from EDEEC and 4.3% improvement from BEENISH in terms of last node dies (LND). First node dies for T-BEENISH is 1911 which was 1661 for BEENISH and 1421 for EDEEC. All nodes die for T-BEENISH, BEENISH and EDEEC is at 7200, 6903 and 6866 respectively as shown in figure 3. Figure 4.shows the comparison in terms of data packets received at the base station. The results show that for both the protocols it goes linearly for around 5000 rounds and after that difference can be seen. It is clear that data sent to BS is more in case of T-BEENISH in comparison to BEENISH. This represents that T-BEENISH has more stability period and lifetime in comparison to the EDEEC and BEENISH. So, T-BEENISH is most energy efficient protocol in comparison to other heterogeneous protocols BEENISH and EDEEC in terms of network lifetime, stability period and packets sent to BS.

Table 2. Tabular comparison of protocols in terms of performance measures

Protocols	*Stability Period*	*Network Lifetime*	*Packets sent to BS*
EDEEC	1421	6866	3.8X
BEENISH	1661	6903	4.5X
T-BEENISH	1911	7200	5.5X

6. CONCLUSION

WSNs comprises of a large number of sensor nodes deployed inside a region, these sensor nodes sense data and transmit it towards the base station (BS). Both sensing and transmitting towards BS requires a high energy amount which results in energy depletion of nodes at a faster rate as the network evolves which results in a finite network lifetime. So in wireless sensor networks, energy efficiency is the main issue. Clustering is an effective technique for energy conservation and extending lifetime of the network and also the presence of heterogeneity in the sensor network increases the energy efficiency, stability and lifetime of the network. So combining both, clustering in heterogeneous wireless sensor networks can result in balanced energy consumption, prolonged network lifetime and stability period. A large amount of research has been conducted on cluster head selection in WSN but there is still scope for the improvement in cluster head selection strategies. T-BEENISH has been proposed with the purpose to improve the cluster head selection in HWSNs. In T-BEENISH threshold equation for the cluster head selection is modified and adjusted according to the different energy levels in heterogeneous wireless sensor networks i.e. normal, advanced, super and ultra-super. This classification of the threshold equation for different energy levels, improves the cluster head selection among different kinds of nodes which were chosen as cluster heads at random before this modification. In this way cluster head selection is improved, simulations show that our proposed protocol T-BEENISH has better performance than the existing heterogeneous protocols BEENISH and EDEEC in terms of network lifetime, stability period and packets sent to BS.

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