An Enhanced Energy Efficient Clustering Scheme for Prolonging the Lifetime of Heterogeneous Wireless Sensor Networks

Suniti Dutt
ME Scholar (Electronics and Communication)
National Institute of Technical Teachers Training and Research, Chandigarh.

O. S. Khanna
Associate Professor (Electronics and Communication)
National Institute of Technical Teachers Training and Research, Chandigarh.

ABSTRACT
Wireless Sensor Networks (WSNs) comprise of a large number of sensor nodes. These sensor nodes have limited energy resources, processing and storage capabilities. The network layer protocols have thus to ensure reliable communication under these conditions. A higher network lifetime is one of the key issues of WSNs. Clustering is a very basic topological concept that cuts down the energy expenditure in WSNs. At present, majority of research is directed towards a homogeneous environment, wherein all the sensor nodes have initially the same amount of energy. Contrary to this, in a heterogeneous environment, a certain population of the sensor nodes is furnished with additional energy resources, thus leading to an energy-hierarchy. This heterogeneity in the sensor nodes results in a higher network lifetime. In this paper, we have proposed an energy efficient clustering scheme called ETDEEC (Enhanced Threshold Distributed Energy Efficient Clustering). Simulation results demonstrate the protocol performs better in terms of network lifetime and packet delivery capacity as compared to others.

General Terms
Networks, Wireless.

Keywords
Clustering; Heterogeneous Wireless Sensor Network; Hierarchical Routing.

1. INTRODUCTION
Wireless communication technologies have seen a continuous growth in diverse areas, leading to provide new opportunities for networking and services. One such area is Wireless Sensor Networks (WSN). WSNs are the products which incorporate the sensing techniques, the embedded techniques, as well as the communication techniques. The emergence of WSNs is a revolution in communication scenario and has generated an unparalleled interest among the researchers due to the sheer number of applications in which they may be used in the near future. The applications of WSNs are endless and limited only by human imagination. Cluster-based routing protocols, better known as hierarchical routing protocols, are based on the grouping of sensor nodes into clusters in order to address some of the weaknesses of flat routing protocols, like network lifetime, scalability and efficiency. The main idea is that the sensors communicate only with a leader in their own cluster, known as a Cluster Head (CH). These CHs are then responsible for aggregating and propagating data from their respective cluster members to the sink or Base Station (BS) [1,2,3].

As compared to homogeneous WSNs, Heterogeneous WSNs (HWSNs) consist of different types of sensor nodes with different abilities in terms of sensing, energy, computation and communication. There are basically four common types of heterogeneity in HWSNs as summarized below [4]:

- The Sensing Heterogeneity, which includes different sensing ranges and varied sizes of data packets.
- The Computational Heterogeneity, which includes different data storage capacities and different data compression techniques.
- The Communication Heterogeneity, which includes different transmission rates and different communication ranges.
- Energy heterogeneity, which includes different energy levels for different sensor nodes.

The rest of the paper is organized as follows: Section II contains the related work done. Section III explains the proposed protocol. Section IV shows the simulation results followed by conclusions, future work and references.

2. RELATED WORK
Qing et al [5] have proposed a Distributed Energy-Efficient Clustering (DEEC) scheme based on the ideas of LEACH [6]. The theme of the protocol is to elect the CHs using probability based approach in order to estimate the ratio of the remainder energy of every node and the average energy of the whole network. Eventually, the node with high residual energy will become CHs more often than the nodes with low energy. DEEC estimates the idealistic value of the network lifetime in order to avoid the global knowledge of the network. This is an advantage of DEEC. The only restraint with this scheme is that the estimated average energy is inversely proportional to the energy consumed in each round. This proves to be a drawback in the model estimation of DEEC. The simulation results show that DEEC achieves a longer lifetime than LEACH protocol in a heterogeneous environment. An improvement over DEEC is

proposed as Stochastic DEEC (SDEEC) [7]. The CH selection is based on a node's residual energy. The Stochastic scheme reduces the intra-cluster transmission. Similar to DEEC, SDEEC considers two-level energy heterogeneity, but it conserves more energy as it puts the non-CH nodes into sleep mode. The drawback of SDEEC is that if the non-CH sensor nodes are in the sleep mode then how are they going to know about the start of CH selection for the next round. Smaragdakis et al [8] were one of the first to address the impact of energy heterogeneity of nodes in WSNs in the form of Stable Election Protocol (SEP) network layer protocol. Their approach was to assign weighted probability to each node based on its energy level as the network evolves. One major characteristic of this approach is that it rotates the CH to adapt the election probability to suit the heterogeneous settings. The authors used two kinds of nodes: normal nodes and advanced nodes. The advanced nodes have more energy by a factor of α over the normal nodes. The advanced nodes take up CH position more than the normal nodes during the same epoch according to SEP model estimation. It has been shown by simulations that SEP always extends the stability period and also increases the average throughput as compared to LEACH clustering protocol.

Developed Distributed Energy Efficient Clustering (DDEEC) [9] is very similar to DEEC. The difference between both lies in the expressions that define the probability for normal and advanced nodes to become a CH. A phase comes during network evolution where the advanced nodes have similar residual energies as the normal nodes. During this phase, DEEC continues to penalize the advanced nodes, which is not an optimal method because by this, the advanced nodes die much faster than the normal nodes. To avoid this unbalance, DDEEC introduces a threshold residual energy. When the energy levels of advanced and normal nodes fall below this threshold residual energy, then same probability is used by all nodes to become a CH, thereby making the CH selection process more efficient. Enhanced Distributed Energy Efficient Clustering or EDEEC [10] uses the concept of three level heterogeneous networks. It consists of three types of nodes-normal, advanced and super nodes-based on initial energies. EDEEC incorporates different probability values for normal, advanced and super nodes. TDEEC [11] uses the same process of CH selection and estimation of average energy as in DEEC. At start of each round, the nodes decide whether or not to become a CH by selecting a random number within 0 and 1. If this selected number is lower than threshold T_s, then the node becomes a CH for that round. Simulation results show that in terms of network lifetimes, both EDEEC and TDEEC protocols are better than DEEC. TDEEC is the best protocol out of these three over DEEC.

3. PROPOSED PROTOCOL

This paper proposes an approach called Enhanced Threshold Distributed Energy Efficient Clustering (ETDEEC) algorithm whose main aim is to increase the network lifetime as well as the packet delivery capacity of the heterogeneous WSN, which is the number of data packets sent to the BS over rounds of communication,

3.1 Network Model

This work considered the radio energy dissipation model as shown in Fig. 1. The transmitter dissipates energy to run the radio electronics and the receiver dissipates energy in order to run the radio electronics. In this model, both the free space loss (d^2 power loss) and the multipath fading (d^4 power loss) channel models were used, based on node distances (d).

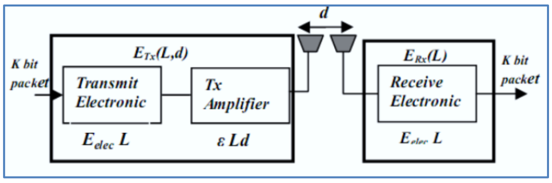

Fig 1: Radio Energy Dissipation Model [18]

To transmit an L-bit message, the energy expended, $E_{TX}(L,d)$, is:

$$E_{TX}(L,d) = \begin{cases} L * E_{elec} + L * E_{fs} * d^2 & if\ d < d_o \\ L * E_{elec} + L * E_{amp} * d^4 & if\ d \geq d_o \end{cases} \quad (1)$$

where d_o is the distance threshold for swapping between the two amplification models and E_{fs} is the amplifier loss due to the application of free space path loss model and E_{amp} is the amplifier loss due to the application of multipath loss model.

To receive a L-bit message, the radio will expend:

$$E_{RX}(L) = E_{elec} * L \quad (2)$$

3.2 Cluster Formation

Each sensor chooses a random number within 0 and 1. If this number is lesser than the threshold for node s_i, $T(s)$, the sensor node becomes a CH. The modified threshold value is given by:

$$T(s) = \frac{p_i}{1-p_i(r mod \frac{1}{p_i})} * \frac{Residual\ Energy\ of\ a\ node}{Initial\ energy\ of\ a\ node} \quad (3)$$

where the probability p_i is defined separately for different types of nodes in two-level and three-level heterogeneous networks.

The probabilities of election of a CH are modified in ETDEEC as compared to the probabilities in TDEEC by introducing a distance factor to it. Let d_i be the actual distance of an i^{th} node from the BS. And let d_{avg} be the average distance from any node to the BS, d_{toCH} be the average distance between the CH and the cluster members, and d_{toBS} be the average distance between the CHs and the BS, then by [11]:

$$d_{avg} = d_{toCH} + d_{toBS} \quad (4)$$

Then, according to the proposed probability, if the distance d_i of i^{th} node is less than or equal to distance d_{avg}, then the probability equation of TDEEC, given by equations, gets multiplied by the factor (d_i/d_{avg}), else it is kept the same as in TDEEC. The idea behind incorporating this modification is that by introducing the distance factor, the far-away nodes from the BS gets lesser chance of becoming a CH, which results in energy saving of these nodes. Had these far-away nodes become CH with same probability as the near nodes, their energy would have drained faster since these would be transmitting to the BS from larger distances. The same has been shown in Fig. 2 and Fig. 3.

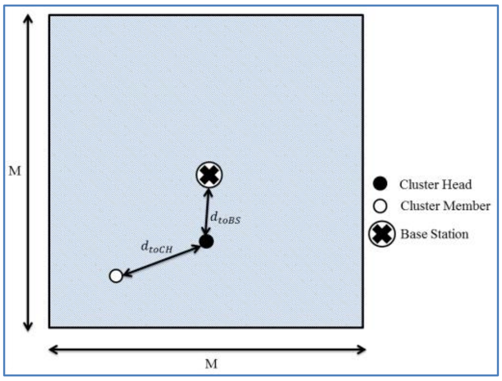

Fig 2: Average distances from a node to the BS

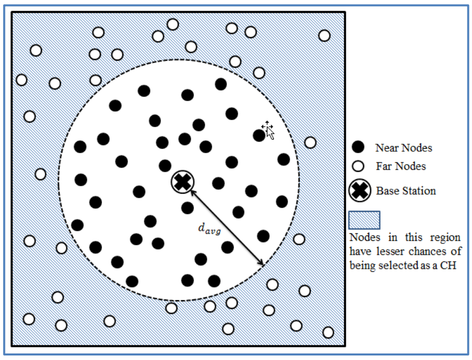

Fig 3: Distance of near nodes and far nodes

3.3 Two-Level Heterogeneity

Two-level heterogeneity consists of two types of nodes−the normal nodes and the advanced nodes. If there are total n nodes in the network, $n * m$ nodes $(0 < m < 1)$ will be advanced nodes and the rest $n * (1 - m)$ nodes will be normal nodes. The energy of normal nodes is E_o and the energy of advanced nodes is $E_o(1 + a)$ with $a > 0$. The modified probabilities of normal and advanced nodes in case of two-level heterogeneity are:

$if\ d_i \leq d_{avg}$ then

$$p_i = \begin{cases} \frac{p_{opt} * Residual\ Energy\ of\ a\ node * d_i}{(1+am) * Average\ Energy\ of\ a\ network * d_{avg}} & if\ s_i\ is\ normal\ node \\ \frac{p_{opt} * (1+a) * Residual\ Energy\ of\ a\ node * d_i}{(1+am) * Average\ Energy\ of\ a\ network * d_{avg}} & if\ s_i\ is\ advanced\ node \end{cases} \quad (5)$$

and $if\ d_i > d_{avg}$ then the factor of (d_i/d_{avg}) is not multiplied in the above equation.

3.4 Three-Level Heterogeneity

Three-level heterogeneity consists of three types of nodes- the normal nodes, the advanced nodes and the super nodes. If there are total n nodes in the network, $n * m * m_o$ nodes $(0 < m, m_o < 1)$ will be super nodes, $n * m * (1 - m_o)$ nodes will be advanced nodes and the rest $n * (1 - m)$ nodes will be normal nodes. The energy of normal nodes is E_o, of advanced nodes is $E_o(1 + a)$ and of super nodes is $E_o(1 + b)$ with $a, b > 0$. The modified probabilities of normal, advanced and super nodes in case of three-level heterogeneity are:

$if\ d_i \leq d_{avg}$ then

$$p_i = \begin{cases} \frac{p_{opt} * Residual\ Energy\ of\ a\ node * d_i}{(1+m(a+m_o b)) * Average\ Energy\ of\ a\ network * d_{avg}} & if\ s_i\ is\ normal\ node \\ \frac{p_{opt} * (1+a) * Residual\ Energy\ of\ a\ node * d_i}{(1+m(a+m_o b)) * Average\ Energy\ of\ a\ network * d_{avg}} & if\ s_i\ is\ advanced\ node \\ \frac{p_{opt} * (1+b) * Residual\ Energy\ of\ a\ node * d_i}{(1+m(a+m_o b)) * Average\ Energy\ of\ a\ network * d_{avg}} & if\ s_i\ is\ super\ node \end{cases} \quad (6)$$

and $if\ d_i > d_{avg}$ then the factor of (d_i/d_{avg}) is not multiplied in the above equation.

3.5 Two-Hop Scenario

Single-hop communication and multi-hop communication are two communication modes which are used in WSNs. In single-hop mode, where data packets are directly sent to the BS without any intermediate relay, the sensors that are located farther away from the BS have higher energy dissipation due to the long-distance communication, and these nodes die out faster as compared to the rest of the nodes. To mitigate this problem, two-hop communication has been used between CHs in the present work. The authors in [12] have considered a disc-shaped sensing terrain with radius r', with the BS located at the centre. Any CH making one hop to the BS is placed in an area which is disc-shaped with radius R. In similar fashion, any CH making two hops to the BS are placed in a ring-shaped area whose inner radius is R and outer radius is $2R$. Consequently, CHs making k hops to the BS are placed in a ring-shaped area whose inner radius is $(k-1)R$ and outer radius is kR. This approach is shown in Fig. 4. This approach can be applied to an arbitrary-shaped network. Similar to this approach, our approach takes into consideration a radius of connectivity R around BS, and chooses an energy-efficient path amongst the CHs. The CHs farther away from BS communicate their aggregated data to CHs closer to the BS. The local CHs communicate aggregated data from their cluster members to nearest relay CHs located within radius R of BS.

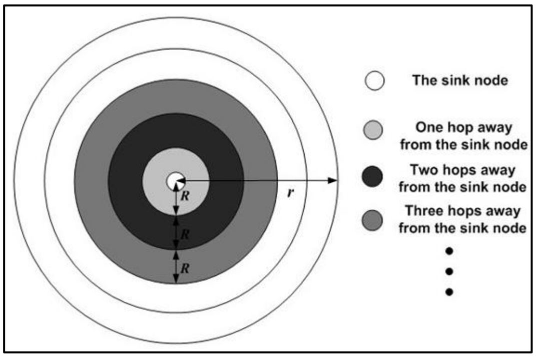

Fig 4: Number of hops from CH to BS [12]

4. SIMULATIONS AND RESULTS

This paper assumes that 100 sensor nodes are randomly scattered in a two-dimensional square field of dimensions 100x100 square metres. It also assumes a two-hop setting. For the purpose of analysis, MATLAB is used to implement the simulation. The network parameters are summarized in Tables 1, 2 and 3.

Table 1: Parameter Settings

Parameters	Value
Network Size (square metres)	100x100
Location of BS (metres)	(50,50)
Number of nodes	100
Data Packet Length (bits)	4000
Threshold Distance, d_o(metres)	70
Transmitter/Receiver Electronics Energy	50nJ/bit
Data Aggregation Energy	5nJ/bit
Transmit Amplifier Energy, E_{fs}, if $d_{toBS} \leq d_o$	10pJ/bit/m^2
Transmit Amplifier Energy, E_{amp}, if $d_{toBS} \geq d_o$	0.0013pJ/bit/m^4
Optimal Probability	0.1
Two-hop radius, R (metres)	25

Table 2: Two-Level Heterogeneity

Parameters	Value
Proportion of Advanced Nodes, m	0.3
Energy Factor for Advanced Nodes, a	1.5
Initial Energy of Normal Nodes (Joules)	0.5

Table 3: Three-Level Heterogeneity

Parameters	Value
Proportion of Advanced Nodes, m	0.5
Proportion of Super Nodes among Advanced Nodes, m_o	0.4
Energy Factor for Advanced Nodes, a	1.5
Energy Factor for Super Nodes, b	3
Initial Energy of Normal Nodes (Joules)	0.5

4.1 Analysis of Experiment

The definitions of the performance metrics used are:

- Network Lifetime: The time up to when the first node of the network dies.
- Packet Delivery Capacity: The number of data packets sent from the CHs to the BS over the number of rounds.

4.2 Comparing Proposed Protocol ETDEEC with TDEEC

4.2.1 Two-level Heterogeneity

The deployment of heterogeneous sensor nodes in the WSN is shown in Fig. 5, where a normal node is denoted by a 'o' and an advanced node is denoted by a '◊'. The BS is at the centre of the field, depicted by 'x'. In this case there are 30 advanced nodes deployed with 1.5 times more energy than normal nodes. The rest 70 nodes are normal nodes.

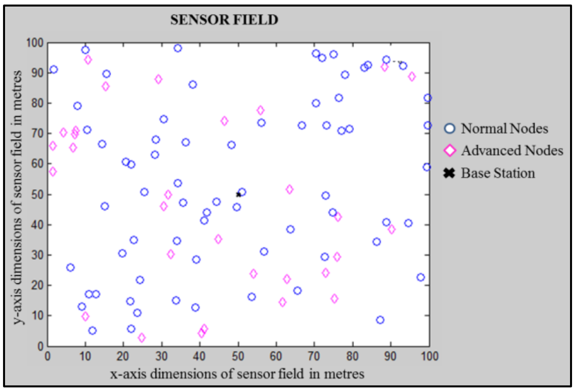

Fig 5: Deployment of two-level heterogeneous network

Fig. 6 shows the graph comparing the proposed protocol ETDEEC with TDEEC protocol in terms of the network lifetime. The graph depicts the number of dead nodes with respect to the number of rounds of network operation. The first node death in case of TDEEC occurs at round 1785 whereas the first node death occurs at round 2189 in case of the proposed protocol ETDEEC. The percentage improvement of the network lifetime is 22.6%. The last node in case of TDEEC dies at round 5562, whereas in case of the proposed protocol ETDEEC the last node dies at round 5873. The normal nodes are the first to die out since these have lesser energy as compared to the advanced nodes. When all the 70 normal nodes die out, no node death takes place for some rounds as the advanced nodes still have enough energy left. This is clearly depicted from the horizontal portion of the curve, after which the nodes again start to die out.

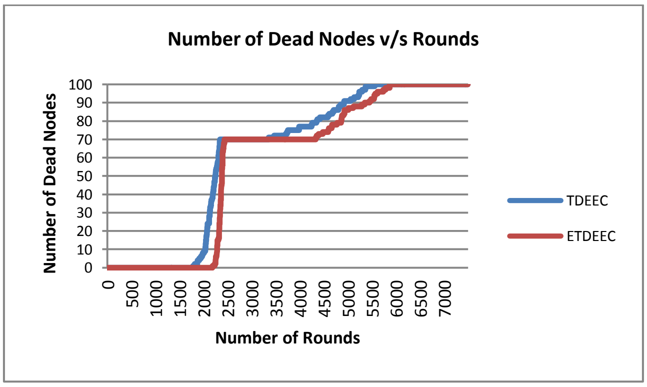

Fig 6: Network Lifetime in case of two-level heterogeneous network

Fig. 7 shows the graph depicting the total remaining energy in Joules over number of rounds of communication. The total initial energy of the network for both the protocols is 72.5 Joules. As clear from the graph, the rate of energy dissipation is larger in TDEEC protocol as compared to the proposed protocol ETDEEC. Also, for both the protocols, the total residual energy curve has a constant slope upto the point when the first node dies.

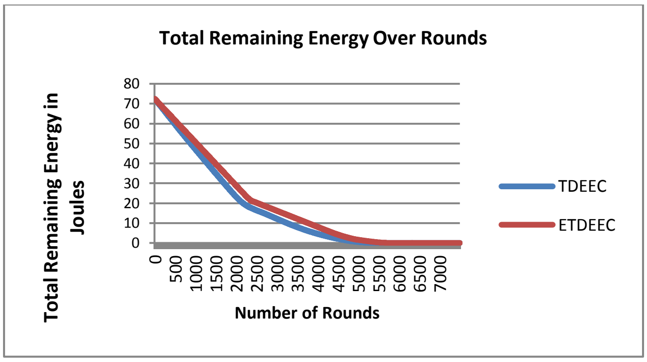

Fig 7: Total remaining energy over rounds in case of two-level heterogeneous network

Fig. 8 shows the graph comparing the proposed protocol ETDEEC with TDEEC protocol in terms of the number of data packets received at the BS. The graph depicts the number of data packets received at the BS with respect to the number of rounds. As clearly depicted, the proposed protocol ETDEEC outperforms TDEEC here also. The total count of data packets received at the BS in case of TDEEC is 1.3×10^5 whereas it is 1.6×10^5 in case of the proposed protocol ETDEEC. The percentage improvement is 23%. As clear from the graph, the number of packets received at the BS increases almost linearly with the number of rounds and then saturate.

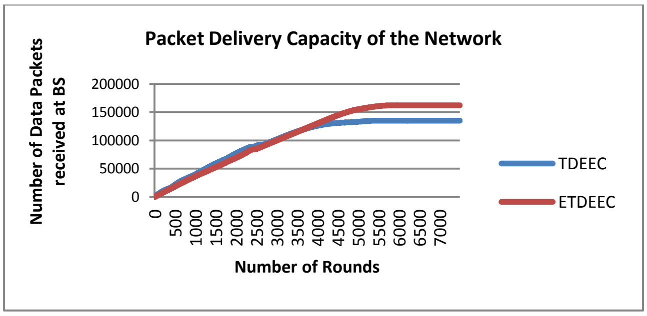

Fig 8: Number of packets sent to BS in case of two-level heterogeneous network

4.2.2 *Three-level Heterogeneity*

The deployment of heterogeneous sensor nodes in the WSN is shown in Fig. 9, where a normal node is denoted by a 'o', an advanced node is denoted by a '◊' and a super node is depicted by '☆'. The BS is at the centre of the field, depicted by 'x'. In this case there are 30 advanced nodes deployed with 1.5 times more energy than normal nodes and 20 super nodes deployed with 3 times more energy than the normal nodes. The rest 50 nodes are normal nodes.

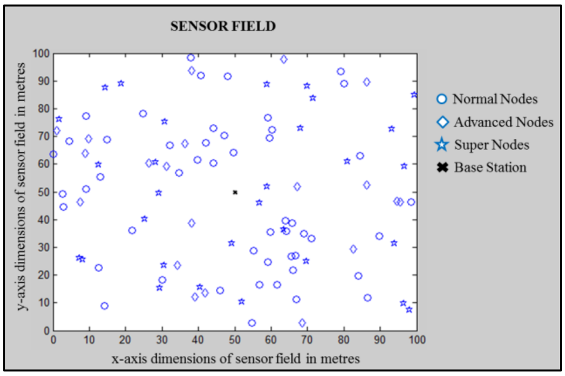

Fig 9: Deployment of three-level heterogeneous network

Fig. 10 shows the graph comparing the proposed protocol ETDEEC with TDEEC protocol in terms of the network lifetime. The first node death in case of TDEEC occurs at round 1876 whereas it is improved to round 2243 in case of the proposed protocol ETDEEC. Clearly, the stability period is improved by 19.6%. The last node in case of TDEEC dies at round 8866, whereas in case of the proposed protocol ETDEEC the last node dies at round 9331.

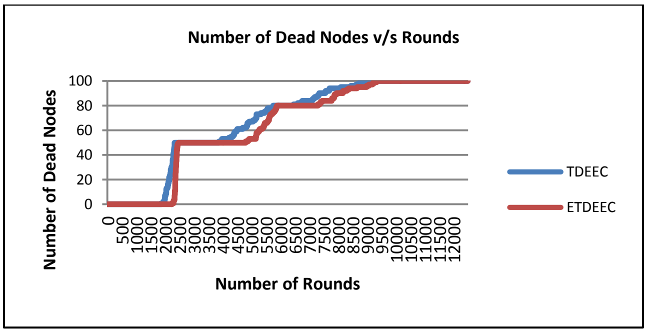

Fig 10: Network Lifetime in case of three-level heterogeneous network

Fig. 11 shows the graph depicting the total remaining energy in Joules over number of rounds of communication. The total initial energy of the network for both the protocols is 102.5 Joules. Clearly, the rate of energy dissipation is larger in TDEEC protocol as compared to the proposed protocol ETDEEC.

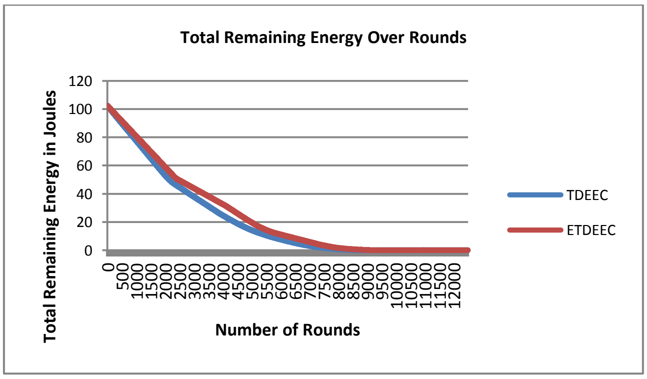

Fig 11: Total remaining energy over rounds in case of three-level heterogeneous network

Fig. 12 shows the graph comparing the proposed protocol ETDEEC with TDEEC protocol in terms of the number of data packets received at the BS. The graph depicts the number of data packets received at the BS with respect to the number of rounds. As clearly depicted, the proposed protocol ETDEEC outperforms TDEEC here also. The total count of data packets received at the BS in case of TDEEC is 2×10^5 whereas it is 2.4×10^5 in case of the proposed protocol. The percentage improvement is 20%.

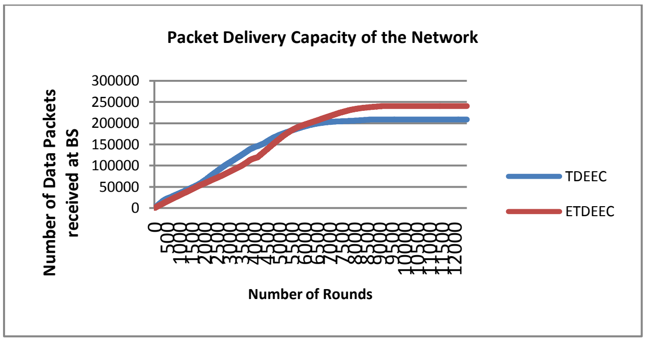

Fig 12: Number of packets sent to BS in case of three-level heterogeneous network

5. CONCLUSIONS

Many researchers have worked towards extending the network lifetime of WSNs, but there still exists a need for developing a more robust heterogeneity-aware design. Following this motivation, this work modified the TDEEC protocol, with an aim to increase the network lifetime as well as the packet delivery capacity of the WSN. The simulation results show that the proposed protocol ETDEEC performs better as compared to the TDEEC protocol in heterogeneous environment for WSNs in both two-level and three-level energy heterogeneities. The network lifetimes improved by as much as 22.6% and 19.6% for two-level and three-level heterogeneity over TDEEC protocol. The number of packets received at the BS improved by as much as 23% and 20% for two-level and three-level heterogeneity over TDEEC protocol. This clearly shows that the proposed protocol ETDEEC outperforms the TDEEC protocol.

6. FUTURE RESEARCH DIRECTION

Following the TDEEC approach a generalized model can be developed for multi-diversity of nodes i.e. more than three types of nodes. This work can also be extended to multi-hierarchy where the communication method is multi-hop instead of a single-hop or two-hop. The traffic pattern used for analysis is Constant Bit Rate (CBR). Since WSNs are evolving into multimedia systems, this demands for the design of new protocols that can allow for different traffic patterns or the Variable Bit Rate (VBR) traffic patterns, comprising of bursty packets.

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