Gateway Based Multi-Hop Distributed Energy Efficient Clustering Protocol for Heterogeneous Wireless Sensor Networks

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ABSTRACT

Wireless sensor network consists of application oriented and cheap micro-devices called sensors nodes having potential of connecting the physical world with virtual world by their sensing abilities. These sensor nodes are having restrained battery sources. Efficient energy management is current area of research in wireless sensor networks. Here we advice one such energy aware multi-hop protocol (G-DEEC) for two level heterogeneous networks. In G-DEEC, the Base Station is placed out of sensing area and rechargeable gateway nodes are placed inside field with other randomly deployed sensor nodes. Simulation shows the proposed protocol G-DEEC is better than single-hop DEEC in terms of number of half dead nodes, alive nodes and dead nodes; thereby showing improvement in network lifetime and stability.

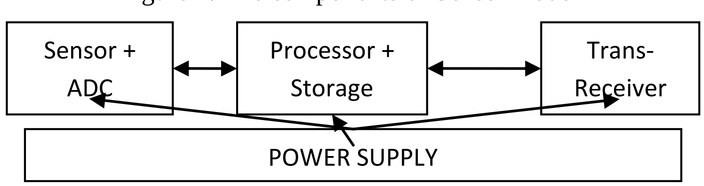
KEYWORDS

Wireless sensor network, DEEC, lifetime, half dead nodes, alive nodes, stability, gateway.

1. INTRODUCTION

Ongoing advancements in VLSI and MEMS (Micro-electro-mechanical Systems) lead to manufacture of sensor networks in large numbers. Sensors have many applications depending on the application they are being used for like forest fire detection in forests, enemy tracking in military areas; they are also used for monitoring temperature, pressure, intensity, chemical concentrations, tracking objects. Sensors are also useful in medical science for monitoring vital body functions [1]. Sensor nodes mainly consists of sensor with analog to digital converter (ADC) which sense the outer environment defending on application they are being used for; then the converter converts the sensed analog data to digital form as shown in figure 1. ADC forward the converted data to processor for processing of data and finally to trans-receiver antennas for sending to final Base station.

Figure 1. The components of Sensor Node



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Sensors are randomly scattered in sensing field connected other sensor nodes and finally connected to base station. In conventional protocols like DT and MTE, data is transmitted directly from sensor nodes to base station (BS) and one node to neighboring node respectively [2]. So nodes away to BS die more often as compared to other nodes as they are require more energy in transmitting data in DT. Nodes near to BS are more probable to transfer data in MTE; so nodes near to BS die more often. Here comes the concept of clustering introduced in LEACH [3] in network field where a group of nodes are grouped together in one cluster with one Cluster head (CH). CH will aggregate the collected data and further transfer this data to BS. Wireless communication architecture as shown in figure 2 consists of nodes like A, B, C, D, E etc scattered in sensing field. If want to send data to BS; it follows multi-hop routing i.e. A send data to B and then to C and so on finally to BS.

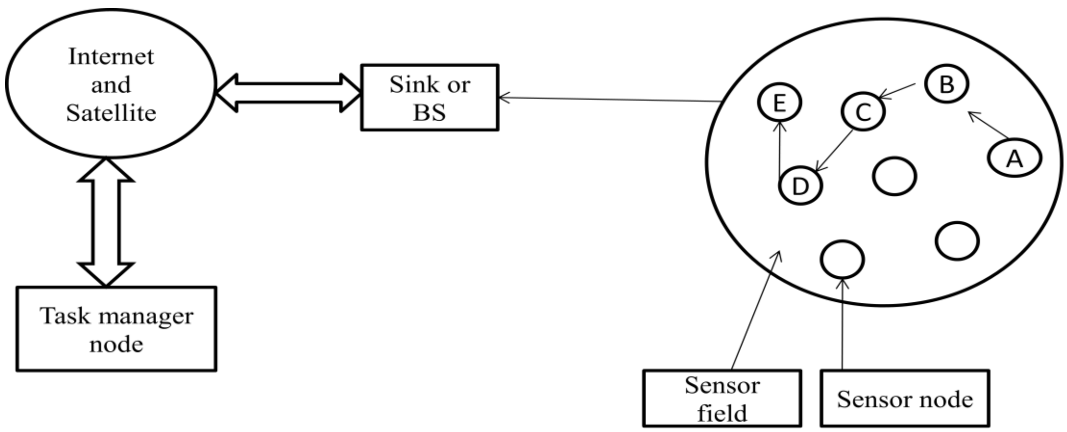

Figure 2. Architecture of multi-hop sensor network

LEACH introduced clustering in homogeneous sensor networks where each sensor node is having same initial energy levels. Routing of data in sensor networks is done through many homogeneous and heterogeneous routing protocols. Homogeneous protocols include LEACH [3], PEGASIS [18], HEED [19], TEEN [16, 21], M-GEAR [23] whereas heterogeneous protocols include SEP [4], DEEC [5], DDEEC [6], E-DEEC [22], DEEC-WIN [12], SEARCH [14]. Homogeneous protocols have all nodes of same type in terms of size, shape and mode of energy supply whereas a heterogeneous protocol utilizes the energy discrimination of sensor nodes. Heterogeneous protocols are helpful in increasing the network lifetime compared to homogeneous protocols. As the sensor nodes are energy constrained in terms of battery power [17, 20] so here we introduce the gateway based multi-hop protocol where 9 gateway nodes are placed in sensor field in systematic manner so that the CH of each cluster formed is near to the gateway node. Deployment of gateway nodes reduces the transmission distance from sensor nodes to BS; thereby increasing the number of half dead nodes, alive nodes. Election of CH is done on basis of ratio of residual energy to average energy making the transmission more reliable.

2. RELATED WORK

In [3], clustering was introduced for homogeneous sensor networks unlike conventional protocols like DT, MTE in order to increase the network lifetime of homogeneous sensor networks. Here the role of CH is rotated so that only one node doesn't keep on draining it initial energy level. Simulation performed showed improvement in stability period of homogeneous sensor networks.

In [4], clustering was used for heterogeneous sensor networks by proposing a new protocol SEP unlike LEACH, PEGASIS [18], HEED [19] etc. CH is chosen on basis of initial energy of sensor nodes. Two level heterogeneity is been considered i.e. normal nodes and advance nodes with additional energy. As advance nodes are having higher energy levels than normal nodes so they are more probable to become CH in each transmitting round. Simulation performed showed improvement in stability than LEACH.

In [5], distributed energy efficient clustering (DEEC) was proposed for heterogeneous wireless sensor networks. CHs are chosen based on residual energy unlike SEP where they are chosen based on initial energy. Simulation performed showed improvement in stability and lifetime of network as compared to SEP.

In [6], developed distributed energy efficient clustering (DDEEC) was proposed for heterogeneous wireless networks which balances the selection of CHs over entire sensor field. Here an improvement in CH selection as compared to DEEC is been done where advance nodes are equally probable of becoming CHs as normal nodes after energy depletion. Simulation performed showed improvement in stability period as compared to DEEC.

In [7], balanced and centralized distributed energy efficient clustering (BCDEEC) for heterogeneous wireless sensor networks is been proposed which is an extension of DEEC. Simulation performed showed improvement in stability period as compared to DEEC and SEP.
In [8], SEP was extended to three-level heterogeneity by considering normal nodes, intermediate nodes and advance nodes with different energy levels in protocol named SEP-E. Simulation performed showed improvement in terms of throughput and stability (First node dead) as compared to LEACH.

In [9], heterogeneity aware hierarchical stable election protocol was proposed which tends to increase lifetime of Wireless sensor networks (WSNs) by reducing transmission cost between CH and BS. Two types of CHs are considered i.e. primary and secondary CHs. Secondary ones are chosen from primary ones. Simulation performed showed improvement in network lifetime as compared to LEACH, SEP and DEEC.

In [10], Away cluster head scheme (ACH), was proposed foe heterogeneous wireless sensor networks which consider number of sensor nodes similar in all clusters so that energy dissipated is similar for all clusters and nodes are considered normal if distance from nearby CH is less than 12m, otherwise they are called as advance nodes. Simulation performed showed improvement in average residual energy as compared to LEACH and SEP.

In [11], Cluster head re-election protocol (CRP), was proposed where re-election of CHs is done from elected ones on basis of residual energy. Simulation performed showed improvement in residual energy deviation as compared to LEACH and SEP.

In [12], DEEC with Isolated Nodes (DEEC-WIN) was proposed where mechanism of nodes joining a cluster is improved. Some nodes near to BS communicate directly to BS. Simulation performed improvement as compared to DEEC.

In [13], Energy efficient two level distributed clustering (EE-TDLC) scheme, was proposed to save transmission cost by considering secondary level CHs after primary CHs. Simulation performed showed improvement in number of CHs and improvement in stability period.

3. SYSTEM MODEL OF PROPOSED PROTOCOL (G-DEEC)

3.1 Basic assumptions of proposed protocol G-DEEC

1. BS is placed out of network field which is stationary after deployment.
2. Bs is location aware and aware about location of other sensor nodes
3. Each sensor node is provided with different identity in network area called as sensor ID (Identifier).
4. Location of gateway nodes is been decided before deployment such that each CH formed is near to gateway node.
5. Gateway nodes are rechargeable and stationary after placement.
6. Transmission distance is reduced between CHs and BS with aid of gateway nodes.
7. Sensor nodes are uniformly distributed over network field.
8. Two level heterogeneous nodes are deployed i.e. normal nodes and advance nodes.

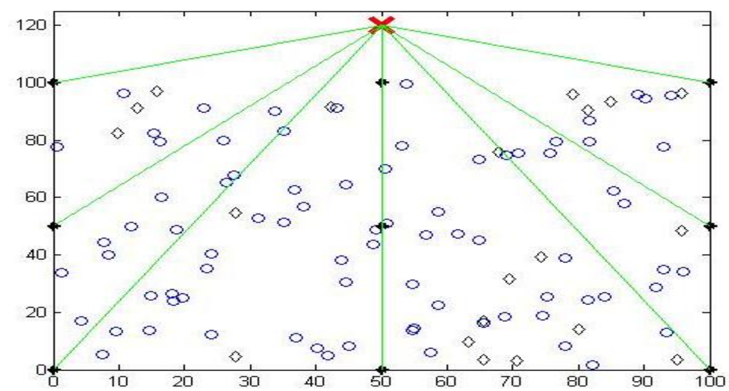

Figure 3. Network model of proposed G-DEEC

- ○ Normal nodes
- ◊ Advanced nodes
- × Base Station
- * Gateway nodes

Here we used first order radio dissipation model as used in LEACH [3] as shown in figure 4. This model describes the amount of energy dissipated in transmitting, receiving and fusing data from sensor nodes to Base station. Energy dissipated by transmitter is higher than receiver. The energy consumption in transmitting l- bit data packet at distance d is given as

$$E_{TX}(l, d) = \begin{cases} L.E_{elec} + L \in_{fs}.d^2, & \text{if } d \leq d_o \\ L.E_{elec} + L \in_{mp}.d^4, & \text{if } d > d_o \end{cases} \quad (1)$$

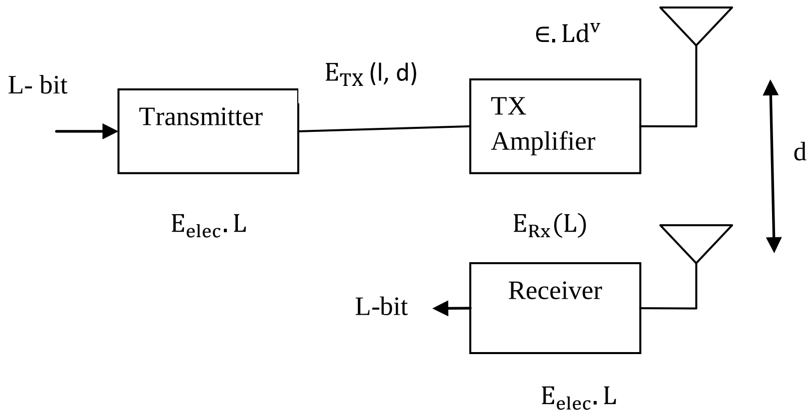

Figure 4. Radio dissipation model

Where E_{elec} is amount of energy dissipated per bit to run electronic circuit. $\in_{fs}$ is free space path loss and $\in_{mp}$ is multi path attenuation constant depending on model. Here d is distance between two interacting ends and d_o is threshold distance calculated as

$$d_o = \sqrt{\frac{\in_{fs}}{\in_{mp}}} \tag{2}$$

3.2 THE G-DEEC PROTOCOL

In this research we proposed a heterogeneity aware multi-hop energy efficient clustered protocol for WSNs. G-DEEC (Gateway based multi-hop DEEC), where gateway are stationary battery rechargeable sensor nodes which are deployed at center of boundaries, corners and middle of sensor field so that the CH from each cluster is each approachable to gateway node. Data transmission in G-DEEC follows multi-hop data transmission i.e. CHs collect and aggregate all of data coming from sensor node members of their cluster and forward this data for further processing to gateway nodes; whose function is to process the collected data from CHs and pass this data to BS. Gateway nodes reduce traffic problems and increase the rate of data transmission. As number of gateways are deployed in network field, increases reliability of network from failures of gateway node as if one gateway node is blocked or damaged in particular case; another nearby located gateway node can do the network operations. Data may follow DT (Direct Transmission) in case they are near to BS or near to gateway node. This protocol considers two types of sensor nodes in terms of energy levels i.e. normal nodes and m fraction of a% advance nodes.

Total energy E_{total} = Energy of normal nodes + Energy of advance nodes

$$= n\,(1\text{-}m)\,E_o + nmE_o(1+a) = n\,(1+ma) \tag{3}$$

where n is total number of nodes and E_o is initial energy of normal nodes and m is fraction of advance nodes having a% extra energy than normal nodes. CHs are elected based on ratio of residual energy and average energy of network as in DEEC [5]. Different election probabilities are considered for normal nodes p_{nrm} and advance nodes p_{adv} as:

$$p_{nrm} = \frac{p_{opt}}{1+m\times\alpha} \times \frac{E_i}{E_a} \quad (4)$$

$$p_{adv} = \frac{p_{opt}}{1+m\times\alpha} \times (1+\alpha) \times \frac{E_i}{E_a} \quad (5)$$

Where E_i is residual energy and E_a is ideal average energy that each node should own to keep network alive to longer extent.

$$E_a = \frac{1}{n} \times E_{total} \times \left(1 - \frac{r}{R}\right) \quad (6)$$

Where r is current round and R is the total number of processing rounds. After election of CHs per round, a single CH is selected per round based on random number generated and comparing this number with threshold value $T(n_{nrm})$ for normal nodes and $T(n_{adv})$ for advance nodes as in equation below:

$$T(n_{nrm}) = \begin{cases} \frac{p_{nrm}}{1-p_{nrm}\left[r \times \mathrm{mod}\left(\frac{1}{p_{nrm}}\right)\right]}, & \text{if } n \in g' \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

$$T(n_{adv}) = \begin{cases} \frac{p_{adv}}{1-p_{adv}\left[r \times \mathrm{mod}\left(\frac{1}{p_{adv}}\right)\right]}, & \text{if } n \in g'' \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

Where r is round number of current processing and g' is set of normal nodes not been cluster heads in last $1/P_{nrm}$ rounds and g'' is set of advance nodes not been cluster heads in last $1/P_{adv}$ rounds.

4. PERFORMANCE EVALUATION

4.1 Simulation settings

In order to improve the performance of G-DEEC, we simulated our proposed G-DEEC protocol in MATLAB. We consider a 100m*100m wireless sensor network field comprised of 100 nodes deployed uniformly over it with some pre-planned Gateway nodes. BS is deployed 25m away from top sensor area boundary. BS is stationary at its place and gateway nodes are also non-movable but rechargeable to increase the number of alive nodes so as to increase the network lifetime. To assess the performance of proposed G-DEEC with DEEC, we ignore the interference in transmission channels. We consider packet size of 4000 bits. 9 Gateway Nodes are located at predefined distance covering the network field. Data can be transmitted directly to BS in case they are near to BS than the CH or gateway node. Simulation parameters are given in Table 1.

4.2 Performance metrics

4.2.1 Network lifetime- This is defined as time till network is operational and calculated from number of half dead nodes, dead nodes, alive nodes.

4.2.1.1 Half Dead nodes (HDN) - These are defined as nodes which are partially dead and partially alive and still perform network operations. They need to high in number to increase network lifetime. Total HDN comprised of NHDN (Normal half dead nodes) and AHDN (Advance half dead nodes).

4.2.1.2 Dead nodes (DN) - These are nodes with no energy left for processing. They need to be low in number for increasing network lifetime. Total DN comprised of NDN (Normal dead nodes) and ADN (Advance dead nodes).

4.2.1.3 Alive nodes (AN) - These are defined as nodes having some left energy after processing so these nodes can still be part of network operations. They need to be high in number to increase network lifetime. Total AN comprised of NAN (Normal alive nodes) and AAN (Advance alive nodes).

4.2.2 First node dead (FND) - This is defined as time interval between start of processing rounds till first node becoming dead. Late the round of dying first node arrives, higher the stability of network.

4.2.3 Remaining energy- This is defined as leftover energy per processing round. Higher this energy increases the network lifetime as network will be operational for much longer time.

4.2.4 Packet transmission- This is defined as amount of data exchanged between CHs and BS. The rate of data transmission from sensor nodes to CH and further to BS via CH; gateway or directly is considered.

4.3 Simulation results and Analysis

4.3.1 Network lifetime: Following in this section we are analyzing the network lifetime in terms of HDN, DN, AN.

4.3.1.1 Analysis of HDN (Half Dead Nodes) - In figure 5, Total number of half dead nodes in DEEC and proposed DEEC is shown. The number is zero in DEEC which is coming out to be 60 in proposed G-DEEC at 2000 iteration showing 60% overall improvement in half dead nodes. Figure 6 shows number of normal half dead nodes in DEEC and proposed G-DEEC. As m= .2 means 80 normal nodes and 20 advance nodes initially. Normal nodes becoming half dead are zero in DEEC at 2000 iteration and 60 in G-DEEC showing 75% overall improvement in normal half dead nodes. Figure 7 shows number of advance half dead nodes in DEEC and G-DEEC respectively. There are 20 advance nodes initially which reduced to zero at 2000 iteration in both DEEC and G-DEEC showing zero improvement in number of advance half dead nodes.

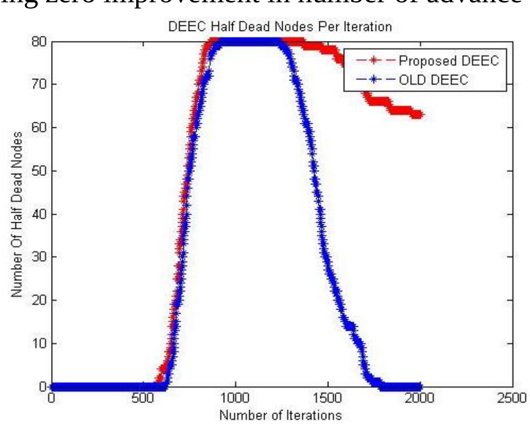

Figure 5. Total number of HDN

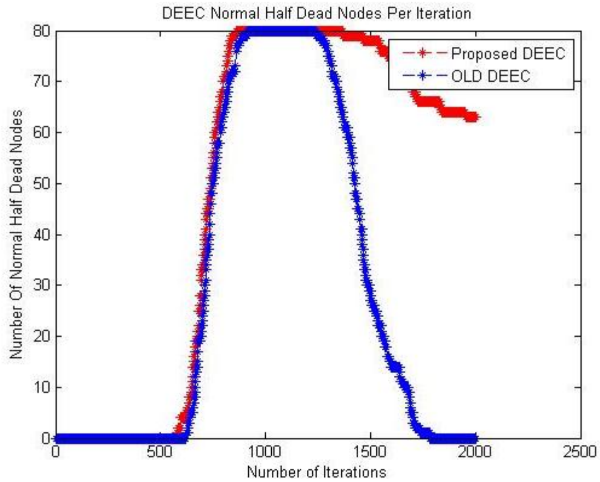

Figure 6. Number of NHDN

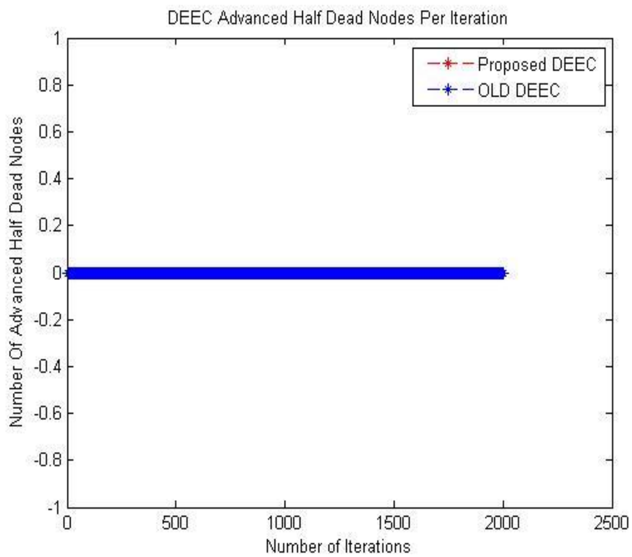

Figure 7. Number of AHDN

4.3.1.2 Analysis of DN (Dead Nodes) – Figure 8 shows number of dead nodes in DEEC and G-DEEC. At 2000 iteration the numbers of dead nodes are 80 in DEEC and 17 in G-DEEC. This high amount of reduction in number of dead nodes shows 63% improvement in lifetime. Figure 9 shows the number of normal dead nodes. Normal nodes were 80 initially which are maintained to be still 80 in DEEC showing no improvement and reduced to 17 in G-DEEC showing 78.75 % improvement in lifetime. Reduction in number of dead nodes increases network lifetime.

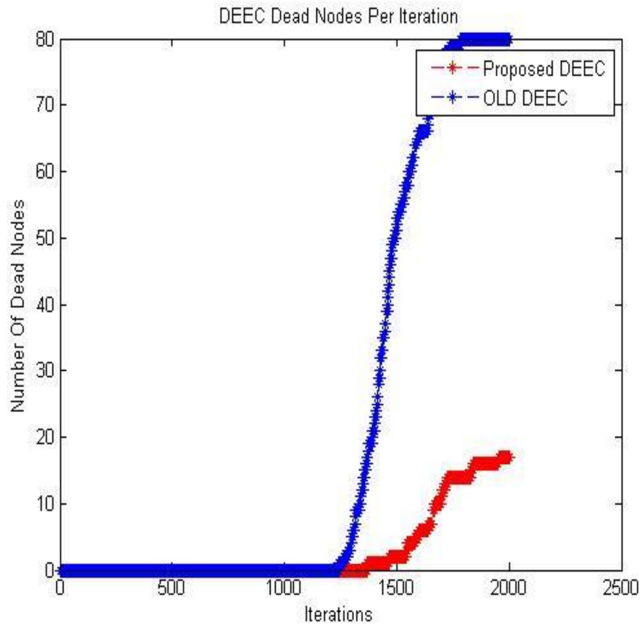

Figure 8. Total number of DN

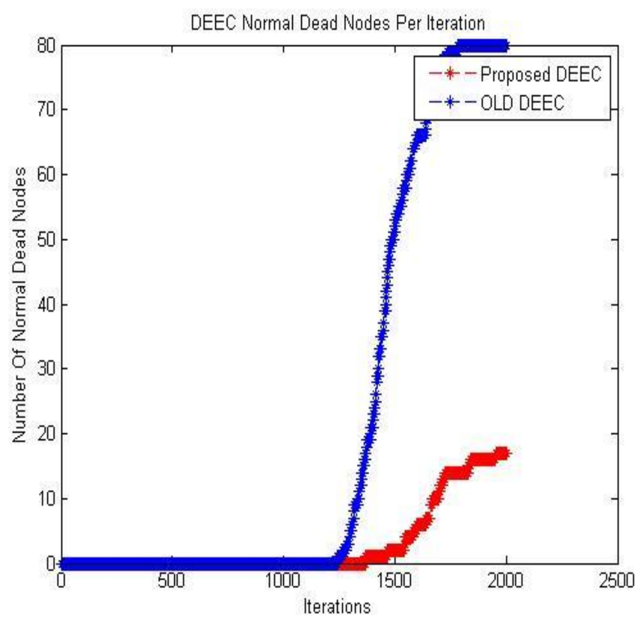

Figure 9. Number of NDN

Figure 10 shows number of advance dead nodes in DEEC and G-DEEC. Initial there were 20 advance nodes which are reduced to zero in both DEEC and G-DEEC showing zero overall improvement.

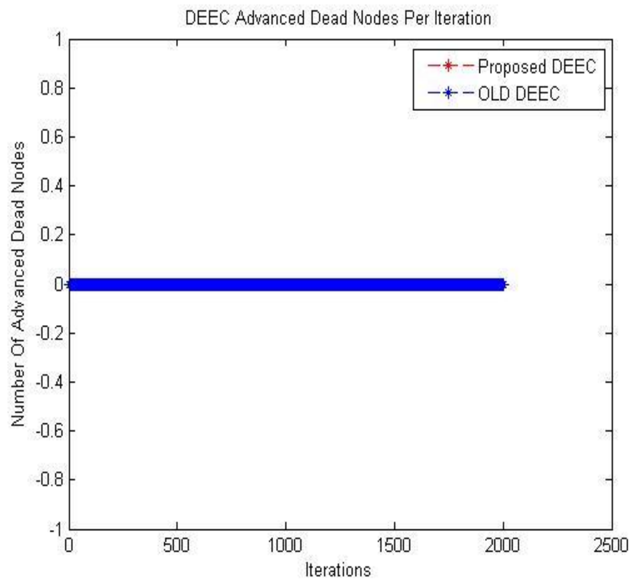

Figure 10. Number of AND

4.3.1.3 Analysis of AN (Alive Nodes) - Figure 11 shows number of total alive nodes in both DEEC and G-DEEC. The number is 20 in DEEC and 83 in G-DEEC. This rise of alive node number increases lifetime by 63%. Figure 12 shows the number of normal alive nodes which are initially 80. The number is 0 in DEEC and 60 in G-DEEC showing 75% improvement.

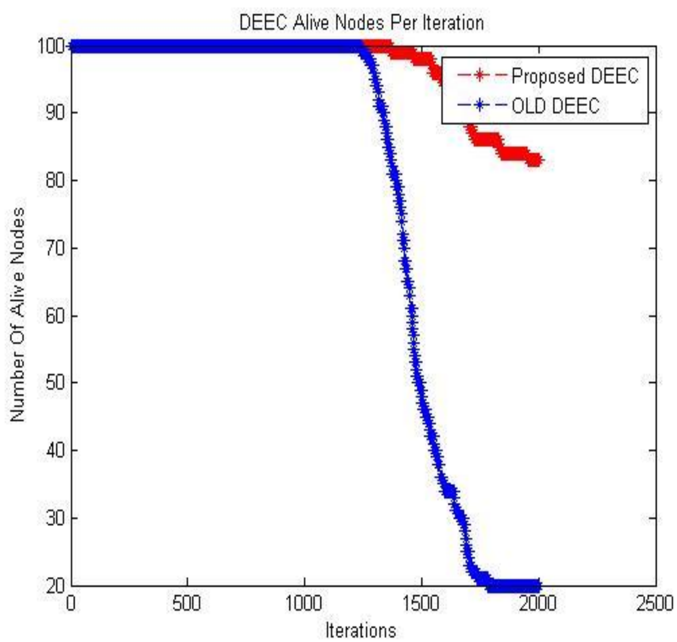

Figure 11. Number of total AN

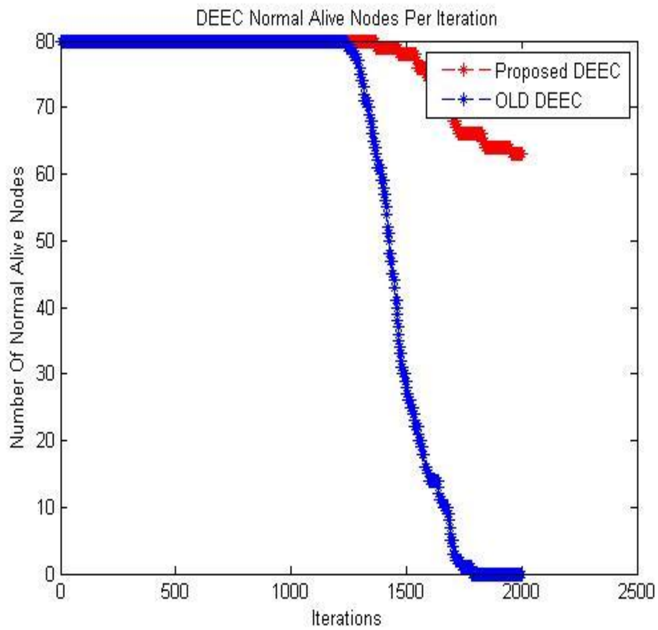

Figure 12. Number of NAN

Figure 13 shows number of advance alive nodes in DEEC and G-DEEC. The number is 20 initially which is still 20 in both protocols showing no improvement.

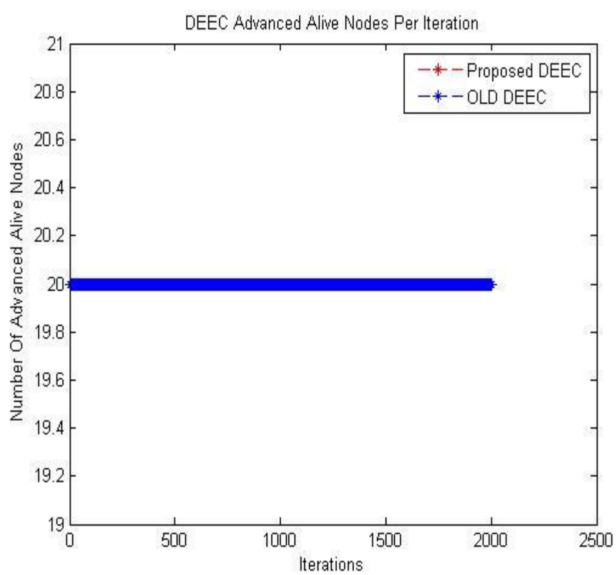

Figure 13. Number of AAN

4.3.2 Analysis of First Dead Node (Stability) - Figure 14 shows bar graph of the time interval till first node dies. The round at which first node died in DEEC is 1242 and 1369 in G-DEEC showing 6.35% increase in stability.

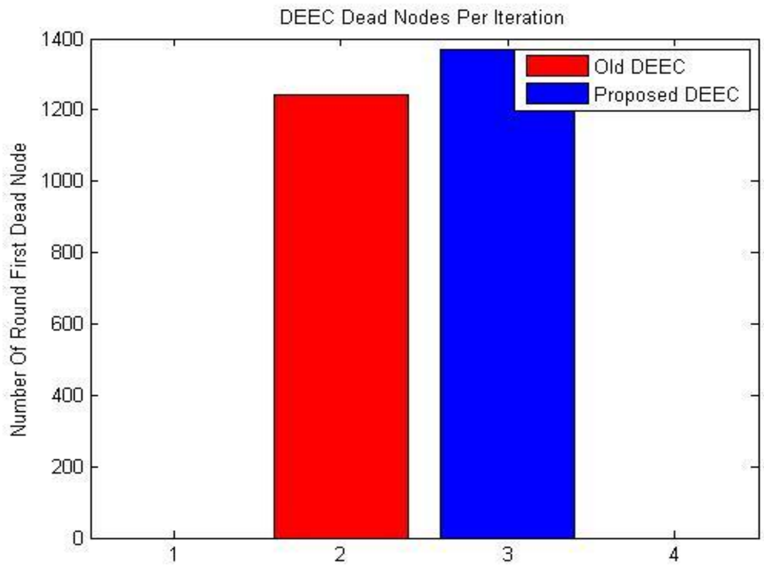

Figure 14. First Node Dead

4.3.3 Analysis of Remaining Energy- Figure 15 shows the network remaining energy per round. The energy remained is 0 joules in DEEC at 1500 iteration and 0.05 joules in G-DEEC showing 10% increase in remaining energy as initial energy was 0.5 joules. The network parameters considered in research are given in Table 1.

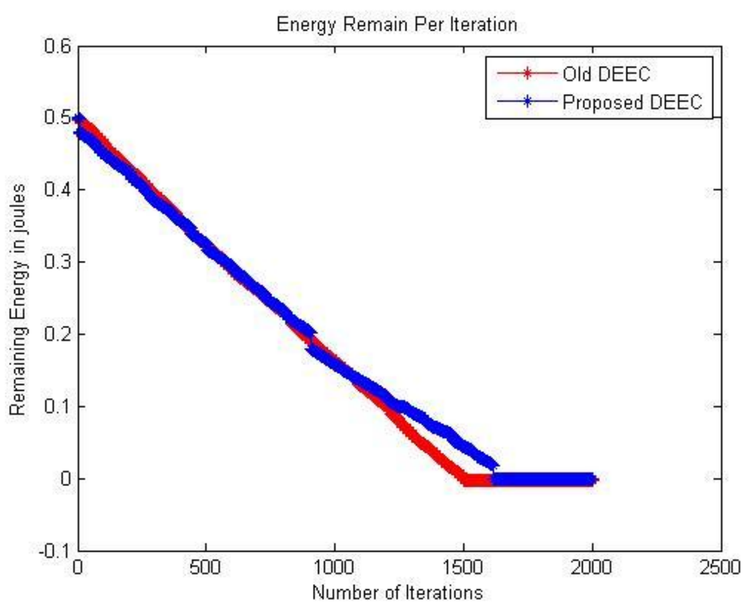

Figure 15. Remaining Energy

Table 1. Network parameters

Parameters	Definition	Values
n	Population of sensor nodes	100
E_0	Initial energy of sensor nodes	0.5J
p_{opt}	Optimal Probability	0.1
E_{elec}	Transmitter / Receiver electronics energy	50nJ/ bit
E_{DA}	Data aggregation energy	5nJ/bit/signal
ϵ_{fs}	Energy consumed by transmit amplifier at shorter distance	10pJ/bit/m^2
ϵ_{mp}	Energy consumed by transmit amplifier at longer distance	0.0013pJ/bit/m^4
d_0	Threshold distance	70m
m	Fraction of advance nodes	0.2
α	Fraction of extra energy	3

4.3.4 Analysis of packets transmission: Figure 16 shows the count of packet transmission from to CH. At 2000 iteration, 80 packets are sent to CH in G-DEEC whereas the number is 20 in DEEC. Each packet is of 4000 bit length.

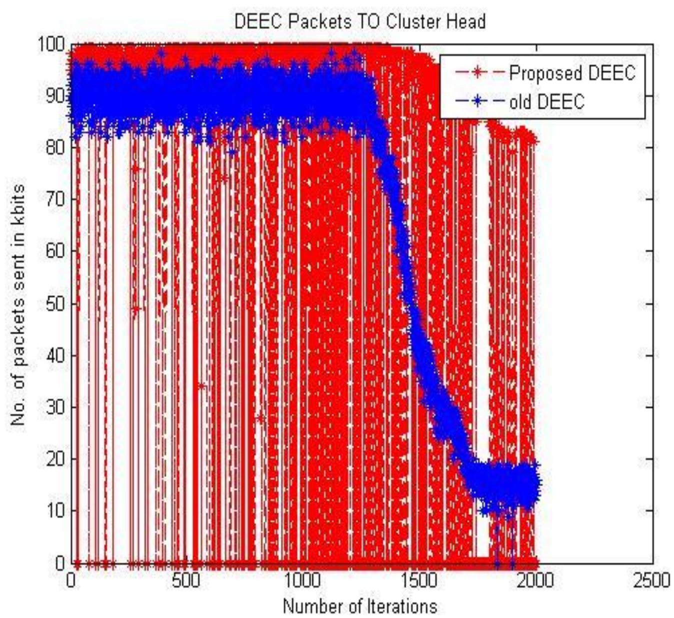

Figure 16. Packets transmission to CH

Figure 17 shows the packets transmission to Base station. The number is 3 in DEEC and 13 in G-DEEC.

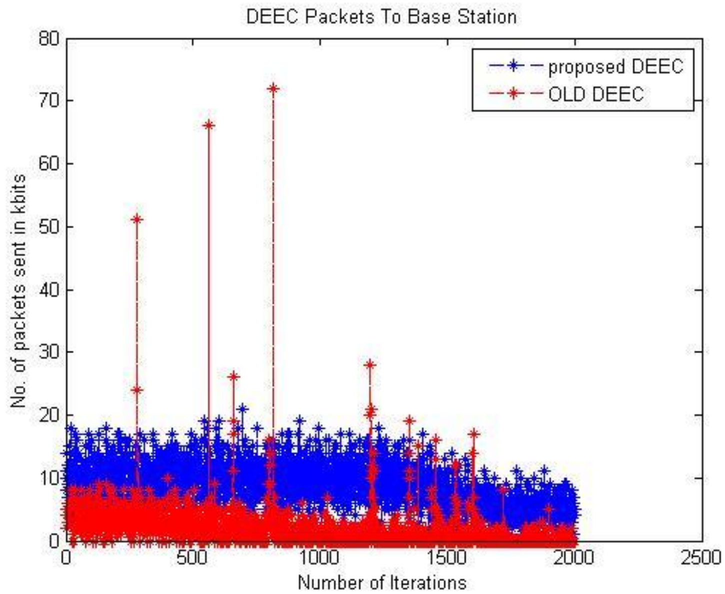

Figure 17. Packets transmission to BS

Table 2. Simulation Results

Performance metric	DEEC	G-DEEC	Overall Improvement (%)
Number of HDN (Total)	0	60	60
Number of NHDN	0	60	75
Number of AHDN	0	0	0
Number of DN (Total)	80	17	63
Number of NDN	80	17	78.75
Number of AND	0	0	0
Number of AN (Total)	20	83	63
Number of NAN	0	60	75
Number of AAN	20	20	0
FND (Stability)	1242	1369	6.35
Remaining Energy (joules)	0	0.05	10

5. CONCLUSIONS AND FUTURE SCOPE

In this research we proposed a multi-hop DEEC in order to increase the number of alive nodes and half dead nodes and decrement in dead nodes. Simulation performed in MATLAB shows 60%, 63%, 63% improvement in number of half dead nodes, Dead nodes and alive nodes resp. in return giving 62% on an average improvement in lifetime, 6.35% improvement in stability and 10% in remaining energy. This work can further be extended to improvement in threshold levels and CH selection criteria.

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