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Enhanced Heterogeneous Cross-Layer Protocol for Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks (WSN's) life span improvement with minimum energy expenditure is the vital issue to address. Lifespan of WSN's can improve with heterogeneous nodes compared to homogeneous nodes. This paper presents a novel MAC-ROUTE cross-layer technique named as Enhanced heterogeneous MAC-ROUTE Cross-Layer protocol. Proposed technique is dynamic in nature and energy efficient compare to existing protocols. The simulation is carried out using MATLAB and it is observed that proposed protocol is efficient than existing WSN routing protocols. The results show the improved stability duration, increased Packet Numbers transmitted to BS and prolonged network lifespan compare to existing protocols.

Key words: Heterogeneous, Protocol, Networks

1. INTRODUCTION

WSN's plays an important and evident role in advancements the networks communication [1]. This is because of cost-effective, sophisticated and tiny sensor devices ability to sense at diverse physical parameters and environments. In WSN, nodes are deployed arbitrarily with limited energy to sense, aggregate, transmit and receive the sensed information. Routing protocol design is a key to improve in efficient method and minimize transmission energy between each node to base station (BS) [2].

Routing protocols in wireless sensor network are classified based on communication model, network structure, route reliability and network topology [3-5]. Based on network structure, Santar et.al classified routing protocols into location based, flat and hierarchical routing [6], among which hierarchical protocols can improve network lifespan of WSN. In hierarchical routing protocols, entire network will be separated into groups called clusters and each group will elect a Cluster Head (CH) [7, 8] with high residual energy. The reason of clustering to condense the transmission distance from all nodes to BS to reduce the energy expenditure [9].

Heinzelman et al [10] recommended Low-Energy Adaptive Clustering Hierarchy (LEACH) is homogeneous hierarchical routing protocol based on clustering to overcome direct transmission, that utilize randomized CH's rotation to stable the energy in a network. LEACH uses the concept of data aggregation to reduce the information passed to BS thereby increase the network lifespan. Threshold sensitive Energy Efficient sensor Network (TEEN) [11] is another popular homogeneous hierarchical routing protocol to address the issue of energy efficiency better than LEACH.

In TEEN, Cluster Head sends data one level above from lower level hierarchy till reaches BS, instead of sending directly. Hybrid Energy-Efficient Distributed (HEED) clustering [12] is another homogeneous routing protocol, it uses a probability of residual energy and node degree as a parameter to select the CH. HEED address the issue of energy efficiency better than LEACH Lifespan of WSN's can also be improved with heterogeneous scheme compared to homogeneous scheme. Adapting heterogeneity in WSN prolongs the network lifespan in comparison with homogeneous LEACH protocol [13-16].SEP comes under the category of clustered heterogeneous WSN's with varied energies for normal and advanced nodes. To select CH, SEP uses weighted election probabilities and it enhances stability duration of WSN compare to homogeneous protocols. SEP is more flexible than LEACH in wisely consuming the additional energy of advanced nodes [17].Further, DEEC [18] is also a heterogeneous WSN's cluster protocol. To select CH, DEEC uses probability *pi* which is the ratio of node residual energy to network average energy. Where both SEP and DEEC are two level heterogeneous WSN's protocols. DEEC increases the WSN life span compared to SEP, SEP-E and LEACH up to amount of 45%, 24% and 21% respectively [19].

Parul et.al is observed the enhancement of DEEC by adding one level to existing design i.e. three level heterogeneity known as as Enhanced Distributed Energy Efficient Clustering (EDEEC)[20]. Stability duration and network lifespan are better in EDEEC compared to SEP and DEEC. Stability period and life span of EDEEC is more as evaluated to SEP and unstable period of SEP is more than EDEEC. EDEEC is enhanced than SEP as it applies the residual energy.
Additionally, Dynamic Distributed Energy Efficient Clustering (DDEEC) [21] is improved compared to DEEC by accumulating dynamic cluster head election probability to existing design. Deploy energy uniformly on the network is the main objective of DDEEC to enhance the lifespan with less energy consumption compare to two level heterogeneity protocols. DDEEC performs better than SEP and DEEC in terms of stability duration and lifespan of network.
Furthermore, Enhanced Dynamic Distributed Energy Efficient Clustering (EDDEEC) [22] is a package of heterogeneous network, energy expenditure and cluster-based routing model. Javid et.al witnessed the enhancement in network lifespan,

improved stability duration and increased packets number sent to BS compared to EEHC, DEEC, DDEEC, and EDEEC. The survey showed that the performance of heterogeneous WSN lifespan can improve with cross layer design instead of traditional OSI model [23-24].

Present research consist a novel MAC-ROUTE cross-layer design with existing EECLCH (Energy Efficient Cross-Layer Cluster Head Selection) Protocol. Here proposed Enhanced heterogeneous MAC-Route cross layer protocol with same parameters as in EECLCH [28] along with optimal CH's distance as addition parameter. The simulation results show the enhanced stability duration, extended network lifespan and increased packets number to BS when compared to existing protocols DEEC, DDEEC, EDEEC, EDDEEC and EECLCH.

2. MOTIVATION

Earlier Literatures, survey on many heterogeneous WSN's protocols found some limitations. In DEEC, selection of CH's probability for normal nodes is lesser than that of advanced nodes, and punishes advanced nodes. EDEEC separate the nodes into three-level heterogeneity as normal, advanced and super nodes. Compare to DEEC, EDEEC punishes both advanced and super nodes during CH's selection. In EDEEC [20], average probability p_i for three types of nodes is given as equation (1).

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+m(a+m_0 b))E(r)} if\, s_i is the normal node \\ \frac{p_{opt}(1+a)E_i(r)}{(1+m(a+m_0 b))E(r)} if\, s_i is the Advances node \\ \frac{p_{opt}(1+b)E_i(r)}{(1+m(a+m_0 b))E(r)} if\, s_i is the Super node \end{cases}$$

…………….(1)

Where, p_{opt} is the average probability p_i's threshold value, $E_i(r)$ is r[th] round residual energy, $E(r)$ is r[th] round average energy of the network, m is advanced nodes fraction, a is advanced and normal nodes energy difference, m_0 is super nodes fraction, and b is super and normal nodes energy difference.In order to avoid three-level heterogeneity penalize and to save energy in both super and advanced nodes. Authors Nadeem Javaid et.al proposed the concept of dynamic change on the CH's election probabilities based on residual energy level $T_{absolute}$, where this value will be same for advanced node and super node as that of normal node . This makes same CH probability for all normal, advanced and super nodes below $T_{absolute}$. Equation (2) calculates probability p_i for CH selection in EDDEEC [22].

$$p_i = \begin{cases} \frac{p_{opt}E_i(r)}{(1+m(a+m_0 b))E(r)} for normal nodes (if E_i(r) > T_{absolute}) \\ \frac{p_{opt}(1+a)E_i(r)}{(1+m(a+m_0 b))E(r)} for Advances nodes (if E_i(r) > T_{absolute}) \\ \frac{p_{opt}(1+b)E_i(r)}{(1+m(a+m_0 b))E(r)} for Super nodes (if E_i(r) > T_{absolute}) \\ c\frac{p_{opt}(1+b)E_i(r)}{(1+m(a+m_0 b))E(r)} for All nodes (if E_i(r) \le T_{absolute}) \end{cases}$$

……(2)

The absolute residual energy level $T_{absolute}$ is calculated as

$$T_{absolute}=ZE_o \text{.........................(3)}$$

Where, E_0 is normal node initial energy. Substituting value of Z as 0 in equation (3) indicates traditional EDEEC. In EDDEEC, not known the exact value of Z used to calculate the absolute residual energy level, where residual energy level is used for selection of normal node, advanced node and super node. Using random best effort find the nearest value of Z=0.7 as the best value.

If node's residual energy is greater than (0.7) E_0, then some of the advanced and normal nodes becomes CH's for first r rounds and same for normal nodes also. Here any nodes should have 70% times of initial energy to become the CH, this amount of $T_{absolute}$ gives less network lifespan.

Where, variable C in equation (2) denotes the number of clusters. If residual energy less than $T_{absolute}$ then, transmission will be direct to the BS without cluster heads involvement. Due to direct transmission, energy consumption is more and nodes will die early leads to less network lifespan. This is not an optimal way of CH's selection using variable C in equation (2). In order to address above mentioned limitations and to achieve efficient lifespan of WSN, proposed Energy Efficient Cross Layer Cluster Head (EECLCH) selection protocol. EECLCH is a dynamic and energy efficient routing protocol which changes the probability of nodes to become CH's based on energy consumption of a node as a role of CH and also considers the Packets Number dropped during transmission between CH and BS. In proposed research [28] irrespective of nodes distance from BS will be selected as CH leads to more energy consumption.

In order to overcome more energy consumption, in this research work selection of CH's based on energy consumption of a node as a role of CH, number packets dropped and also considers optimal distance of a node.

3. HETEROGENEOUS NETWORK MODEL

Heterogeneity is added energy allocated to the nodes with different fractions. The heterogeneous equation is carried on the assumption that a fraction of nodes are enlarged with extra energy than the lull of nodes. Three types of heterogeneous WSN's are two- level, three-level and multi-level heterogeneity. EECLCH selection protocol believes three-level heterogeneous network includes three dissimilar stages of energies as normal, advanced and super nodes.

Assume N number of nodes deployed randomly, and then number of normal nodes is $N(1-m)$ similarly, advanced and super nodes given as $Nm(1-m_o)$ and Nmm_o respectively.

The total normal nodes initial energy E_{normal} is given in equation (4)

$$E_{normal} = N(1-m)E_O \quad \ldots(4)$$

The total advanced nodes initial energy $E_{advanced}$ is given in equation (5)

$$E_{advanced} = Nm(1-m_o)E_o(1+a) \quad \ldots(5)$$

Similarly, the total super nodes initial energy E_{super} is given in equation (6)

$$E_{super} = Nmm_oE_O(1+b) \quad \ldots(6)$$

Then the total heterogeneous network energy E_{total} is given Equation (7) and Equation (8)

$$E_{total} = E_{normal} + E_{advanced} + E_{super} \quad \ldots(7)$$

$$E_{total} = N * E_O * (1 + m(a + m_o * b)) \quad \ldots(8)$$

Where, E_0 is energy for normal nodes, $E_0(1+a)$ is energy for advanced nodes and $E_0(1+b)$ is energy for super nodes, m is advanced nodes fraction, a is advanced and normal nodes energy difference, m_0 is super nodes fraction, and *b* is super and normal nodes energy difference.

4. ENERGY CONSUMPTION MODEL

In this section considered the impact of both node power and external environment energy to propose energy consumption model [22, 25-26].The architecture of a WSN node is divided into mainly four modules like sensing, processing, wireless communication, and power supply modules. Where, power supply is the one common module to supply power to remaining three modules-sensing, processing, and wireless communication modules.

Then the node total energy consumption is given as equation (9)

$$E_T = E_S + E_P + E_W \quad \ldots(9)$$

Where energy consumption by the sensing module is given as E_S, Processing module energy consumption cost is given as E_p and wireless communication energy cost is given as E_W.

4.1 Sensing module:

Sensing module (E_S) energy consumption includes energy dissipated due to Switch-on sensing module (E_{ON}), Switch-off sensing module (E_{OFF}) and to sense information (E_{Active}) for a given period T. Then, total sensing module energy consumption is given as follows:

$$E_S = E_{ON} + E_{OFF} + E_{ACTIVE} \quad \ldots(10)$$

4.2 Processing module:

Sensor controlling, protocol-based communication and data processing are three major task performed by the sensing module. States changes between sleep, idle and run supported by processing module.

Total processing module energy consumption is given in equation (11)

$$E_P = E_P^{state} + E_P^{change} \quad \ldots(11)$$

Where, Energy spent during each state and change of each state is given as E_P^{state} and E_P^{change} respectively.

4.3 Wireless communication module:

In this section given wireless communication model same as the wireless first order radio model [25].

$$E_T = E_{ele} \times k + \varepsilon_{amp} \times k \times d^2, d < d_0 \quad \ldots(12)$$

$$E_T = E_{ele} \times k + \varepsilon_{amp} \times k \times d^4, d > d_0 \quad \ldots(13)$$

Where E_{ele} and ε_{amp} are transmitting energy circuit loss and power amplification loss respectively. When *d* is less than d_0, use free space model, otherwise, use multi-path model.

Similarly, consumption of energy to receive (E_R) and aggregate (E_A) k bits of data is given as

$$E_R = E_{ele} \times k \quad \ldots(14)$$

$$E_A = E_{Agg} \times k \quad \ldots(15)$$

The total energy consumption (E_{Total}) of a wireless module for each node is given as

$$E_W = E_{Total} = E_T + E_R + E_A \quad \ldots(16)$$

5. ENHANCED HETEROGENEOUS MAC-ROUTE CROSS LAYER PROTOCOL

Here proposed protocol consists of two modules-network module and radio module

5.1 Network module

In this section, proposed protocol chooses CH's with less energy consumption in each round with optimal distance. N_{Total} is total nodes number in the network and deployed randomly in an area of M*M. N_{CH} nodes became CH's among N_{Total} number of nodes, then possibility of $N_{CH}+1$ Clusters. To determine the cluster head N_{CH}, assumed that all $N_{CH}+1$ clusters are equally separated, so in each cluster on an average $N_{Total}/N_{CH}+1$ nodes. Average number of nodes in every cluster is calculated as:

$$N_{Cluster}^{AVG} = \frac{N_{Total}}{N_{CH}+1} \quad \text{.........................(17)}$$

Energy spent in each round is calculated as:

$$E_{Total} = E_{CH\rightarrow BS} \cdot N_{CH} + E_{nonCH\rightarrow CH} \cdot N_{nonCH\rightarrow CH} + E_{nonCH\rightarrow BS} \cdot N_{nonCH\rightarrow BS} \quad \text{...(18)}$$

5.2 Radio module

Average energy of r[th] round is same as [27] shown in equation (19)

$$E_{avg}(r) = \frac{1}{N} E_{Total}\left(1 - \frac{r}{R}\right) \quad \text{..........................(20)}$$

Where R is the total number of rounds and given as equation (21)

$$R = \frac{E_{Total}}{E_{Round}} \quad \text{...(22)}$$

Where E_{Round} is each round energy consumption and given as equation

The threshold is determined at beginning of each round to decide node to become a CH or not as shown equation (23)

$$T(S_i) = \begin{cases} \dfrac{p_i}{1-p_i\left(mod\left(r,\frac{1}{p_i}\right)\right)} & if\ S_i \in G \\ 0 & otherwise \end{cases} \quad \text{..................(23)}$$

Set of eligible CHs for the rounds r represented as G in equation (23) and p_i represents selection probability of CH among eligible nodes. The new threshold is determined as shown in equation (23), once the CH is elected with probability p_i.

Based on threshold each non CH will decide to join nearby cluster, once after CH broadcast in entire network. Then, every CH is acknowledged by join message.

6. SIMULATION RESULTS

Simulation results for different heterogeneous WSN's protocols DEEC, DDEEC, EDEEC, EDDEEC and proposed protocol are presented using MATLAB. In our simulation, randomly deployed N=100 nodes in an area 100m ×100m and placed Base Station at the center and considered simulation limitations as shown in Table.1.

Table 1: Simulation Limitations

Limitation	Value
E_{elec}	50n Joule/bit
E_{mp}	0.0013p Joule/bit/m[4]
E_{da}	5n Joule/bit/signal
E_{fs}	10n J/bit/m[2]
E_o	0.5J
L	4000bits
d_o	Sqrt(E_{fs}/E_{mp})

In this simulation used Stability duration, network lifespan and Packets Number sent to BS as a performance metrics to evaluate proposed protocol with existing protocols. Results along with discussion are given as follows.

SCENARIO 1: m=0.8, m_0=0.6, a=2.0, and b=3.5

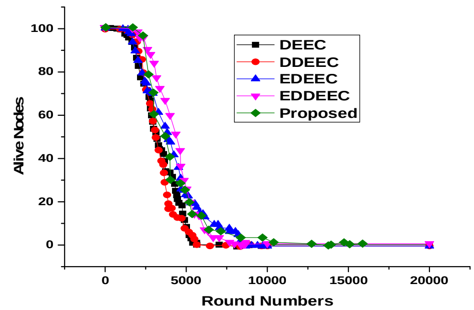

Figure .3.The Number of Alive Nodes vs. Rounds Number (Scenario-1)

6.1 Network lifespan

The simulation carried out in the heterogeneous network for 20000 rounds in comparison of EECLCH selection protocol with existing protocols. Considering the Heterogeneous network with initial energy of E_0 for 20 normal nodes, 2 times more energy than E_0 for 32 advanced nodes and 3.5 times more energy than E_0 for 48 super nodes. Figure 3 shows that proposed protocol network lifespan and stability duration are better compare to existing protocols, which are approximately 10011 and 2120 respectively. Due to efficient energy utilization, proposed protocol network lifespan is 18.08% better than EDDEEC. Proposed protocol also has good stability duration compared to EDDEEC around 2120 and 1717 rounds respectively. In proposed protocol entire network dies at 10011 and in EDDEEC dies at 8638, so stability duration in proposed protocol is 13.71% more than EDDEEC. Most importantly, unlike existing protocols, proposed protocol also has significant instability duration which is around 7891 as shown in Figure 3. In proposed protocol instability duration is better to compare to EDDEEC and other existing protocols like DEEC, DDEEC and EDEEC because of energy efficient cross-layer cluster head selection and optimal CH's distance.

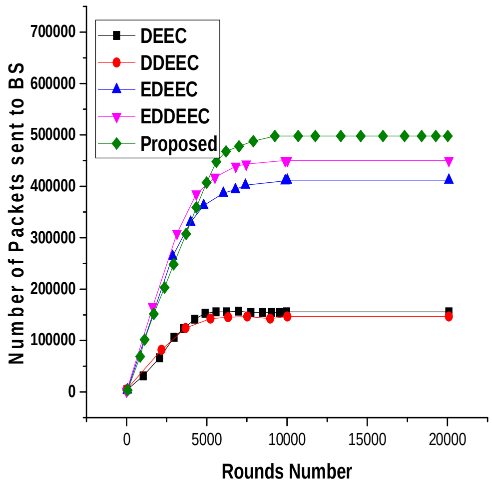

Figure.4. Packets Number sent to BS (Scenario-1)

Packets Number sent to BS

Even though normal nodes are less compared to advance and super nodes in scenario 1, performance of EECLCH protocol with respect to network life span, stability duration and packets number sent to BS is more efficient than existing protocols as shown in Figure 4.

DEEC selects the CH's based on residual energy of nodes and network average energy, nodes residual energy is the parameter considered to select CH's in DDEEC, nodes residual energy is the parameter considered to select CH's in EDEEC added another energy level of nodes, EDDEEC dynamically adjusts the CH's selection probability. Improvement in existing protocol by incorporating cross-layer clustering parameter leads to efficient dynamic CH's selection with optimal CH's distance called Enhanced Heterogeneous MAC-Route cross layer protocol.

In addition to energy consumption of a node as a role of CH, cross-layer communication between MAC and network layer considers the Packets Number retransmitted as a parameter to select upcoming efficient CH's. Thus, cross-layer cluster protocol consumes almost very less energy to select efficient CH's, which leads to enhanced network life span and stability duration compared to existing protocols. Enhanced network life span and stability duration of proposed protocol, means that nodes are able to send more packets to BS as compare to other existing protocols as shown in Figure 4.

Figure 5 and Figure 6 shows the stability and instability duration of EDDEEC and proposed protocol respectively for 100000 rounds for Scenario 1(m=0.8, m0=0.6, a=2.0, and b=3.5), which shows that proposed protocol's stability and instability duration is better than EDDEEC.

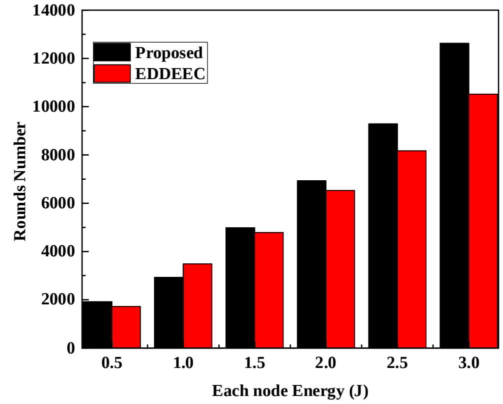

Figure.5. Stability duration versus Rounds Number (Scenario-1)

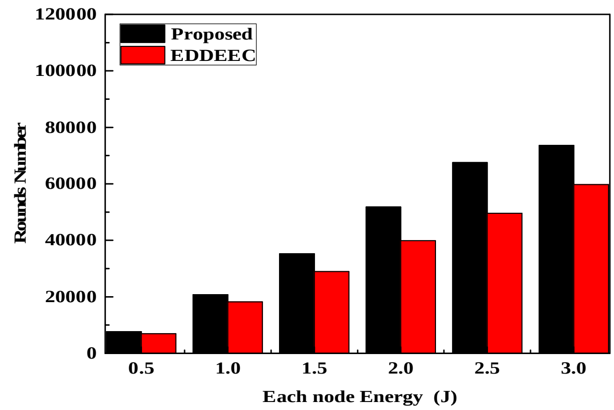

Figure.6. Instability duration versus Rounds Number (Scenario-1)

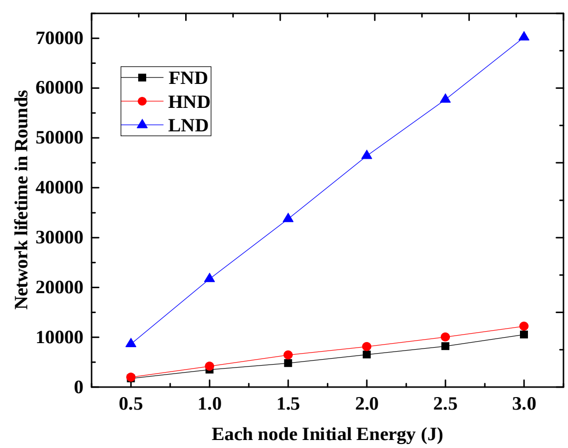

Figure.7. Network lifespan in rounds of EDDEEC versus Each Node Initial Energy (Scenario-1)

Figure 7 and Figure 8 shows the influence of initial node energy on the network life span of EDDEEC and proposed protocol respectively for Scenario 1 with First Node Die (FND), Mid Node Die (MND) and Last Node Die (LND). Here simulation was done for 6 different initial energy for each node and conclude that network lifespan of proposed protocol is 18.08% better than EDDEEC because of MAC-ROUTE cross-layer scheduling technique with optimal CH's distance.

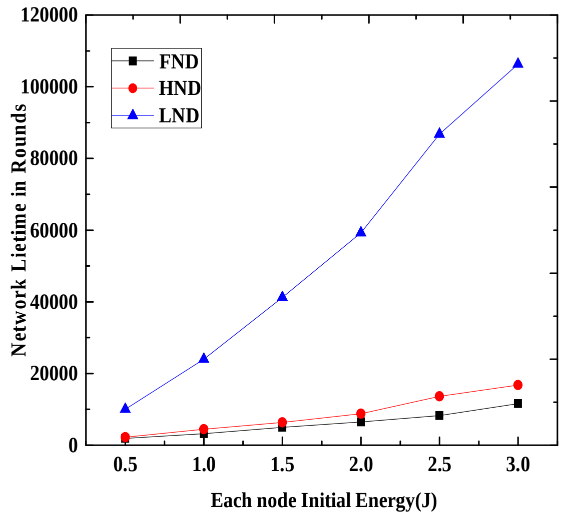

Figure.8. Network lifespan in rounds of Proposed Protocol versus Each node Initial Energy (Scenario-1)

SCENARIO 2:m=0.3,m$_o$=0.2,a=1.2,and b=2.5
6.2 Network lifespan

In scenario 2, Simulation carried out in a heterogeneous network for 20000 rounds in comparison of proposed protocol with existing protocols. Consider heterogeneous network of 70% of nodes having energy of E_0, 1.2 times energy than E_0 for advanced nodes of 24, and 2.5 times energy than E_0 for super nodes of 6. Figure.9 shows the proposed protocol network life span and stability duration are better compare to existing protocols, which are approximately 7423 and 2632 respectively. Due to efficient energy utilization proposed network lifespan is 19.17% better than EDDEEC. Proposed protocol also has good stability duration compared to EDDEEC around 2632 and 1682 rounds respectively. In the proposed protocol entire network dies at 7423 and in EDDEEC dies at 5789, so stability duration in the proposed protocol is 22.01% more than EDDEEC. Most importantly, unlike existing protocols, the proposed protocol also has significant instability duration which is around 4791 as shown in Figure.9. In the proposed protocol instability duration is better to compare to EDDEEC and other existing protocols like DEEC, DDEEC, and EDEEC because of energy efficient cross-layer cluster head selection with optimal CH's distance.

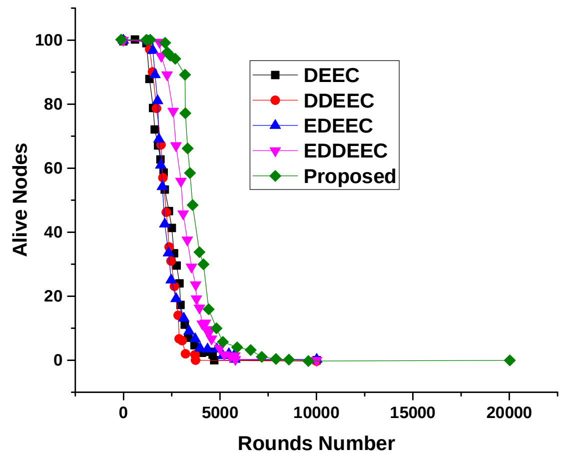

Figure.9 Network lifespan (Scenario-2)

Packets Number sent to BS

Compare to existing protocols-DEEC, DDEEC, EDEEC and EDDEEC Packets Number sent to BS is more in proposed protocol shown in Figure.10.

It is noticeable from the result that proposed protocol is most competent among all other existing protocols in terms of stability duration, network life span and the Packets Number sent to BS, even the number of normal nodes is less compare to advanced and super nodes. Normal nodes number increased in scenario 2 as compare to scenario 1. Similarly, super and advanced nodes number decreased in scenario 2 compare to scenario 1. As evaluate to super and advanced nodes, normal nodes have less energy; thus as a whole, the total energy expenditure of network is less as contrasted to the preceding scenario.

Compare to scenario 1, same protocols simulation carried out in scenario 2 and implementation of all protocols uses less initial energy resources in similar way.
Therefore, as a complete, the network lifespan, stability duration, and Packets Number sent to BS are less in scenario 2 as compare to the scenario 1.

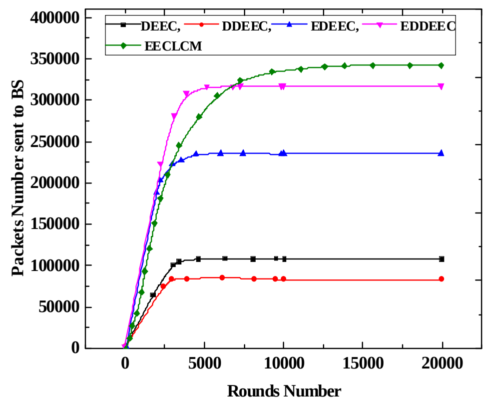

Figure.10 Packets Number sent to BS (Scenario-2)

Figure 11 and Figure 12 shows the stability and instability duration of EDDEEC and Proposed protocol respectively for 10000 rounds for Scenario 2 (m=0.3,m_o=0.2,a=1.2,and b=2.5).

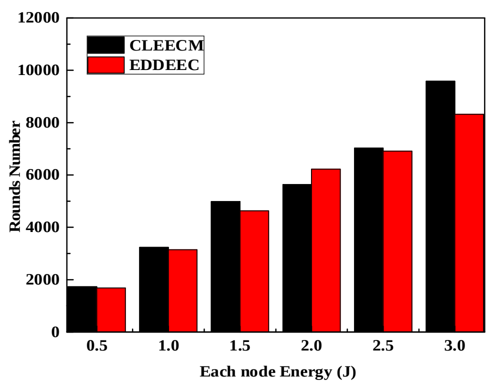

Figure 11.Stability duration versus Rounds Number (Scenario-2)

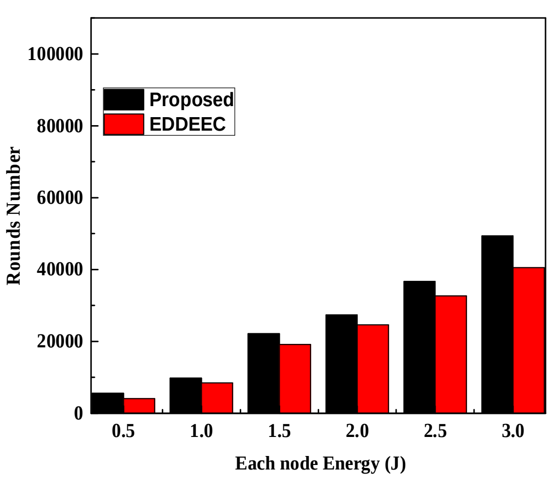

Figure.12 Instability duration versus Rounds Number (Scenario-2)

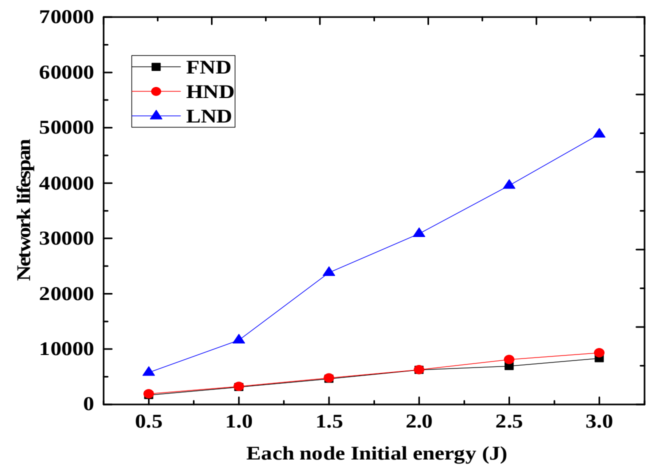

Figure 13.Network lifespan in rounds of EDDEEC versus Each node Initial Energy (Scenario-2)

Figure 13 and Figure 14 shows the impact of initial node energy on the network lifespan of EDDEEC and proposed protocol respectively for Scenario 2 with First Node Die (FND), Mid Node Die (MND) and Last Node Die (LND). Here simulation was done for 6 different initial energy for each node and conclude that network lifespan of proposed protocol is better than EDDEEC because of MAC-ROUTE cross-layer scheduling technique with optimal CH's distance.

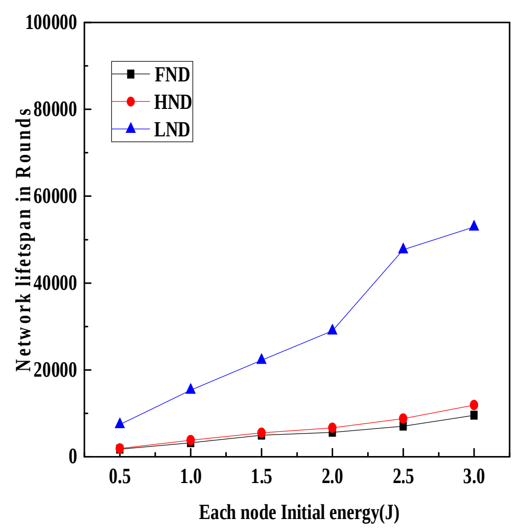

Figure .14 Network lifespan in rounds of EECLCH versus Each Node Initial Energy (Scenario-2)

Conclusion

In this paper, proposed protocol is dynamic in nature and energy efficient which changes the probability of nodes to become CH's based on energy consumption of a node as a role of CH, Packets Number dropped during transmission between CH and BS, and also considers the optimal CH's distance. An extensive simulation carried out to evaluate the performance of the proposed protocol using MATLAB. Metrics used to analyze EECLCH performance are stability duration, network lifespan and Packets Number sent to BS. Stability duration of proposed protocol improved for scenario 1 and scenario 2 than EDDEEC due to energy efficient cross-layer cluster head selection with optimal CH's distance. Proposed protocol network lifespan improved for scenario 1 and scenario 2 than EDDEEC due to competent energy utilization. The simulation results show that performance of proposed protocol is better than DEEC, DDEEC, EDEEC and EDDEEC for the chosen performance metrics.

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