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AN EFFICIENT HYBRID FRAMEWORK FOR MAXIMIZATION OF ENERGY EFFICIENCY OVER HETEROGENEOUS WIRELESS SENSOR NETWORKS

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ABSTRACT

In wireless sensor networks, energy efficiency and optimizing energy usage play crucial roles, particularly in data transmission. Achieving a balanced distribution of energy across the network is essential to enhance the lifespan of sensor nodes and ensure data integrity during transmission. Extending the network's overall lifespan involves reducing energy consumption for long-distance transmission. The introduction of relay nodes (RN) is beneficial in facilitating data transfer from the cluster head (CH) to the main station (MS) and providing data storage capabilities. To maximize energy efficiency, the proposed protocol, known as I-EADC_RN, adopts a hybrid framework. The network area is divided into two distinct sections: the sensing region [A] and the storage region [B]. In the storage region, the nodes are known as Relay Nodes (RNs). The process of selecting Cluster Heads (CHs) involves the participation of nodes deployed in the sensing region, considering the average energy of the surrounding nodes. When the Mobile Sink (MS) approaches, the RNs transmit the data they have captured and stored to the MS. The main objective of the proposed algorithm is to optimize the network's overall lifespan by utilizing the capabilities of Relay Nodes (RNs) and Mobile Sink (MS) technologies. It effectively tackles the energy hole problem by efficiently distributing energy throughout the network. This is achieved by assigning an appropriate competition radius that ensures optimal energy utilization. Furthermore, the algorithm enhances data transmission efficiency by selecting relay nodes based on their energy expenditure during transmission and reception. By considering energy consumption, the algorithm aims to minimize the depletion of energy in subsequent relay nodes. Additionally, data loss is minimized through the utilization of data storage capabilities in the relay nodes, further enhancing the overall performance and reliability of the network.

Keywords: RN-Rendezvous Node, RN-Region, Deployment Region, MS-Mobile Sink, CH-Cluster Head

I. INTRODUCTION

Lightweight components, known as sensor nodes, are often used to monitor environmental characteristics and regularly transmit data to the base station (BS). The BS is a node in the network that is thought to have an infinite or larger amount of energy compared to other nodes. Before deployment, the sensor nodes are given an initial amount of energy. These nodes are widely spread across areas such as farmland, woods, railroad tunnels, etc. Due to the requirement of wireless sensor networks (WSNs) for data from all locations, this could necessitate the use of solar photovoltaic cells in a grid, etc. [1-4]. The finite and non-rechargeable energy of the sensor nodes determines how long a sensor network will last [5,6]. Thus, it is necessary to save the energy of these nodes. Uneven clustering, multi-hop communication, and role division have all been introduced to save energy. Energy is distributed throughout the network based on its proximity to the BS using unequal clustering. The use of multi-hop communication reduces the energy required for long-distance transmission. To alleviate the strain on a specific node, the roles assigned to the nodes are divided. Continuous monitoring has shown hierarchical topology clustering to be effective. [7-10].

Optimising network lifetime is complicated by the issues listed below: The network's lifespan must remain constant for a long period of time. The time until the first node fails is the stable lifespan of the network. The network's useful lifespan is the amount of time before 25% of the nodes fail. The network can continue for a maximum amount of time before the last node fails. However, because the lifetime requirement varies depending on the application, it is important to take the first node as dead into account [11] as there are several types of sensor network nodes that cater to various applications [12]. The pre-determination of the sensor nodes' locations and their deployment in certain regions takes some time and effort during network building. Uneven clustering has been implemented to ease the complexity of network construction.

A node that dies in a round must be removed from the cluster in subsequent rounds; hence, the wireless network has a dynamic topology for every round of the network's lifespan. In addition to refreshing the member list count, this could decrease the CH's load. The cluster size fluctuates often, which helps to balance the energy used by the cluster's nodes.

The location information of the sensor nodes plays a crucial role in determining the optimal routing path for efficient data transmission to the BS. Once the nodes are deployed, obtaining the location information of all nodes in the network becomes the next step. In order to overcome these limitations and enhance network efficiency, a new protocol needs to be proposed that ensures the prolonged lifespan of nodes in the network. Several multi-hop communication techniques, such as Multi-hop LEACH [13][14][15], EADC [16], EDUC [17], etc., offer more energy-efficient inter-cluster communication, further improving the overall performance of the network,

2. Literature Survey

For addressing the issue of energy holes, a variety of solutions have been used, including mobility, MS, data compression, non-uniform clustering and traffic aggregation [18], node dispersion [19], etc. With its residual energy, the MS goes throughout the network and aids in cutting down on the energy used for long-distance transmission. When we shift the BS, the network develops an energy imbalance. The planned work takes into account the costs associated with transferring the BS. transmit nodes assist in the multi-hop connection used to transmit the data to the MS. The MS uses a beacon signal to regularly update the other nodes in the network on its location. There are several forms of MS, including the following:

- ❖ The sensor field is split into regions in restricted multi-hop relaying, and the MS is moved to the center of each zone while the nodes provide data to the MS. The nodes in such areas communicate their data to the BS as the MS goes through those areas. However, the MS shifts to a predetermined place in one round and to a different point in the following round.

- The MS stations are placed at each and every point in a round for passive data collecting. The benefit of this approach is that it maximizes the network's lifespan while decreasing the quantity of data that is gathered in a cycle.
- In a dynamic mobile BS scenario, the BS moves randomly within the network, without any specific pattern. Nodes located within a pre-determined distance (d0) from the BS are responsible for transmitting data to it.
- Predictable mobility involves the MS moving to a specific RN location based on a variety of factors, including the amount of energy left, the quantity of nodes, and the distance between them. Prior to the data transmission phase in this manner of mobility, the BS must be given information about the parameters. If a specific region's data is not received at the BS, it is presumed that the nodes in that region have run out of energy.

This led the path to energy hole problem [20,21]. Energy hole problem can be rectified by several mechanisms:

- Assistant approach [12]: A number of assistance nodes with more powerful batteries and greater transmission range are installed in the TTDD scheme. On the upper side of the sensor's lower initial energy sensor, these nodes create a relay region.
- Based on nodes distribution strategy: Nodes must be installed with a predetermined distribution function if there are more nodes nearby in the RN region.
- Transmission range adjustment: the ranges for sensor communication that can be adjusted. However, there are limitations on the sensor field's size.
- Mobility of the sink: The mobility of the BS is considered in the event-driven network.

LEACH [22] (Low Energy Adaptive Clustering Hierarchy) is categorized as a hierarchical network. This technique is a self-organizing, adaptive clustering mechanism that uses randomization to spread the network's energy load equitably. The nodes deployed over the field are homogeneous. The BS is immobile and fixed at a great distance from the sensor field. The Cluster Formation Algorithm in LEACH: CH uses CSMA MAC to broadcast an advertisement message (ADV).

ADV= nodes ID + distinguishable header------------- (1)

Based on the signal strength of the received ADV (RSS), each non-CH nodes determine the CH near them.

The main objectives of TDMA scheduling in intra-cluster communication are to conserve energy for non-CH (Cluster Head) nodes and prevent collisions in data transmission. The CH communicates with cluster members during their designated time slots, and the nodes remain active during this time but quickly conserve energy by turning off. Within each node, data from cluster members is transmitted to the CH using a TDMA schedule, aiming to minimize collisions within the cluster. The CH collects the data from its member nodes and employs a direct sequence spread spectrum (DSSS) for communication. Each cluster utilizes a different spreading algorithm to reduce interference during inter-cluster communication. To transmit data from the CH to the BS (Base Station), a fixed spreading code and CSMA (Carrier Sense Multiple Access) are used. In the sensor network's setup phase, it is assumed that every node is time synchronized and initiates the process simultaneously. The CH remains continuously active, while the BS periodically pulses the nodes in synchronization.

A combination of static and dynamic layouts makes up this HUCL protocol [22]. Static clustering decreases the overhead associated with CH node election because clusters are generated only once. Each and every round's setup involves energy being used to broadcast control messages in order to learn about the nearby nodes and the routing path. These control signals increase the overhead of the CH, which in turn depletes its energy. A dynamic clustering mechanism is developed to address these flaws, and CH is only elected once over the course of multiple rounds. The ratio between the residual energy of the node and the network's average energy determines which CH is chosen in DEEC[15] .

3. PREREQUISITES

The field is split into two areas in our suggested protocol: the sensing zone, and the storage region. In both areas, heterogeneous nodes are randomly placed. Out of all nodes deployed, 80% are normal nodes, while the remaining nodes are considered to have energy higher than the normal nodes. This divides the initial energy of the nodes into two levels. The RN are a fusion of the advanced and normal nodes. Within a specific area, the MS is rendered mobile. Only the middle of the y-axis dimension is traversed by the MS in the proposed I-EADUC_RN.
Purpose of the proposed I-EADUC_RN algorithm:

- The network's lifespan is extended through the utilization of RNs and the MS.
- The energy hole problem is mitigated by effectively distributing energy across the network through efficient assignment of the competition radius.
- Relay node selection based on energy expended in transmission and reception facilitates efficient data transmission.
- Data loss is minimized by storing data in the RN.

Two-level heterogeneity is implemented, where the RN region is predetermined. Nodes have minimal roles in the initial stage. Every 100 rounds, the MS returns to its initial position.3.1 Energy Model:

The energy expended in transmission, as described in Equation (2), is directly related to the distance. When the distance exceeds a threshold distance (do), the energy consumption increases exponentially, specifically by the fourth power of the distance.

Elx(l,d)= Elx –elsc(l)+ Elx-amp(l, d)--------------------(2)

The energy spent in reception Eq. (3) is same with different distance,

ERx(l) = Erx-elec(l) = l*Eelec------------------------(3)

3.2 Data Aggregation:

In the data aggregation model, the cluster head (CH) utilizes an infinite compressibility model to aggregate the data it collects. Irrespective of the cluster's size and the number of nodes involved, the CH combines the collected data packets into a single data packet of a predetermined length.

4. PROPOSED PROTOCOL

The goal behind the introduction of the RN node in the I-EADUC_RN model is to increase the network's useful lifetime; as a result, the network's lifetime before 25% of its nodes die is greater than it is for other existing protocols. I-EADUC_RN phases:

- Set-up phase,
- Steady state phase.

4.1 Set-Up phase:

The nodes are initially planted at random, with MS located at y-axis/2. So that nodes nearest to the BS receive the strongest signal, the BS emits a beacon signal with less energy. Until

every node in the network receives the beacon signal from the BS, this process is repeated. Each node determines its distance from the BS using the signal strength it has received.
The setup phase is segmented into three sub-phases, each assigned a specific time duration: T1, T2, T3. These three sub-phases are:

- Cluster Formation (CF)
- Neighbour node information collection (NNIC)
- CH Competition (CHC)

A predetermined area in the sensor field is designated as the rendezvous region at the start of the setup process using Eq. (3) and the nodes Ym represents y-axis dimension, yi represents the percentage of RN region to be covered [16]. The lifetime extension increases as the number of sub-phases decreases and computing energy increases. During the allocated time periods, each sub-phase completes its task. For subphase (1), neighbor node information gathering begins at the beginning of "T1," when each node broadcasts a node message containing the node's residual energy and node id. Similar to this, each sensor node in the field shares its remaining energy with its next-door neighbors. Consequently, a node in the network can acquire leftover energy from nearby nodes at a predetermined distance. Based on the received data, each node computes its average energy among its neighbor nodes Eq. (4). The node with remaining energy higher than the average energy gets a chance to participate in the CH selection.

$$Eavg = \frac{\sum_{sj-1}^{m} Er}{nb} \text{------------------------} (4)$$

Sj represents the present node, Sj. Er represents the remaining of the neighboring nodes, and Nb he node denoted as Sj represents the current node, while Er represents the remaining energy of neighboring nodes, and Nb represents the number of neighbors. After the completion of the neighbor node information collecting sub-phase, the wait times for each node are calculated. This calculated wait time, determined using Equation 4, is used to decide whether the node will be elected as a cluster head (CH) in the present round or in future rounds.
A random value Vr [0.9, 1] is employed to minimize the chances of multiple nodes sending Head_Msg simultaneously, as unique random values are generated for each node. The node elected as the CH transmits a Head_Msg to indicate its selection as the CH for the particular round. Nodes that do not receive any Head_Msg broadcast a Head_Msg within their competition radius.
At the conclusion of time 'T1', the CH computation commences at the start of time 'T2'. The parameters considered for computing the competition radius, using the provided equation, include residual energy, distance from the BS, and the number of neighboring nodes. Based on this computation, the number of member nodes to be included in the cluster is determined.

$$Rc = [1 - \propto \left(\frac{dmax - d(si,Bs)}{Dmax - dmin}\right) - \beta\left(1 - \frac{Er}{Emax}\right) + \gamma(1 \frac{sj(nb)}{nbmax}) \text{-------------}(5)$$

The weights α and β are represented by the values (0, 1) respectively. Rmax denotes the maximum transmission radius, while dmax and dmin represent the maximum and minimum distances of nodes from the base station (BS). The distance of the jth node from the BS is denoted as d(si, BS). Er represents the residual energy of nodes, Emax signifies the maximum initial energy value of a node in the network, Sj(nb) denotes the number of neighboring nodes of the jth node, and Nbmax signifies the maximum value of neighboring nodes.

Nodes that satisfy the conditions of higher residual energy, greater distance from the BS, and a lower number of neighbors should possess a larger competition radius. The cluster size of a node is determined by its distance, remaining energy, and the number of neighboring nodes in the network. The cluster head (CH) closer to the RN region has a smaller competition radius, enabling it to conserve energy during intra-cluster communication and allocate more energy towards relaying data to the RN node located at the minimum distance. CH nodes broadcast a Head_Msg with the competition radius Rc.

After the competition radius phase concludes, the cluster formation sub-phase begins at time 'T3'. Nodes that are neither CH nor RN join the CH within their competition radius, based on proximity. These nodes send a Joint_Msg to the CH that is at the minimum distance, and upon acceptance, the CH updates its Member_List. The CH then responds to the member nodes with a TDMA schedule, which reduces energy consumption during channel sensing. Each neighboring node is assigned a separate time slot, and member nodes are active only during their allocated time slot, conserving energy. This approach facilitates energy conservation within the network.

Member nodes in a cluster communicate with the Cluster Head (CH) directly, transmitting data in a single hop, which is referred to as intra-cluster communication. Once the setup phase's three sub-phases are finished, the steady-state phase of data transmission commences. Each member node in the cluster transfers the accumulated data to its respective CH. The CH then combines the collected data and sends the compressed data to the RN (Relay Node) located in the RN region, which is at the minimum distance. In cases where the CH is far from the RN region, the data is forwarded from one CH to the next layer CH. The selection of the subsequent layer CH for relaying the data depends on the remaining energy of CH 'j' after transmitting the data to the RN node with the minimum distance in the RN region. The decision on the next relay node is made using Equation (6) for calculation purposes.

$$Erealay - \frac{Sj[Er - Sj.count + 1 + EDA * DM - \quad * Dm}{Dmax} \text{-----------(6)}$$

The variable Sj, Er represents the current remaining energy of the jth node. Sj.count represents the number of member nodes connected to the jth node. ERx denotes the energy cost associated with receiving data from these member nodes. DM represents the length of the received data packet from the members. EDA represents the energy spent on aggregating the received data. ETx represents the energy consumed in transmitting the data packet from the current CH.si to CH.sj, considering the relay distance, and from the relay node to the RN node located at the minimum distance. Emax represents the maximum value of the initial remaining energy available in the network. In other words, the node with the highest remaining energy is chosen as the next hop relay node. The CH, represented by sj, with the highest value of Erelay (indicating the highest remaining energy) is elected as the subsequent relay node. If the sink is located within a predetermined distance, the relay node transfers the data to the MS (main station).For each elected CH, a minimum distance is assigned to it to be designated as an RN node. In the event that the RN node becomes unavailable, the next RN node with the minimum distance is selected as the replacement RN node for that particular CH.

NNIC	CHC	CF	Mini Slot 1	Mini Slot 2	Mini Slot 3	Major slot 1	Mini Slot 1

Fig.1. Data transmission format with the Concept of Major slot ‘M’ and Mini slot ‘m’

In addition to the aforementioned improvements, the introduction of major slots and mini slots provides an advantage to the protocol. The formed cluster is maintained for a few data transmission phases. In this system, the data transmission phase is divided into multiple major slots, denoted as 'M', and each major slot consists of several mini slots, denoted as 'm'. The mini slot is the phase where the actual data transmission occurs, and once the allotted mini slot count is reached, a major slot is initiated. During the major slot phase, the Cluster Head (CH) rotation takes place. A new CH is elected within the previously established cluster. The selection of the new CH is based on the remaining energy of the nodes. The node with higher remaining energy than the current CH, while also having the minimum distance to the current CH, is chosen as the new CH. This process of CH rotation takes place in each major slot. Implementing this process helps reduce the overhead on the CH during each setup phase. Consequently, the energy expended in transmitting control messages is conserved through this combination of static and dynamic clustering approach.

Proposed Algorithm

- ❖ For each node with index 1 to n:
- ❖ If the role of node i is 'N':
- ❖ If (condition):
- ❖ Set the role of node i as 'R'.
- ❖ If the distance between nodes i and j is less than or equal to d and the role of node i is 'N':
- ❖ Add the remaining energy of node i to the average energy (Eave).
- ❖ Calculate the average energy for node i by dividing Eave by the count of nodes.
- ❖ If the average energy is greater than the remaining energy of node i:
- ❖ Calculate the wait time as Eavg divided by Er multiplied by T2 and Vr.
- ❖ If the average energy is less than or equal to the remaining energy of node i:
- ❖ Set the wait time as T2 multiplied by Vr.
- ❖ Sort the nodes based on their wait time.
- ❖ Assign the role 'C' (Cluster Head) to the nodes with the shortest wait time.
- ❖ Sort the non-CH (non-Cluster Head) nodes and select the closest one as the CH for each node.
- ❖ Assign the role 'M' (Member) to node i.
- ❖ Transmit data from the cluster members to the CH.
- ❖ Transmit data from the CH to the selected relay node.
- ❖ The relay node forwards the data to the Relay Node (RN) that is at the minimum distance.
- ❖ Then, the RN transfers the data to the Base Station (BS) in a single hop.

5. PROTOCOL ANALYSIS

- ❖ The introduction of Relay Nodes (RNs) helps alleviate the CH's burden and serves as a mediator between the CH and the MS, reducing overload.

- ❖ To prolong the network's lifespan, the sink is made mobile. The RN region, positioned in the middle of the sensor field, reduces the need for long-distance data relaying.
- ❖ The computation of remaining energy among neighboring nodes is performed to decrease the frequency of CH selection.
- ❖ The computation of the competition radius considers the remaining energy, the number of neighbor nodes, and the distance from the BS. This calculation assists in distributing the CH's workload within the cluster based on these parameters.
- ❖ Relay nodes are chosen based on their energy and distance to avoid depleting the energy of the next hop CH during data relaying.

6. Results and Discussion

There are four scenarios considered in order to prove the efficiency of the proposed protocol I-EADUC_RN. This simulation has been performed using NS-2 Simulator.

Table -1: - NS-2 Simulator Pre-set Parameter values

PARAMETERS	**VALUES**
Dimension	200*200,300*3 00,400*400
Number of nodes	100,200,200,600
Initial Energy	0.5 - 1.5 J
Energy consumed by radio electronics in transmit mode (ε_{Tx})	50 nJ/bit
Energy consumed by radio electronics in receiving mode (ε_{Rx})	50 nJ/bit
Energy consumed by the power amplifier on the free space model (ε_{fs})	10 pJ/bit/m^2
Energy consumed by the power amplifier on the multi path Model (	0.0013 pJ/bit/m^4
Energy consumed for data aggregation (ε_{DA})	5 nJ/bit/signal
R_{max}	110
c1,c2,c3 (i.e., α, β, γ)	0.33

6.1 Compared Study On Alive Nodes

The study compares the live nodes present in the sensor network field, with color indications used to represent different characteristics or parameters.

• The GREEN color represents the I-EADUC_RN (MS) protocol without Major slot and Mini slot.

• The BLUE color represents the I-EADUC_RN (MS) protocol with Major slot and Mini slot.
• The RED color represents the I-EADUC (STATIC SINK) protocol without Major slot and Mini slot.
• The BLACK color represents the I-EADUC (STATIC SINK) protocol with Major slot and Mini slot.

Table 2:- . I-EADUC_RN (Static sink) without Major and Mini slot compared with I-EADUC_RN MS without and with major slot and mini slot.

ROUNDS	**I- EADUC (STATIC SINK- M2,m3)**	**I- EADUC_RN (MS)**	**I- EADUC_RN (MS-M2,m3)**
500	98	99	99
600	96	99	99
700	96	98	98
800	92	98	98
900	90	96	97
1000	85	18	97
1500	70	8	84

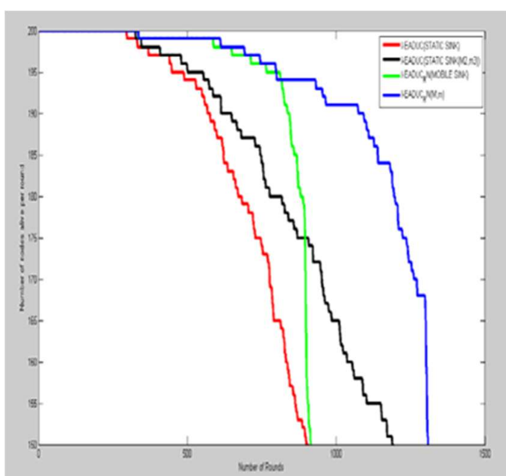

Fig.2. 200 nodes deployed in 300*300 region with RN region from 126 to 174

Table 3:- . I-EADUC_RN (Static sink) with Major and Mini slot compared with I-EADUC_RN MS without and with major slot and mini slot.

ROUNDS	**I-EADUC (STATIC SINK-M2,m3)**	**I- EADUC_ RN (MS)**	**I- EADUC_ RN (MS- M2,m3)**
500	195	199	199
600	192	198	199
700	187	197	198
800	189	195	195
900	175	169	194
1000	161	141	192
1200	154	22	182

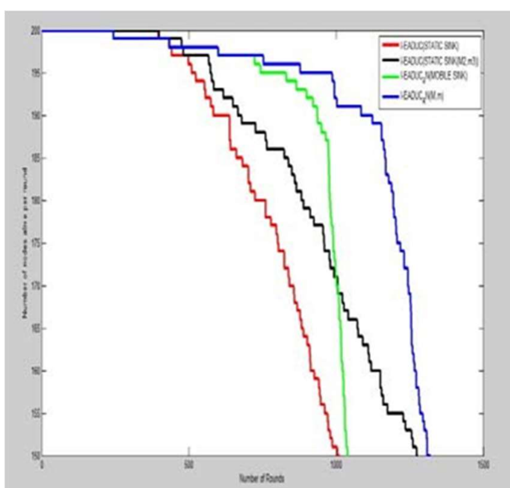

Fig.3:- . 200 nodes deployed in 400*400 region with RN region from 168 to 232

From the depicted graph, it can be deduced that Fig.2 exhibits a higher level of effective stability compared to Fig.3. This can be attributed to the larger number of nodes deployed within the RN region. Consequently, the cluster head (CH) near the RN region has a greater likelihood of preserving its energy during data transmission from the CH to the RN. This is because even if an RN node situated at the minimum distance ceases to function, the probability of selecting the next RN node at the minimum distance remains considerable. The RN continues to transfer data to the base station (BS) until the BS remains within a distance of d0 (87.5).

6.2 Residual Energy Compared Study:

The residual energy of the network corresponds to the total remaining energy of all active nodes within the network.Four different scenarios are considered

200*200 M2 with 100 nodes deployed

300*300 M2 with 100 nodes deployed

400*400 M2 with 100 nodes deployed

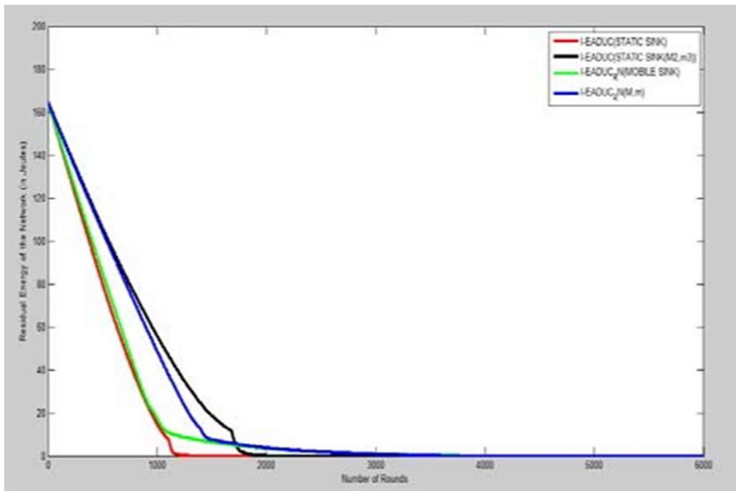

Figure. 4:- . The remaining energy of 200 nodes in 300*300 m2

6.3 CH Count Compared View on Average Energy:

There are two scenarios considered

400*400 m2 with 200 nodes deployed

Upon comparing the existing protocol, I-EADUC with the proposed I-EADUC_RN, it becomes evident that the average energy consumption of the network is reduced. Consequently, the count of cluster heads (CHs) decreases. This occurs because the energy expenditure is higher and relatively balanced for a certain duration. However, as losses accumulate, the network suddenly shuts down. In this scenario, there are still a few nodes with higher energy levels due to their underutilization (specifically, RN nodes that are not located at the minimum distance to the CH in proximity to the RN region). Additionally, the CHs near the RN region experience a relatively lower depletion of their energy resources.

6.4 Throughput Compared Study:

The proposed algorithm compared with the previously existing algorithms using simulation in NS2 under different scenarios.

200*200 m^2 with 100 nodes deployed:

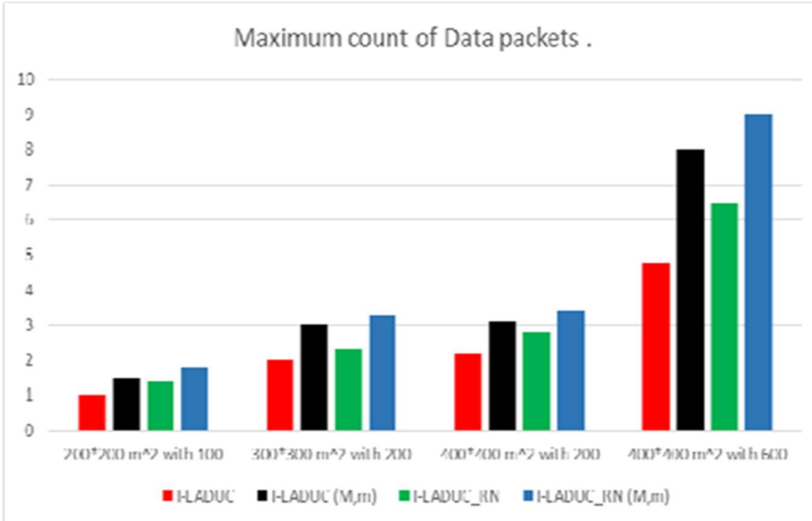

Fig 5:-. Throughput of data packets

The provided graph illustrates that a higher number of active nodes results in an increased number of data packets reaching the base station (BS). In the proposed I-EADUC_RN protocol, data packets from the RN node only reach the BS when the distance between the RN node and the BS is less than a threshold value, d0. Since the mobile station (MS) returns to its initial position every 100 rounds, there is minimal delay in data packets reaching the BS, as the distance constraint for data transmission is d0. The throughput refers to the incremental count of packets successfully reaching the MS. It accumulates all the packets that have reached the BS from the beginning until the end. The packet count in the proposed algorithm increases with a higher number of active nodes, thus maintaining a higher count of cluster heads (CHs), resulting in a larger number of packets reaching the BS. However, the compression employed in this protocol is not very advantageous, as it only reduces the packet size to a single packet of fixed length.

7. Conclusion

The suggested I-EADUC_RN protocol demonstrates improved efficiency, resulting in a longer effective lifespan of the network, specifically before 25% of the nodes become inactive. This protocol proves to be more efficient when compared to others due to the implementation of the Static and Dynamic CH concept, which effectively reduces the CH overhead. Moreover, when considering I-EADUC_RN with (M,m) instead of without (M,m), it is observed that the former is even more efficient and enhances the network's lifespan. To further enhance this protocol, future studies could explore the integration of the mobile RN concept.

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