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Research Article

An Unequal Radial Division-based Clustering to minimize Energy Hole for Larger Wireless Sensor Networks

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ABSTRACT

Energy conservation in Wireless Sensor Networks (WSN) is a key research area because sensors are energy-constrained devices. Sensor energy saving in the large and harsh geographical environment is a major challenge in WSN. This paper presents novel strategies for enhancing energy efficiency in routing and data collection, employing clustering techniques and mobile sinks to address this challenge. The sensing area is considered a circular shape and divided into blocks. The blocks are formed by dividing the circular area into concentric circles and dividing sector lines to form unequal blocks. Based on the block node centroid, the block head is selected. The block and block head are similar to the cluster and cluster head respectively. Two mobile base stations (MBS) are used to collect block head data. Two MBS move with a predefined path with constant speed and halt at sojourn points to collect data from the blockheads. After collecting data, it transfers data to the gateway nodes or base station. In simulation results, the mobile node-based scenario outperforms the centralized base station and static block heads communication. The proposed work is also compared with existing works and this scheme shows a 21% improvement in network life and end-to-end delay.

Keywords: Large Sensor Network (LSN), Cluster Head (CH), Block Head (BH), Mobile Base Stations (MBS), Energy Hole.

INTRODUCTION

Wireless Sensor Networks (WSNs) are infrastructure less networks which communicate wirelessly and are deployed in a sensing area to sense parameters such as temperature, pressure, humidity etc. [1],[2],[3],[4]. The use of sensors and WSN are increasing more and more day by day due to the broad IoT applications. In general, nodes are low-power and limited resources devices consisting of sensing, processing and communication units. Sensor nodes sense their surroundings and transfer their data to the base station (BS) directly or via other nodes with multiple-hop routing. Sensor nodes dissipate their maximum energy during communication only [5]. Transferring data through the shortest path with less delay is the main objective of any WSNs. Due to this, a lot of energy can be saved which is an important resource to increase the network's lifetime. Therefore, selecting a routing scheme is a major task to handle. Many energy-efficient routing techniques are already proposed for WSN, but still, many scopes are available for improvement. Conventional routing schemes are mostly comprised of single and multi-hop with static BS [6]. In single and multi- hop routing techniques, energy hole is a common problem [7]. During an energy-hole scenario, nodes close to the BS experience higher energy depletion than those farther away. To address the energy hole problem, cluster-based routing and data collection by mobile nodes emerge as effective solutions [8]. We are using both cluster and mobile nodes in our proposed work. Multi-hop routing proves superior to single-hop alternatives. However, both routing strategies encounter challenges associated with the energy hole problem. In single-hop routing, far nodes from the BS dissipate more energy due to long-distance communication and in multi-hop, nearer nodes of the BS consume power quickly due to higher data traffic load. Opting for a multi-hop routing protocol over a single-hop one is preferable in large sensor networks. Nonetheless, significant challenges such as energy holes and data delivery delays persist with this routing approach [9]. Consequently, numerous routing strategies have been proposed to mitigate these issues.

In WSN, designing a routing protocol is not easy due to the limited resources of the sensor nodes. Clustering routing with mobile data collectors works efficiently for large area sensor networks. Within each cluster, a cluster head (CH) is designated to gather data from member nodes. The CH then transmits this data directly to the base station (BS) or mobile collector nodes, ensuring minimal energy consumption [10]. CH rotation is the best way to balance overhead energy consumption but it is hard to achieve. In the recent past, many schemes have been proposed with a mobile sink that can be single or multiple. The mobile sink changes its place for data collection from sensor nodes directly. Collecting data from individual nodes or CH directly resolved the energy hole issues and reduced the delay. Despite all the advantages, the mobile sink has many challenges which need to be handled efficiently; else, performance may decrease [11]. Due to mobility, the network became dynamic and all nodes should always keep the mobile sink's location updated. Many data diffusion protocols have been developed in the recent past with the help of flooding schemes, but these are more power hungry. Virtual infrastructure is another method to find out the last location of the mobile sink in which some set of nodes keep the position of the mobile sink [12]. This paper introduces a novel routing algorithm for WSN based on unequal blocks designed using concentric circles and sectors. In this work, two MBS traverse in two concentric circles and gather data from designated blocks Each mobile node pauses at alternating blocks facilitating data collection in opposite directions.

The remaining paper is structured as follows: the next section illustrates some latest related literature on clustering and mobile BS in WSNs. The network model and proposed work are introduced in section 3 and section 4 respectively. In section 5, performance analysis is presented with simulation results. In the last, section 6 summarizes the paper with a few future directions.

RELATED WORK

Several protocols using clustering have presented mobile sinks to collect data to save energy and delay. The proposed protocol falls into clustering with a static sink in the energy-hole scenario and a mobile sink. All schemes presented in this section are clustering with static sink and clustering with mobile sink-based.

LEACH [13],[14] is the first clustering protocol designed for energy efficiency in WSN. In LEACH, all nodes generate a random number between 0 and 1. The node compares this number with a predefined threshold value. If the number falls below the threshold, the node designates itself as a CH. After receiving the CH message, other nodes are attached to that node and form a cluster. The CH broadcasts a time division multiple access (TDMA) header packet for each node. Utilizing TDMA, each member node transfers its data to CH. After that, CH filters all the data and directly transfers it to BS. As an initial protocol, LEACH has better performance, but it has several issues also. Later on, various variants of LEACH [14] developed to overcome the issues in it. Heinzelman et al. [15] have extended their previous LEACH protocol with LEACH-centralized (LEACH-C) to reduce the drawbacks. They centralized this protocol and fixed the number of CHs for all the rounds. This scheme reduces the extra overhead for forming new clusters every round. Though its performance is better than LEACH, it has problems like a single-hop transmission from CH to the BS, CH selection etc. Younis et al. introduced HEED (Hybrid Energy-Efficient Distributed Clustering) [16], an energy-efficient multi-level clustering approach. This method efficiently selects CHs based on intra-cluster cost and residual energy. A significant amount of energy saves by not going for CH selection in each round. Due to multi-level rounding, it suffers from an energy hole problem. MS-LEACH [17] is designed to minimize the energy consumption of the network by restricting transmission energy dissipation at a rate of square of transmission distance. The communication within the cluster is either single-hop or multi-hop, depending on the cluster size. In the case of large-size clusters, a shortest path tree is created within the cluster for communication. EEM-LEACH [18] is designed in such a manner that nodes nearer to the BS communicate directly to it as they are not members of any cluster. This scheme reduces the energy hole problem. Minimum communication cost is the parameter for route discovery. All the multi-hop routing protocols suffer from the energy hole problem due to the heavy data load near the BS. A grid-based scheme for reducing the energy hole issue has been presented by Lui et al. and they called it GFTCRA [19]. The transmission distance of the cluster is used as the main parameter for selecting the CH. The best-suited CH is selected in this protocol as the relay nodes and their numbers are limited. This protocol balanced the energy consumption and the nearest clusters of the BS consume less energy. The Grid-Based Routing (GBR) [20] is another grid-based routing protocol where CH within each cluster is selected based on proximity to the BS with the node closest to the BS being chosen. However, this approach tends to increase the intra-cluster communication cost, consequently reducing the network's lifetime. Jannu and Jana presented a novel grid-based routing named Low Power Grid-based Cluster Routing Algorithm (LPGCRA) [21]. This scheme mainly focuses on mitigating the energy hole problem. They divided the whole network into equal grids and selected the maximum remaining energy node as the CH in each grid. The primary limitation of this protocol is its reliance on single-hop communication between the BS and CHs which constrains its applicability in large-scale networks. Gupta et al. have projected an upgraded version of distributed unequal clustering based on energy- aware named (EADUC) [22]. This scheme is mainly designed to solve hot spot problems using multi-hop transmission. The unequal clusters are formed based on the BS location and remaining energy. By considering the node degree and these two parameters, the CHs are selected. The relay nodes for multi-hop communication are selected using their distance from CH and energy expenses. The main problem with this scheme is heterogeneity which increases the overall cost and complexity.

Singh et al. [23] introduced a protocol incorporating a mobile base station. The authors partitioned the entire rectangular area into levels and grids where data from each grid is forwarded by cluster heads (CHs) to edge CHs. A mobile mule collects data from each level with two mules visiting based on round numbers, specifically even or odd rounds. However, this scheme may not be suitable for large sensor networks. In [12], a new data collection scheme is developed by Kaswan using controlled mobility. An extension has been done in [23] with new trajectory patterns [24] of mobile mule. Kaushik et al. use a controlled drone in their work to localize the sensor nodes [25]. The drone can also be used to collect data from the ground sensors. In this work, the authors have incorporated unequal clustering within a grid structure. Agarwal et. al. [26] proposed an intelligent data-gathering approach using the mobile sink to collect data from cluster heads. Particle Swarm Optimization is employed to create optimal clusters. After cluster formation, the scheme selects the optimal number of rendezvous points and plans a data-gathering tour for the mobile sink. Jukuntla and Dondeti introduce a new protocol named Energy Efficient Mo- bile Sink Data Collection (EEMSDC) [27]. This protocol focuses on achieving balanced energy consumption, preventing sensor node overload, and ensuring efficient data delivery to the Mobile Sink (MS) via Relay Nodes (RNs). The approach optimizes the MS's traversal in Wireless Sensor Networks (WSNs) by utilizing pre-determined TDMA slots for effective data transmission with RNs. Taleb et al. [28] have developed a new data collection scheme using Bipartite Graphs with mobile nodes from CH and delivered to BS. This approach ensures that stationary nodes are visited and planned efficiently reducing routing overhead and enhancing the network's performance. Zheng et al. [29] introduce an intelligent and energy-efficient data routing strategy for Wireless Sensor Networks (WSNs), utilizing a mobile sink (MS) to enhance energy conservation and prolong network longevity using evolutionary computing algorithms. The scheme operates through two main phases: configuration and operation. In the configuration phase, a novel clustering mechanism is employed initially, and a prescheduling method is used to select cluster heads (CHs), ensuring balanced energy utilization among sensor nodes (SNs). The scheduling technique strategically determines successive CHs for each cluster throughout the WSN's operational cycles, centrally managed at the base station (BS) to minimize sensor node energy.

SYSTEM MODEL

A. Network Model

In a circular area, C numbers of sensor nodes are randomly deployed with a static and mobile BS in two different scenarios. Static BS is placed in the centre of the area and mobile BS is in motion to collect BH data. There are a few assumptions considered during the design of this scheme. After deployment, all the sensor nodes are static. All nodes are homogeneous and the BS knows all information of nodes such as their ID, coordinates, energy etc. Two mules move in a predefined path with no resource issue.

B. Energy Model

Our protocol uses the radio energy model described in [13]. The Equations 1 and 2 provide energy consumption details while transmitting and receiving the message by sensor nodes.

The energy consumed in transmitting l bit packet of data over a d is given by Equation 1.

$$E_{trans}(l,d) = \begin{cases} \left(E_e * l + l * e_{fsf} * (d)^2 \right), & d < D_0 \\ \left(E_e * l + l * e_{mpf} * (d)^4 \right), & otherwise \end{cases} \quad (1)$$

The energy dissipation during receiving a message of l bit packet is derived using Equation 2.

$$E_{recv}(l) = (E_e * l) \quad (2)$$

The threshold radio range (D_o) is calculated with the help of Equation 3.

$$D_0 = \sqrt{\frac{e_{fsf}}{e_{mpf}}} \quad (3)$$

THE PROPOSED PROBLEM STATEMENT

This section gives a complete description of the proposed scheme. Our network consists of a set of sensor nodes S = 1, 2, 3, 4,….,n and a sink node. We have considered two different scenarios based on the sink's data collection strategy. In the first scenario, the sink is static and situated in the middle of the networks. In the second scenario, the sink is mobile, moving on a predefined path. The following basic assumptions have been considered for the network model. Deployment area is circular and 2D in nature and all sensor nodes are stationary after deployment. The sink is moving in a fixed path and all nodes are aware of their locations. Network is divided into unequal blocks with the help of an equal concentric circle and equal sectors. Each block has one block head (BH) like in cluster's CH. Nodes can transfer information using single hop or multi-hop transmission. Each block has a different number of nodes. Each node knows the size of the block.

A. Network Division and Blocks Formation

In this phase, we divide the whole network into c equal numbers of concentric circle (CC_1, CC_2, CC_3,…., CC_c) and further sectors are formed with equidistant but not in equal numbers in all the CC. Initially, two sector lines formed, which divided all the CC into four parts.

Algorithm 1: Network Partition Algorithm

procedure NETWORK PARTITION
Require: Area of Interest Radius:R, Concentric Circle distance: r
Ensure: Blocks with their ids
Blocks Formation.
i) Compute network area with Radius R.
ii) Set concentric circle distance as r.
iii) Divide the sensing area into CC_1 to CC_c concentric circles with equal distance r.
iv) Divide these CC into blocks starting from CC_1 with 4 blocks and doubles these blocks in each CC.
Total number of blocks $(B) = 2 * (2^{c+1})$ where, c is no. of CC.
v) Assign block_id for every block.
Group all the nodes resides in the same blocks.
    Every node broadcast $node_{msg}$, which contains ($node_{id}$ $node_{loc}$, $node_{eng}$ and $block_{id}$)
    if $(T_{init} \neq expire)$ **then**
    Nodes capture $node_{msg}$ and update Node table (NT)
    else
    Nodes engage in the selection of CH.
    end if
end procedure

In the CC_1, four blocks have been formed, which we fixed. Next, for the rest of the CC_s, we divide them into four equidistant sectors, and this time, we get eight blocks in CC2. We repeat this process up to CC_c, and at each step, we get new blocks in that CC, as shown in Figure 1. This scheme gives us different numbers of blocks in all the CC. These blocks are unequal in shape due to the circular area. The complete process of a network partition is formulated in an algorithmic shape as shown in Algorithm 1.

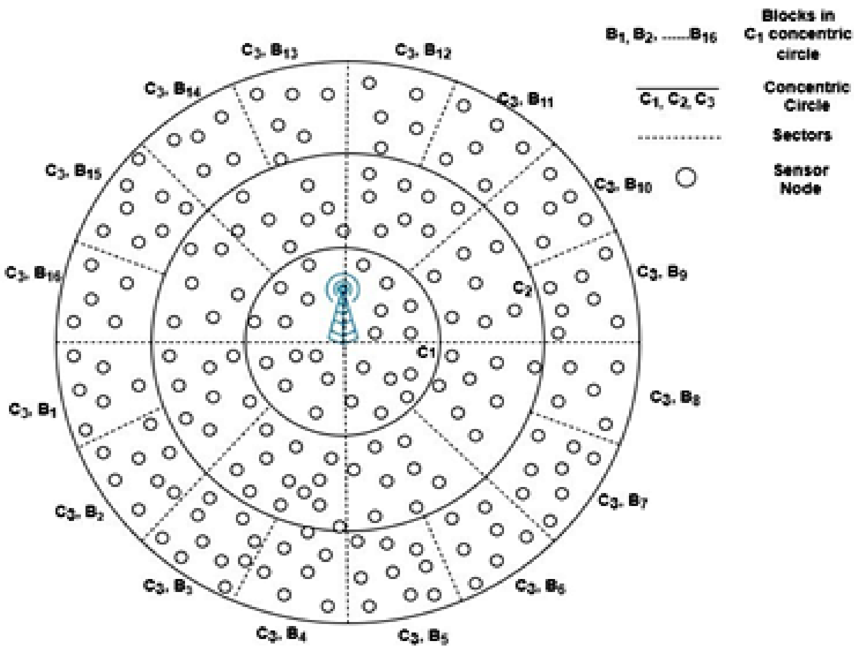


Figure 1: Network Division Model

B. Network Block Head (BH) Selection

Algorithm 2: Cluster_Head_Selection

procedure: CLUSTER_HEAD_SELECTION

Require: Centroid to node Min dist: $(C_{to}n_i)min_{dis}$ and
Average Energy of each block: $AE = \frac{\sum_i^s RE_i}{s}$

Ensure: BHs in each block

Determine centroid C by equation 4
Each node computes its dist from CDS & update NT
for all $nodes \in n$ **do**
  if $(n_i(RE) >= b_i(AE)$ && $n_i! = BH_{past})$ **then**
    n_i node will participate in BH election
  else
    n_i not authorize to participate in BH election
    if $(n_i == RE_{max}$ && $n_i == (C_{to}n_i)min_{dis})$ **then**
      i) n_i send BH_{Adv}
      ii) n_i became BH
      iii) Receives $join_{Adv}$
      iv) Send ack_{msg}
    else
      i) Receives BH_{Adv}
      ii) Send $join_{Adv}$
      iii) Receive ack_{msg} from BH

```
            end if
        end if
    end for
end procedure
```

After block formation completion and T_{init} expiration, the BH selection should have been schemed at the beginning of a new round. In each block, all the nodes participate in the BH selection competition, and anyone will get the chance to become BH. All the blocks BH selections are independent and isolated. Each BH keeps the neighbor's BHs information by exchanging hello packets. Each BH's primary task is to gather data in each block. Only BH will communicate with the Mobile sink, so the rest of the sensor nodes go into sleep mode and save time.

BH selection time may differ in various blocks. The centroid distance and node energy are the main criteria for BH selection. A node with higher energy and nearer to the centroid has a higher chance of being selected as BH. Over time, these parameters may vary according to the network condition. Within each grid or cluster, nodes calculate the centroid of deployed CDS (Connected Dominating Set) sensors in every block. This computation is based on the coordinates of all sensor nodes as defined by the equation 4.

$$\text{CDS(a,b)}= \left(\frac{1}{s}\sum_{i=1}^{s} a_i ,\ \frac{1}{s}\sum_{i=1}^{s} b_i \right) \tag{4}$$

Each node computes its distance from the centroid CDS and updates its NT. A node S_i nearest from CDS with maximum residual energy RE_{max} declares itself as BH for the existing round. Based on the NT table information, any node can easily see whether it will be eligible for BH and shorten the communication cost. The selected BHs broadcast a block head message (BH_{Adv}) containing block head id (BH_{id}), location information (loc_{info}) and block id ($Block_{id}$) with 2r radio signal. This double range radio signal 2r facilitates the identification of neighboring BH (Cluster Head) nodes for relay transmission. The algorithm 2 provides the details of this phase.

C. Mobile BS Trajectory and Data Collection

A predefined trajectory of two mobile BS moves with alternate perimeter of the circular area as seen in Figure 2. Mobile BS rotates along this path and sojourns some fixed points to collect data. In the data collection procedure, two data mobile BS are traversed along with perimeter and halt at Alternate block junction of sensor field and gather data from adjacent blocks as indicated in Figure 2. The first mobile BS moves clockwise, and the second mobile BS moves in anti-clockwise. Once the data from all sojourn points is gathered, both mobile BS transmit their data to the gateway upon reaching the axis point. The amount of data accumulated by the BS and the overall data transmission delay are contingent upon the driving speed and trajectory path of the BS.

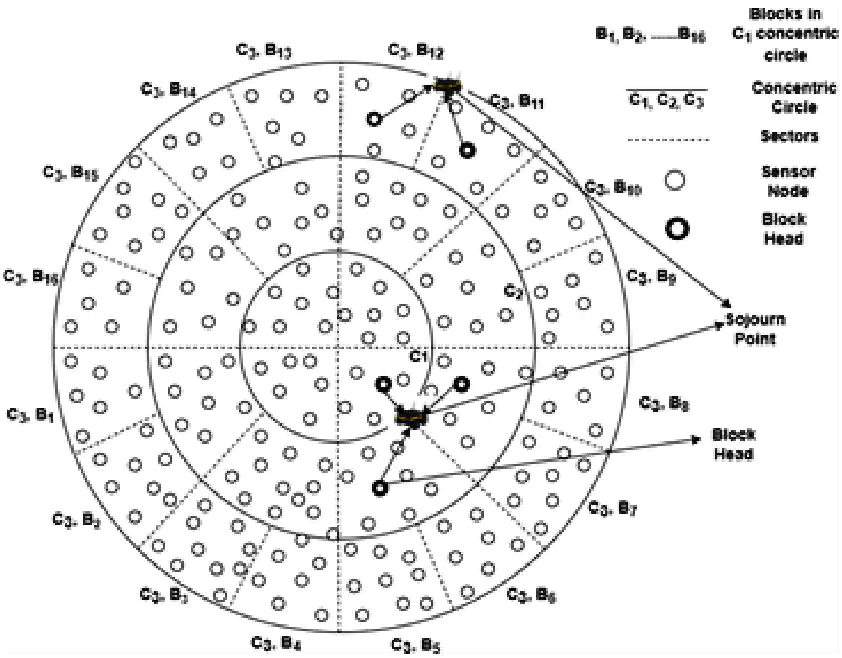


Figure 2: Network Model with Mobile Sinks for data collection

To ensure timely and reliable data aggregation by a mobile BS, BHs need to track the path of the most recent location of the mobile BS. To enable regular data collection from the sensor network, the mobile BS traverses the perimeter of the sensor area from both directions. It periodically broadcasts beacon messages along its motion path. When borderline BHs receive the beacon messages from mobile BS, they send the BH_{msg} as an acknowledgment marking the completion of the discovery process for the mobile BS. If BH receives multiple beacon messages within a certain time (dt) are tossed away. Once the mobile BS is discovered, the BH transmit all collected data from that level during the contact time t as depicted in Figure 2. If a BH does not have any data to transmit, it sends a negative acknowledgment (Nak_{ag}) during the discovery procedure. Figure 2 illustrates complete data collection process from sensor node to the central processing unit with the help of mobile BS. The algorithm 3 provides the details of this data collection process.

Algorithm 3: Sink_Trajectory and Data_Collection

```
procedure MOBILE_BS_TRAJECTORY AND DATA_COLLECTION
Require: Mobile sink informs about its location by hello packets to the neighbor BHs.
Ensure: The proximate BHs become agent BHs (ABH) for data transfer to mobile sink.
    if (ABH_{pvs-nxt-hop}! = MBS) then
        Set next-hop of ABH = MBS
        ABHs Send route update packets to next down CC BHs
        for Downstream BHs receive route update packets do
            if (BH_{pvs-nxt-hop}! = CurrentSender) then
                Set next-hop of BH = current sender
                if (BHnxt-down-hop! = C1B1) then
                    Set sender = current BH
                    All BHs Send route update packets to next down CC BHs
                else
                    drop the packets.
                end if
            else
                drop the packets.
            end if
        end for
    else
        drop the packets.
    end if
end procedure
```

Data transfer across various devices occurs using different communication protocols. Initially, sensor nodes transmit their data to BHs using the Zigbee protocol which supports a data rate of less than 1 Mbps. This protocol predominantly functions at the physical and data link layers. Lower-level sensor node transmits its data to the next-tier BHs which in turn communicate with higher-level mobile base stations (MBS) using a low-data-rate short-range protocol.

SIMULATION RESULTS AND PERFORMANCE ANALYSIS

A. Simulation set-up

We have simulated our scheme in MATLAB a2019b. The region of interest is considered with 200m diameters of 31416 m^2. Results were obtained by randomly deploying between 600 and 1200 nodes. Each node had an initial energy of 1 Joule. The data packet length was 1000 bits, and the control packet length was 100 bits. The constant Ee, efsf and empf have values 50 nJ/bit, 10 pJ/bit/m^2 and 0.0013 pJ/bit/m^4 respectively. We have simulated the proposed protocol by placing mobile BS at the outside border of the network. This scenario is examined by deploying 1200 to 600 sensor nodes. Three protocols of similar nature (i) LPGCRA [19], (ii) GBR [20] and (iii) GFTCRA [21] are also simulated with the same parameters to compare our protocol. The simulation results are detailed in the upcoming section.

B. Positions of mobile BS

The mobile BS is the designated place in both axes of circular areas where the mobile BS comes and stops for a predefined time for collecting data from the BHs. We have considered a predefined trajectory path for the mobile BS in this work. In this predefined path, the mobile BS moves on the outside edge of the network. The positions of mobile BS in this scenario are marked with solid blue circles as shown in Figure 2.

C. Comparison table for dead nodes in different rounds

In WSN, the first node dies (FND), half node dies (HND) and the last node dies (LND) are the important parameters for measuring the performance of WSN. The value of these parameters is tabulated concerning different round numbers. We have calculated different round numbers in which FND, HND and LND event occurred during our simulation with 1200 and 600 nodes.

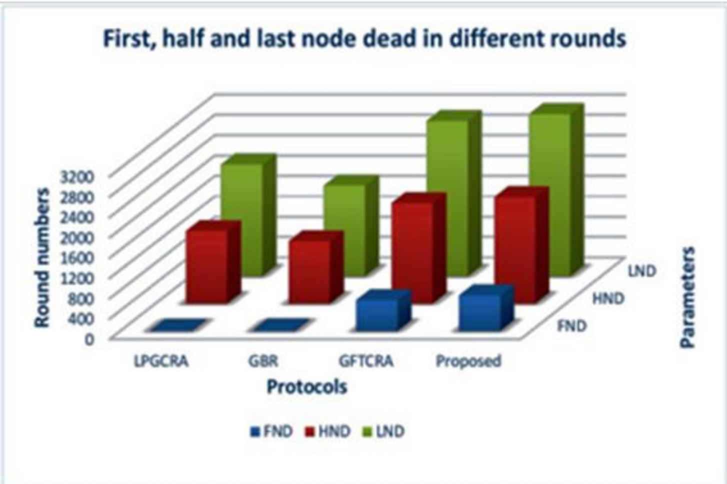


Figure 3: FND, HND and LND in different rounds for 1200 nodes

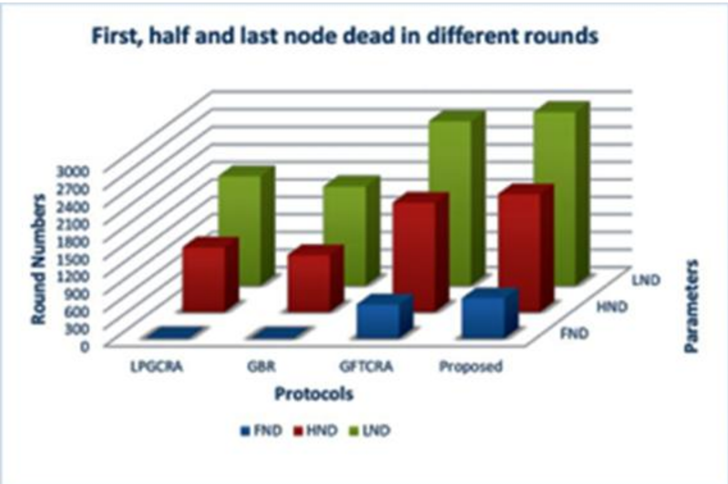


Figure 4: FND, HND and LND in different rounds for 600 nodes

Along with the simulation of the proposed work, we have also simulated three other schemes. The outcome of the simulation is shown in Tables 1 and Table 2 for both the deployed nodes scenarios. It can be seen from both Tables and Figures 3 and 4 that our scheme sustains up to maximum rounds of operations and the first node dies at 765 rounds which is far better than other three schemes.

Table 1: FND, HND and LND in different rounds for 1200 nodes

Schemes	FND	HND	LND
LPGCRA	21	1432	2198
GBR	32	1233	1786
GFTCRA	610	1982	3054
Proposed	702	2097	3189

Table 2: FND, HND and LND in different rounds for 600 nodes

Schemes	FND	HND	LND
LPGCRA	13	1111	1872
GBR	8	981	1698
GFTCRA	653	1988	2812
Proposed	765	2023	2971

D. Performance evaluation based on Dead nodes

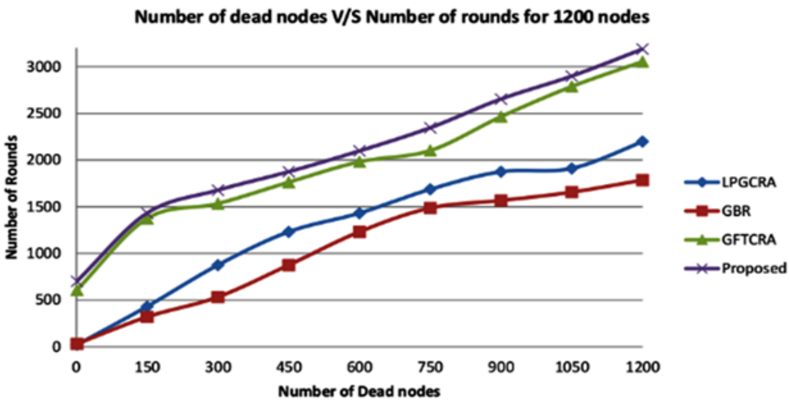


Figure 5: Dead nodes vs Round numbers in 1200 nodes

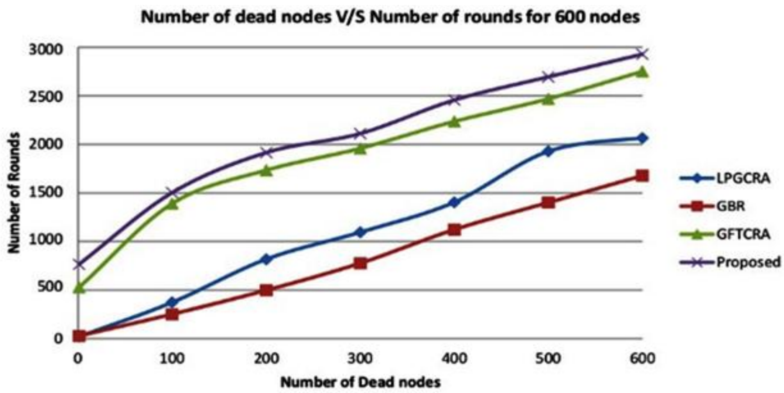


Figure 6: Dead nodes vs Round numbers in 600 nodes

The Mobile Base Station (MBS) moves at a uniform speed along the perimeter of the network following a fixed circular trajectory as depicted in Figure 2. All Access Points (APs) are predefined at each level where the MBS will pause for data collection. We compared the results of the proposed protocol with existing protocols such as LPGCRA, GBR and

GFTCRA. Figures 5 and 6 show the relationship between the number of rounds and the number of dead nodes for deployments of 1200 and 600 sensor nodes, respectively. As illustrated in these figures, the proposed protocol results in fewer dead nodes across different rounds compared to other schemes. Our scheme significantly outperforms others in terms of the number of dead nodes in both densely deployed (1200 nodes) and less dense (600 nodes) scenarios.

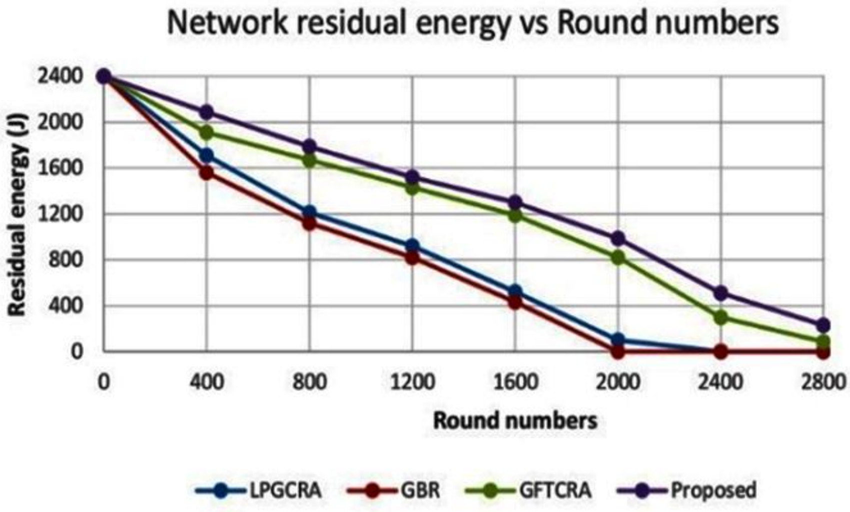


Figure 7: Residual energy vs Round numbers in 1200 nodes

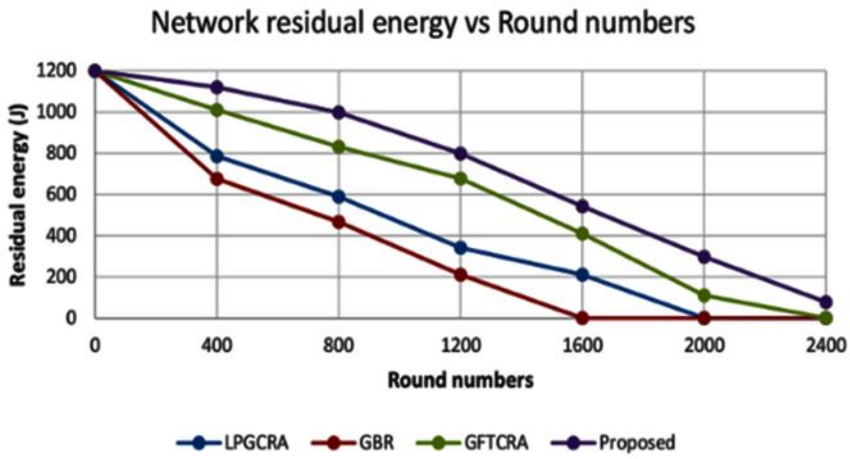


Figure 8: Residual energy vs Round numbers in 600 nodes

The superior performance of our scheme can be attributed to the BH change factor and the efficient unequal clustering which ensures uniform energy consumption across the nodes. This protocol enhances the lifespan of nodes closer to the Base Station (BS) and mitigates the energy hole problem by limiting the transmission distance to the threshold transmission distance. Consequently, this scheme conserves the nodes transmission energy and extends the overall network lifetime.

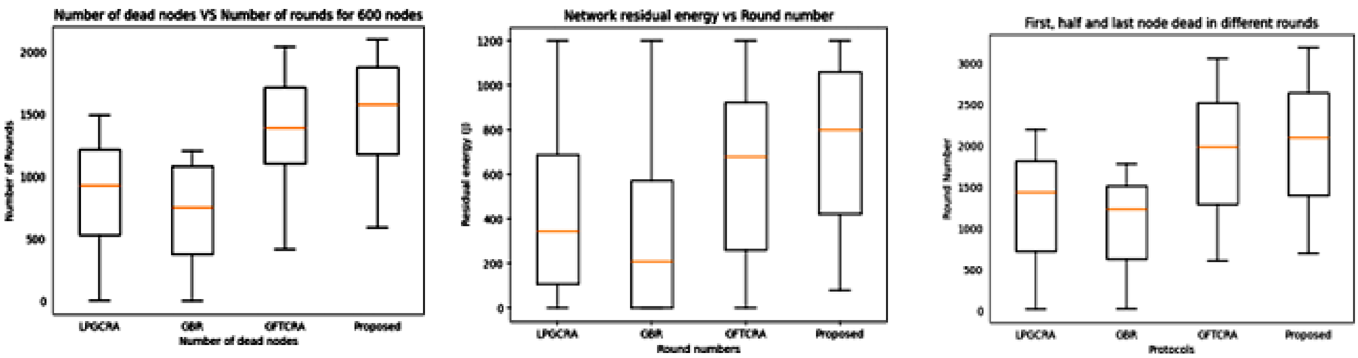
Figures 7 and 8 depict the remaining energy of the network after each round for deployments involving 1200 and 600 nodes respectively. The analysis reveals that the network's residual energy surpasses that of existing protocols significantly in both scenarios. This is attributed to the fact that fewer nodes have depleted their energy at the corresponding round number. The improved performance is due to the efficient selection of cluster sizes and the data collection method utilizing the Mobile Base Station (MBS). The MBS reduces the number of transmissions by directly collecting data from the Block Heads (BHs), thereby conserving a substantial amount of energy.

E. Analysis Of Variance (ANOVA)

ANOVA, a statistical analysis technique, is employed to mathematically validate results by comparing means across two or more groups [30],[31]. The F-ratio formula is used in ANOVA to evaluate variability both within and between samples. In the null hypothesis, we assume equal means for different samples. For a study involving 600 nodes, ANOVA is performed with a significance level of αANOVA is 0.05.

Table 3: Comparison of the sum of the square, df, mean square, F value, p-value, and F critical for LPGCRA, GBR, GFTCRA & proposed schemes in terms of FND-HND-LND, Residual energy & Dead nodes.

Source of Variation	SS	df	MS	F-ratio	P-value	F crit
First, Half and Last Dead Nodes						
Between Groups	2106546	3	702182	0.553078963	0.660310843	4.066180551
Within Groups	10156698	8	1269587.25			
Total	12263244	11				
Dead Nodes Vs Round Numbers						
Between Groups	7011427.429	5	1402285.486	4.3891768	0.003193788	2.477168673
Within Groups	11501536.57	36	319487.127			
Total	18512964	41				
Residual Energy Vs Round Numbers						
Between Groups	3012177.143	4	753044.2857	2.456841414	0.067035857	2.689627574
Within Groups	9195273.429	30	306509.1143			
Total	12207450.57	34				

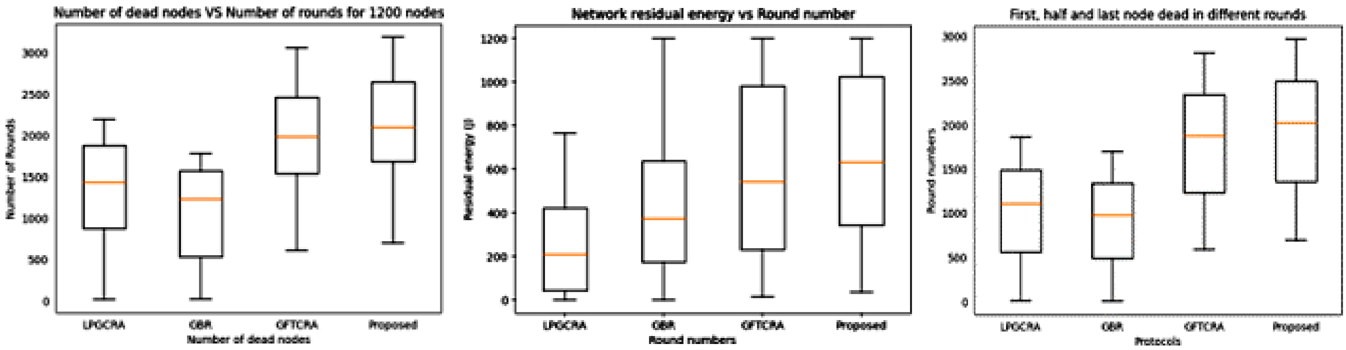


(a) (b) (c)

Figure 9: ANOVA result under FND, HND and LND, Dead nodes with Round Numbers and Residual energy with Round Numbers. Compared to other state-of-the-art methods under different communication, the proposed method has less FND, HND and LND, Dead nodes and Energy consumption with 600 nodes deployment.

The results of the ANOVA analysis for various parameters including FND-HND-LND, Dead Nodes, and Residual Energy are summarized in Table 3. Across all tables derived from the ANOVA test, we observe that the calculated F-value exceeds the critical F-value, leading to rejection of the null hypothesis in our study. Moreover, the obtained p-values are significantly less than 0.05, indicating unequal sample means. Table 3 illustrates the efficacy of the proposed method across performance metrics such as active nodes, waiting time, charging delay, and total distance traveled. The degree of freedom (df) and critical F-values (F-critical) are also considered. To assess statistical reliability, we compute 95% confidence intervals for means. Interval plots based on normal distribution are generated for LPGCRA, GBR, GFTCRA and the proposed approach as seen in Figures 9 (a, b, c) and Figures 10 (a, b, c).

1. The non-overlapping intervals for all methods indicate statistically significant mean differences.
2. Figure 9 (a) and Figure 10 (a). show that the proposed method has fewer dead nodes than the other methods.
3. Figure 9 (c) and Figure 10 (c). energy utilization is relatively lower than the other methods.



(a) (b) (c)

Figure 10: ANOVA result under FND, HND and LND, Dead nodes with Round Numbers and Residual energy with Round Numbers. Compared to other state-of-the-art methods under different communication, the proposed method has less FND, HND and LND, Dead nodes and Energy consumption with 1200 nodes deployment.

CONCLUSION

The paper introduced a method involving unequal block sizes, where blocks closer to the centre are smaller than those farther away. This configuration allows larger clusters to assist more nodes, resulting in a higher number of nodes participating in the Base Head (BH) election. This approach extends the lifetime of these nodes and reduces the likelihood of an energy hole. Additionally, horizontal-level routing is employed towards the Access Points (APs) and Mobile Base Collector (MBC) to gather data from these APs. This strategy minimized the number of transmissions, thereby enhancing the network's overall lifetime. The predefined trajectory of the Mobile Base Station (MBS) simplified and increased the efficiency of the scheme compared to other protocols. Centralized clustering and adjusting the BH based on a BH change factor helped balance energy depletion across the network. Simulation results indicate that the network's lifetime reaches approximately 3200 rounds, demonstrating the superiority of this scheme over others.

In future work, we will explore different movement patterns of the MBS at various speeds for further analysis.

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