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Prolonging Network Life using Grid-based Cluster Routing and Mobile Data Collectors in Wireless Sensor Networks

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Abstract: The energy hole problem is a significant challenge in wireless sensor network (WSN) that uses multi-hop routing protocols. Nodes near the base station (BS) typically experience higher energy consumption due to higher data traffic resulting in faster network energy depletion and creating an energy hole near the BS. To address this issue, the paper proposes a solution involving a mobile data collector (MDC) in an unequal grid cluster. The number and size of the clusters are determined based on the radio energy model's threshold transmission value to provide balanced data traffic distribution in the network. The cluster head (CH) is elected based on the node's distance from the cluster nodes centroid and the residual energy of the node. Furthermore, an MDC is deployed to collect data from the CHs of vertical boundaries effectively reducing the occurrence of energy holes and extending the network's lifetime. Simulation results demonstrate the superior performance of our protocol compared to similar existing schemes.

Keywords: Wireless Sensor Network (WSN), Mobile Data Collector (MDC), Access Point (AP), Unequal cluster, Energy Hole

1. Introduction

A wireless sensor network (WSN) [1] consists of compact sensor nodes strategically positioned to monitor various environmental factors such as temperature, humidity and pressure in their surroundings [2]. In most of the scenarios, a static base station (BS) is situated either inside or outside the network and this BS is the destination communication point for all the sensor nodes. In large area network, sensor nodes generally transmit their data in multi-hop mode to the static BS because the energy consumption of these source sensors are directly proportional to their distance from the destination node. Use of multi-hop routing in large area network saves a lot of energy and makes protocol energy efficient. Despite of various benefits of multi-hop routing protocols, it has a major drawback known as energy hole [3]. In multi-hop routing, far away nodes from the BS transmit their data through one-hop range neighbors called relay nodes and these relay nodes transmit the aggregated data to the upper layer relay nodes towards the BS. This process continues till the data reaches to the BS. The relay nodes near the BS have more data to send as compared to other nodes. Therefore, they die early which results in an energy hole in between sensor nodes and the BS. Due to this energy hole, other nodes cannot able to communicate their data to the BS even though they have sufficient energy to transmit.

To resolve this issue, three methods are frequently used by the researchers: (i) unequal clustering, (ii) heterogeneity and (iii) mobile elements. To the best of our knowledge, first time we are using unequal clustering and mobile data collector (MDC) together in this paper. In WSN routing, clustering emerges as the optimal technique for energy efficiency. Sensor nodes are organized into groups known as clusters with each cluster designating a coordinator node referred to as the cluster head (CH) whose selection is based on specific parameters [4]. These CHs collect data from their member nodes, aggregate it and transfer this data to the relay node or the BS. The role of CH is rotated among the CMs to balance energy depletion of all nodes within the cluster. The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [5] stands as the pioneering clustering-based routing protocol. It shows superior energy efficiency compared to other protocols of its time [6], [7]. The primary drawback of this protocol is its reliance on single-hop transmission to the BS by the CH. Subsequent successors of LEACH have embraced multi- hop transmission to enhance energy efficiency, thereby extending the network's lifespan [8]. Use of unequal clustering reduces the energy hole problem to a certain extend [9],[10].

However, most of the researchers in unequal clustering have considered smaller cluster sizes near the BS with increasing cluster size as move away from the BS. The logic behind it is that intra-cluster communication energy loss is less due to small cluster size (smaller intra-cluster transmission distance) as well as a smaller number of nodes (less intra-cluster communication data) within it. By limiting the maximum cluster size based on distance D_o of the first order radio model, we get the flexibility to reverse the unequal scenario. In large area network, decreasing the rotation frequency of a CH in each CM is a dominating factor as

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compared to increasing the intra-cluster data. As CH consumes more energy than a simple node, a particular node of small cluster (accommodate a smaller number of nodes) gets more chance to act as CH resulting in higher energy depletion. Hence, the size of the clusters in close proximity to the BS can be larger in large area network in order to reduce the energy hole problem. Therefore, we have considered a bigger size cluster near the BS so that the rotation frequency of a cluster node as CH will be reduced. The heterogeneous network performs better and solves the hot spot problem but increases the network cost and complexity [11], [12].

In modern times, mobile elements are extensively employed in WSN to optimize data collection efficiency and reduce energy consumption. Generally, two kinds of mobile elements are popularly used which are: (i) mobile data collector (MDC) and (ii) mobile sink. The MDC serves as an intermediary between the sensor nodes and the BS. It gathers data from individual nodes or relay nodes during its journey and transfers all collected data to the BS upon reaching it. Whereas mobile sink is the BS with mobility which also collects data from the nodes in its trajectory path and directly transmits to the external world when required. The mobile elements move in different trajectories such as random path, fixed path, on-demand, priority-based etc. In this paper, we have used MDC with a predefined fixed path trajectory for data collection from the CHs.

In this paper, we have introduced an energy-efficient unequal clustering protocol which resolves the occurrence of energy holes near the BS. It also reduces the overhead associated with cluster formation, CH selection and rotation. To balance the network load, the scheme uses unequal grid-based clusters and fix their maximum size based on the threshold distance. Further, the selection of CH is based on minimum transmission distance from centroid of cluster nodes and frequency of CH rotation within a cluster is efficiently handled in the proposed protocol. The protocol also defines a varying threshold energy value of each cluster which depends on the round number. The previously chosen CH of any cluster undergoes a change during the setup phase only if the energy level of the CH falls below its threshold value for that round. The protocol is centralized in nature and the BS divides the whole network region into levels. Further, each level is divided into rectangular grids of different sizes called grids (clusters). The selection of CH relies on two key parameters residual energy and distance from the centroid. The BS calculates the centroid of the nodes within the cluster and then selects the node closest to the centroid with energy levels surpassing the average energy of the cluster. The integration of the MDC makes our scheme more energy efficient. The remaining sections of the paper are organized as follows: Section-2 provides a summary of related works. Section-3 elaborates on the system model encompassing the network model, radio energy model and cluster size selection. Section-4 delves into the proposed protocol. Simulation parameters, results and performance analysis are presented in Section-5. Lastly, Section-6 concludes the paper discussing future avenues for research.

2. Related Work

LEACH was the pioneering hierarchical routing protocol founded on distributed clustering principles [5]. This protocol operates on a round-based mechanism where each round begins with all nodes generating a random number between 0 and 1. If the generated random number of a node falls below a threshold value, it becomes selected as a Cluster Head (CH) for that round, broadcasting a CH message to its member nodes. Despite its energy efficiency, this protocol has several drawbacks including (i) lack of consideration for node energy in CH selection, (ii) direct single-hop transmission of data from CHs to the BS and (iii) random placement of CHs within clusters. Consequently, various researchers have proposed solutions to address these issues [8]. Heinzelman et al. [13] have extended their previous LEACH protocol with LEACH- centralized (LEACH-C) to reduce the drawbacks. They made this protocol centralized and fixed the number of CHs for all the rounds. This scheme reduces the extra overhead for forming new clusters in every round. Though its performance is better than LEACH, this protocol still faces challenges such as single-hop transmission from CH to the BS and issues in CH selection. Younis et al. presented an energy-efficient multi-level clustering called HEED (Hybrid energy-efficient distributed clustering). This scheme selects the CH very efficiently by using 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 [14] is designed to minimize the energy consumption of the network by restricting transmission energy dissipation at a rate of square of transmission distance. Intra-cluster communication can be either single-hop or multi-hop depending on the size of the cluster. For large-size clusters, a shortest path tree is created within the cluster for communication. Multi-hop LEACH [15] employs a multi-hop communication path to relay data to the BS. A multi-hop tree is established between the CH and the BS for communication purposes. Although this approach enhances network energy efficiency, it encounters a significant issue known as energy hole which our scheme aims to mitigate. EEM-LEACH [16] 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 reduces the energy hole problem. Minimum communication cost is the parameter for the route discovery. The energy hole problem affects all multi-hop routing protocols which arises due of heavy data traffic in close proximity to the BS. A grid-based scheme for reducing the energy hole issue has been presented by Lui et al. and they called it FCEEC [17]. The transmission distance within the cluster serves as the primary parameter for CH selection. In this protocol, the most suitable CH is chosen as the relay node with their numbers being restricted. This balanced the energy consumption and the BS nearest clusters consume less energy. The Grid-Based Routing (DBSCAN) [18] is also a grid-based routing protocol which selects the node with the minimum distance from the BS as the CH in each cluster. Due to this, the intra-cluster communication cost increases and as a result, the network lifetime decreases. Jannu and Jana presented a novel grid-based routing which named as Low Power Grid-based Cluster Routing Algorithm (FBECS) [19]. This scheme is mainly designed to mitigate 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 major problem of this protocol is single-hop communication from CH to the BS which restricted it from applying this scheme in large area networks. Gupta et al. have projected an upgraded version of distributed unequal clustering based on energy-aware named (EADUC). 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 along with these two parameters, the CHs are selected. The relay nodes for multi-hop communication are selected by using their distance from CH and energy expenses. The primary issue with this scheme is its heterogeneity which amplifies the overall cost and complexity.

Shah et al. [20] introduced a three-layer reference model wherein the lower layer comprises numerous sparsely deployed sensor nodes. The middle layer involves mobile data carriers known as MULES which traverse the network randomly to gather data from the nodes. These MULES then transmit the collected data to the upper layer access point which is IP-enabled and linked to the wider network. This model functions like to an opportunistic network, characterized by increased delays and uncontrolled behaviour of MULEs. Singh et al. [21] introduced a grid-based clustering routing scheme with mobile mules. They employed an odd-even level routing approach for data forwarding within each level, while the mobile mules collected data from the boundary CHs of each level. Although the scheme utilizes two mules, only one mule visits a level at a time based on round numbers. However, due to its centralized clustering approach, it may not be suitable for large-area networks. Kaswan et al. [22] proposed two new techniques, EDT and DAEDT, for data collection utilizing controlled mobility of mobile sinks. Rendezvous points are calculated based on the energy density of each sensor node in a flat network where one-hop communication is prioritized. In EDT, the algorithm calculates the impact of every other node within communication range on a sensor node, selecting nodes with the lowest impact as Rendezvous Points (RPs). A subset of RPs covering all deployed nodes is determined and a Traveling Salesman Problem (TSP) path covering these RPs is constructed. However, EDT does not account for the delay bound associated with the application, making it unsuitable for applications requiring timely responsiveness. Its worst-case time complexity is O(n3) where n is the number of deployed nodes. In DAEDT, the TSP path is constrained by a user defined delay limit, resulting in fewer RPs and increased communication distance. Consequently, when considering delay, sensors can no longer strictly communicate within a one-hop distance leading to higher energy consumption. Singh et al. [21] expanded their earlier scheme by incorporating unequal clustering and mobile mules with various trajectory patterns [23]. In this enhanced scheme, they devised a method to compute a near-optimal Cluster Head (CH) change factor and a reduction factor for the cluster's size.

3. System Model

3.1. Network Model

In a rectangular area, a total of S sensor nodes is deployed randomly with a stationary BS positioned on the outer edge of the network. The MDC is used to collect data from the specific CHs. There are few assumptions considered during the design of this scheme which are as follows:

- After deployment, all the sensor nodes are static.
- All nodes are homogeneous.
- The BS knows all information of nodes such as their ID, coordinates, energy etc.
- A single MDC moves in a predefined path and it has no resource issue.

3.2. Energy Model

Our protocol uses the same radio energy model as described in [5]. The Equation-1 and Equation-2 provide details of energy consumption while transmitting and receiving the message by sensor nodes. The notations used in the equations are mentioned in Table-1. The energy consumed in the transmission of p bit packet of data over a distance d is given by Equation 1.

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

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

$$E_{recv}(p) = (E_e * p) \tag{2}$$

The threshold radio range D_0 is calculated with the help of Equation 3.

$$D_0 = \sqrt{\frac{e_{fsf}}{e_{mpf}}} \tag{3}$$

3.3. Cluster Size Selection

Considering the radio energy model of sensor nodes, cluster size is chosen such that the maximum transmission distance is less than the threshold transmission distance D_0 as calculated in Equation-3. Figure-1 shows the proposed network division into unequal sized clusters having unique IDs. Intra-cluster communication and inter-cluster communication represent the two types of communication possible between sensor nodes within the network area. Figure-2 shows the two adjacent clusters in a level having cluster id $C_{level_{id},(numCL-1)}$ and $C_{level_{id},(numCL-2)}$. The length l of all the clusters in the network are same and size of clusters are varying by changing the width w of the clusters. The length and width of largest clusters are equal i.e., $l = w = W$.

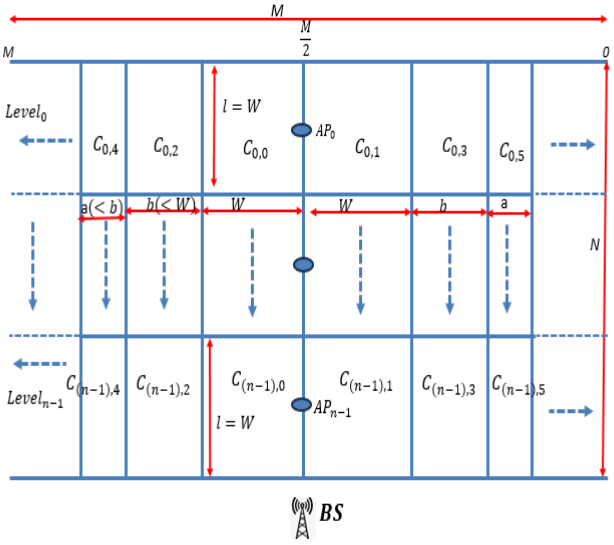

Fig. 1. Division of network into unequal clusters

For cluster having id $C_{level_{id},(numCL-1)}$ which is near to AP and having largest cluster size,

$$length = width = \ l = w = W$$

For calculation of the width of the largest cluster in terms of D_0, suppose $C_{level_{id},(numCL-1)}$ and $C_{level_{id},(numCL-2)}$ are of same size then width of the cluster $C_{level_{id},(numCL-2)}$, $w = b = W$

$$\text{As such,} \quad \sqrt{l^2 + (2W)^2} = D_0$$

$$\text{i.e.,} \quad \sqrt{W^2 + (2W)^2} = D_0$$

$$\text{Therefore ,} \quad W = \ D_0/\sqrt{5} \tag{4}$$

From Equation-4, it is clear that if the maximum width of the cluster is $D_0/\sqrt{5}$ then the maximum transmission distance for any node is equal to the threshold distance D_0 for any possible inter-cluster communication within the network as this distance is the diagonal distance between two adjacent clusters as shown in Figure-2.

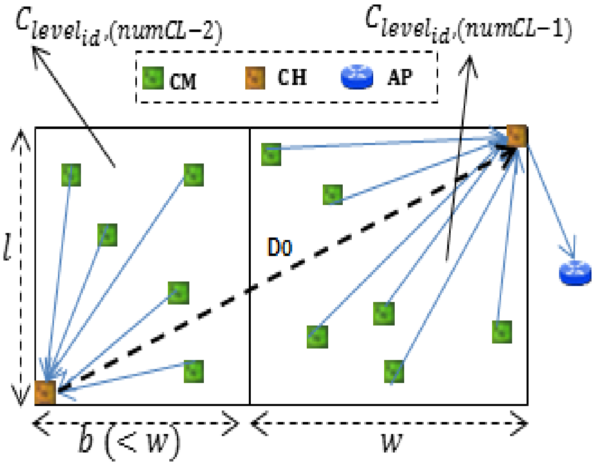

Fig. 2. Communication between two clusters

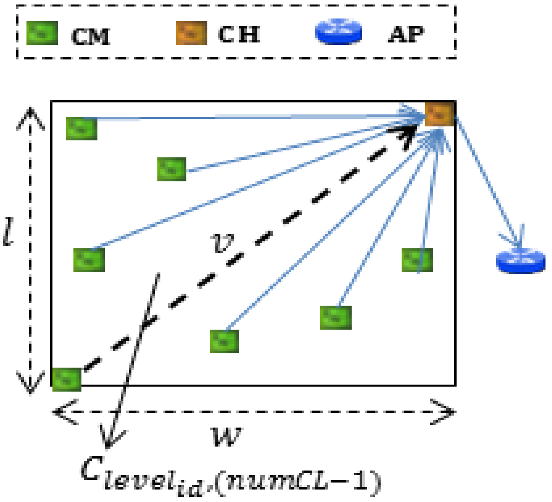

Fig. 3. Communication within clusters

In real scenario, width of the cluster $C_{level_{id},(numCL-2)}$ is always less than cluster $C_{level_{id},(numCL-1)}$ i.e., $b < W$

Therefore, maximum transmission distance for any node is always less than the threshold transmission distance D_0 for a maximum cluster width $D_0/\sqrt{5}$. Figure-3 shows communication between CM and CH of the largest cluster in the worst-case scenario when they are at diagonally opposite corners of the grid. The maximum cluster width W

ensures that the communication distance between any two nodes within the cluster is always less than D_0. Hence, maximum calculated width W of the cluster ensures that all the nodes in the network deplete their energy at a rate of d^2 which is respectively very less than d^4.

4. Proposed Solution

The proposed protocol is a centralized protocol based on a fixed clustering approach. The protocol consists of four stages: (i) Cluster Formation, (ii) Setup, (iii) Data Forwarding and (iv) Steady. Table-1 illustrates the notations used in the proposed protocol.

Table 1. Notations used in proposed scheme

Symbol	Description
M and N	Rectangular area of interest
D_o	Threshold distance
S	Numbers of sensors
CH	Cluster head
MN	Member node
W	Maximum width of the grid or cluster in the network
l	Width of a level or Length of the cluster
L	Total number of levels
r	Cluster width decreasing rate
CHC	Multiplier having integral value between 1 to 10
S_i	Sensor node ID
$level_{id}$	Level ID
$C_{level_{id},i}$	ID of the cluster belongs to $level_{id}$
$CH_{level_{id},i}$	CH belongs to cluster $C_{level_{id},i}$
$C_{level_{id},i}[\ ]$	Node IDs of cluster $C_{level_{id},i}$
$numSC_{level_{ic}}$	Total number of nodes in cluster $C_{level_{id},i}$
$numCL$	Total clusters in a level
$E(Th)$	Threshold energy of a node to become CH
$NodeSet[\ ]$	Node IDs which have energy E > E_{avg}
$Dist[\ ]$	Distance of nodes from the centroid in a cluster
E_{min}	Active node's threshold energy
p	Packet size transmitted by sensor node
$E_{recv}(p)$	Energy consumed to receive p bit
$E_{trans}(p,d)$	Energy consumed to transmit p bit over distance d
E_e	Energy consumes by electronic circuit
e_{fsf}	Amplification energy in free space model
e_{mpf}	Amplification energy in multi-path fading model
AP_{id}	Anchor point at each level

4.1. Cluster Formation Phase

The prime objective of this phase is division of the network into levels and grids (clusters) of varying sizes with unique IDs. Algorithm-1 elucidates the complete process of this stage.

Mathematically,

$$\text{number of levels, } L = \frac{N}{W}$$

$$\text{and width of each level, } l = \frac{N}{L}$$

$$\text{length of each cluster} = \text{width of each level} = l \qquad (5)$$

where N is the length of the network.

The varying width of the clusters in a level is calculated by the Equation-6 where w is the width of the smallest cluster in the level and $numCL$ is the number of clusters in that level.

$$w = W - \left(\left\lfloor \frac{numCL}{2} \right\rfloor \right) * r \qquad (6)$$

Algorithm-1 is executed only once at the start of network setup phase by the BS. It calculates D_0 for the network and divides network into levels with $level_{id}$ and then each level into unequal size grids called clusters. It assigns a unique ID $C_{level_{id},i}$ to each cluster and assigns sensor nodes to the cluster. It maintains a record of cluster IDs and node ids belonging to that cluster. A vertical path is defined passing through middle of the network area for movement of MDC. The path has anchor points (APs) where MDC stops to collect data from CH nodes. The size of the grids or clusters decreases linearly with a constant rate r in a level as moves away from these APs. This is because the cluster nearer to the APs have more data load as it handles its own cluster data as well as other cluster data also. Increasing the size of the cluster leads to more sensor nodes within that cluster. This decreases the frequency with which a particular node within the cluster is selected as CH. This saves a lot of energy which improves the lifetime of these nodes and therefore it prevents the occurrence of energy hole. Figure-1 explains the working of Algorithm-1. It also shows the division of network area into equal size levels of width l, levels into unequal size clusters and assignment of unique IDs to each level and cluster after execution of this algorithm.

4.2. Setup Phase

The Setup phase includes Algorithm-2 and Algorithm-3 namely CH Change Algorithm and CH Selection Algorithm. Both the algorithms are executed by the BS outlining the working of this phase. Algorithm-2 determines whether the current CH of a cluster will change or continue acting as CH after completion of a round. At the start of each round, it identifies the nodes within each cluster that are not capable of transmitting the data due to lower energy level and set their status as dead node in its record table.

Algorithm 1. *Unequal Grid Formation Algorithm*

```
procedure GRID-FORMATION
Required: Network Size: (M,N), Node's Radio Range: $D_0$
          Number of Sensor Nodes : S
Ensure: Unequal Grids

x=0, $W = D_0/\sqrt{5}$
Number of Levels, $L = N/W$
Width of Level, $l = N/L$
for k=0 to (L-1) do
    Denote $level_{id}$ = level k to the horizontal region
     from y to (y+l)
    y = y+l
end for
for $level_{id}$=0 to (L-1) do
    $x = z = M/2$, numCL = 0
    while y ≤ M do
        $w = W - \left( \left\lfloor \frac{numCL}{2} \right\rfloor \right) * r$
        Assign $C_{level_{id},numCL}$ for the network area
        between x and (x+w)
        Initialize $C_{level_{id},i}[cl]$, $cl = 0$ and
        $numSC_{level_{id},i} = 0$
        for m = 0 to (S-1) do
            if $S_m$ is in the cluster $C_{level_{id},i}$ then
                Store $S_m$ to $C_{level_{id},i}[cl]$
                cl++
            end if
            $numSC_{level_{id},i}$ = cl
        end for
        numCL++
        x = x+w
        Assign $C_{level_{id},numCL}$ for the network area
        between z and (z-w)
        Initialize $C_{level_{id},i}[cl]$, $cl = 0$ and
        $numSC_{level_{id},i} = 0$
        for m = 0 to (S-1) do
            if $S_m$ is in the cluster $C_{level_{id},i}$ then
                Store $S_m$ to $C_{level_{id},i}[cl]$
                cl++
            end if
            $numSC_{level_{id},i}$ = cl
        end for
        numCL++
        z = z – w
    end while
end for
Total number of clusters = numCL*L
end procedure
```

After that, it calculates the threshold energy for each cluster and compare it to the energy of their current CHs. If the energy of current CH is greater than CHC (an integral value) times of the calculated threshold energy of that cluster, CH will not change. Otherwise, Algorithm-3 is executed for selection of new CH among cluster's alive nodes. CHC is a predefined integral value which affects the frequency of rotation of CH in a network. Algorithm-3 calculates the centroid and average energy of the active nodes for that cluster. The node nearest to the centroid and having greater energy than the average energy of the cluster is selected as new CH. The combination of both the algorithm optimizes the frequency of CH rotation and reduces overhead energy loss of changing CH in each round in the network.

Algorithm 2. *CH Change Algorithm*

```
procedure CLUSTER HEAD-CHANGE
Required: $C_{level_{id},i}$ , $CH_{level_{id},i}$
Ensure: CH rotates or not after the completion of a round

for all $C_{level_{id},i}$ (where $level_{id}$ = 0 to (L-1), i = 0 to
    (numCL-1) do
 $E_{min}(p,Z) = (p * E_e + p * e_{fsf} * (Z)^2)$
for i = 0 to ($numSC_{level_{id},i} - 1$) do
    if $E_{resi}\{ C_{level_{id},i}[i] \} \leq E_{min}$ then
        In table, status of node is dead
        $numSC_{level_{id},i}$--
    end if
 end for
for $level_{id}$ = 0 to (L-1) do
    NoN = 0
    for i = 0 to (numCL-1) do
        $E_{recv}(nrCl - data) = (NoN * p * E_e)$
        $E_{recv}(onCl - data) = (numSC_{level_{id},i} - 1) * l * E_e$
        $NoN = NoN + numSC_{level_{id},i}$
        $E_{trans} = NoN * p * E_e + e_{fsf} * (Z)^2$
        $E(th)_{level_{id},i} = E_{recv}(nrCl - data) +$
         $E_{recv}(onCl - data) + E_{trans}$
    end for
end for
Initialize CHC
for $level_{id}$ = 0 to (L-1) do
    for j = 0 to (numCL-1)
        if (CH-$E_{level_{id},i} \geq CHC * E(th)_{level_{id},i}$) then
            CH will not change
        else
            Perform CH selection based on Algorithm-3
        end if
    end for
 end for
end for
end procedure
```

4.3. Data Forwarding Phase

In this phase, data forwarding routes are discovered to transmit the data packets towards APs. In each round, the BS performs this task. Initially, it selects the $CH_{level_{id},i}$ of the cluster $C_{level_{id},i}$. It searches the $CH_{level_{id},i-2}$ of the apparent neighbor cluster $C_{level_{id},i-2}$ toward the $AP_{level_{id}}$. If

$C_{level_{id},i-2}$ is present in the same level, then the CH of that cluster works as a relay node for $CH_{level_{id},i}$. If one-hop neighbor CH is not found in the same level, then it searches the upper level $CH_{level_{id+1},i-2}$ and lastly lower level $CH_{level_{id-1},i-2}$. Each CH performs this process till all the CHs get their relay node for data forwarding. The process can be easily analysed by using network division diagram as shown in Figure-1.

The total energy consumed in transmission and reception of any packet (E_{TxRx}) in a cluster can be calculated by Equation-9 using Equations-7 and Equation-8 where $data_{onCl}$ and $data_{nrCl}$ are the total data of one cluster and its neighbor's cluster total data respectively.

$$E_{trans} = (data_{onCl} + data_{nrCl}) * E_e + (data_{onCl} + data_{nrCl}) * e_{fsf} * {D_0}^2 \qquad (7)$$

$$E_{recv} = (data_{onCl} + data_{nrCl}) * E_e \qquad (8)$$

$$E_{TxRx} = E_{trans} + E_{recv} \qquad (9)$$

4.4. Steady Phase

The TDMA time-slot allocation to CMs, CHs and MDC for transmission and reception of the sensed data is the key task of this phase. Due to the random distribution of nodes in the network, each cluster has a different number of nodes. Therefore, the BS detects the maximum number of node's cluster (max $\_numSC_{level_{id},i}$) and assigns the maximum TDMA time slots to that cluster. Suppose the BS allots t Sec to each MN in their TDMA slots, then the maximum TDMA time slots will be $t *$ (max $\_numSC_{level_{id},i}$) Sec.

For example, if a cluster has 12 nodes, its TDMA time slots will be 11$*$ t Sec. The communication within a cluster is known as intra-cluster communication and communications between two CHs or relay nodes are called inter-cluster communication. The average one-hop inter-cluster time is of t_{CH}. The MDS moves with a uniform speed of v m/s and it stops for t_{wait} Sec at each AP to collect data from borderline CHs.Therefore, we can find out the average period t_{round} for a complete round by using Equation-10.

$$t_{round} = t_{setup} + t * (\max\_numSC_{level_{id},i} - 1) + t_{CH} * \frac{numCL}{2} + \frac{N}{v} + t_{wait} * m \qquad (10)$$

Here, t_{setup} is the average time needed to complete the set-up phase. After executing the rectangular grid formation phase, set up phase and data forwarding phase of the first round, the BS knows the total time required for completion of a round with the help of Equation 10. It also maintains a table which consists of all cluster and CH information. The BS shares this table with all nodes at the beginning of each round. After the lapse of t_{setup} Sec, CMs transmit their sensed data as per their TDMA slots. In each round, nodes wait for control packets from the BS during their t_{setup} time. If sensor nodes receive any control packets, they update their table and use this updated table for future communications. In each round, the BS checks the residual energy of each CH and if any CH's residual energy goes below the threshold energy $E(th)$, the BS change sends a control message for CH change in that cluster.

Algorithm 3. *CH Selection Algorithm*

```
1: procedure CLUSTER HEAD-SELECTION
Required: $C_{level_{id},i}$ , $CH_{level_{id},i}$
Ensure: The selection of best-suited node of each cluster as a CH
2:  for all $C_{level_{id},i}$ (where $level_{id}$ = 0 to (L-1), i = 0 to (numCL-1) do
3:    E = 0, a = 0, b = 0
4:    for i = 0 to ($numSC_{level_{id},i} - 1$) do
5:        $a = a + a_{node\_x-coordinate}\, C_{level_{id},i}[i]$
6:        $b = b + b_{node\_x-coordinate}\, C_{level_{id},i}[i]$
7:        $E = E + E_{energy-of-node}\, C_{level_{id},i}[i]$
8:    end for
9:    $Centroid_{level_{id},i}(a,b) = ( {}^{a}/_{numSC_{level_{id},i}} , {}^{b}/_{numSC_{level_{id},i}} )$
10:   $E_{avg} = {}^{E}/_{numSC_{level_{id},i}}$
11:   Initialize S-set [ ], counter = 0
12:   for k = 0 to (numCL-1) do
13:       if ($Eng - of - C_{level_{id},i}[k] \geq E_{avg}$) then
14:           S-set [counter] = $C_{level_{id},i}[k]$
15:           counter++
16:       end if
17:   end for
18:   for k = 0 to (counter-1) do
19:       Dis[k] = $\sqrt{(a_{s-set[k]} - a_{centroid})^2 + (b_{s-set[k]} - b_{centroid})^2}$
20:       $Dis_{\min} = \min_0 \leq k \leq counter\ \{Dis[k]\}$ and $C_{level_{id},k}[k]$ is the$Dis_{\min}$ node
21:       if $E\{C_{level_{id},k}[k] \geq E(th)_{level_{id},k}\}$ then
22:           $C_{level_{id},k}[k]$ is selected as the $CH_{level_{id},k}$
23:       else
24:           $Dis_{\min} = next\, Dis_{\min}$
              $C_{level_{id},k}[k]$ be the $Dis_{\min}$ node & $go - to$ 17
25.       end if
26:   end for
27: end for
28: end procedure
```

The new CH information is also attached to this control message. The $E(th)$ can be calculated by using Equation-11.

$$E_{th} = CMC * E_{TxRx} \tag{11}$$

Here, CHC is the CH change factor which we have fixed 5 based on the simulation results. The value of CHC is 5 means that CH does not change for 5 rounds. It will change after the 5th round. We have simulated our scheme for CHC value from 1 to 10 for 1200 nodes and analysed the number of dead nodes in different rounds. For value of CHC = 5, we get the best results as the numbers of dead nodes are less in a different range of rounds at this value. Hence, we have selected this value for our simulation. The E_{TxRx} is the combined energy required for transmission and reception of data by a node as calculated in Equation-9. More frequent CH change leads to more energy loss of the network in transmission and reception of control packets whereas less frequent leads to the early death of the sensor nodes. Therefore, an efficient CH rotation is needed to prolong the network lifetime.

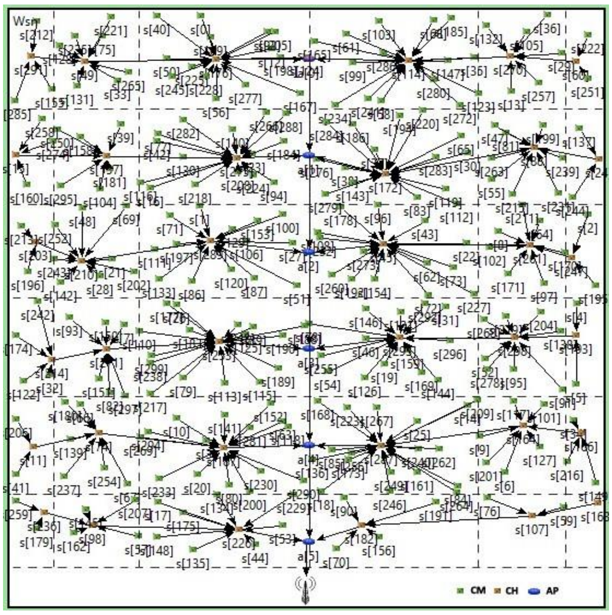

Fig. 4. Network Scenario and AP positions for MDC stoppage

During data collection by the MDC, all the CHs transmit their cluster's aggregated data received from the member nodes to their predefined neighbour forwarding CH towards APs. The data transmission from CH to forwarding CH and CH of a level to the MDC is performed based on the three-handshake protocol as discussed in the data forwarding section. The total time required to transmit the data for a borderline CH to CH nearest to AP in same level is $t_{CH} * numCL/2$ Sec and in upper and lower-level CH requires time is $t_{CH} * numCL/2 + 1$ Sec. When all data of a level reaches at the last CH nearest to AP of that level, CH transfers its aggregated data to the MDC. The MDC maintains a constant velocity while traversing the network's middle path. Its trajectory remains fixed, following a straight path as depicted in Figure-4. Along this path, predetermined access points (APs) are positioned at each level where the MDC pauses to gather data from the CHs of each level. Upon reaching the range of the BS, the MDC transfers its accumulated data to the BS.

5. Simulation and Result Discussion

This section discusses the simulation parameters used for our scheme and three other schemes. It will also cover the position of APs and the CH change factor (CHC) for CH rotation. The simulation results are analysed using various performance parameters such as round numbers, dead nodes and residual energy. These performance metrics will be discussed in two different scenarios of deployed nodes along with comparison graphs of three existing protocols.

5.1. Simulation Setup

We conducted simulations of our scheme using OMNet++ [24] on the Windows 10 platform. The deployment area is a 500 X 500 square meter region. We have randomly deployed 1200 and 600 nodes to obtain the results. Each node has an initial energy of 1 Joule. The data and control packets have lengths of 1000 bits and 100 bits respectively. The constant values for E_e, e_{fsf} and e_{mpf} are 50 nJ/bit, 10 pJ/bit/m2 and 0.0013 pJ/bit/m4 respectively. In our simulation, we placed the APs in the middle section of the network. We also simulated three similar protocols (i) FBECS [25], (ii) DBSCAN [26] and (iii) FCEEC [27] with the same parameters for comparison. The simulation results are discussed in the next section.

5.2. Positions of APs

The APs serve as a designated location where the MDC stops to collect data from the CHs. In our work, we have defined a specific trajectory path for the MDC. This predefined path describes movement of MDC in a vertical path at the middle section of the network. The positions of the APs in this scenario are indicated by blue solid circles as shown in Figure-4.

5.3. Comparison for dead nodes in different rounds

We have evaluated the performance with 1200 and 600 nodes using key parameters: first node dies (FND), half node dies (HND) and last node dies (LND). Along with our proposed scheme, we simulated three other schemes for the comparison. The results for these parameters are summarized in Table-2 and Table-3 for both scenarios of node deployment. Upon analysing the data presented in Table-2, Table-3, Figure-5 and Figure-6, it becomes evident that our scheme surpasses the other three schemes. Our scheme demonstrates superior performance by sustaining operations for the maximum number of rounds and first node dies at 765 rounds which is notably better than the alternatives.

Table 2. FND, HND and LND in different rounds for 1200 nodes

Schemes	FND	HND	LND
DBSCAN	24	1043	2558
FBECS	32	1438	2806
FCEEC	467	1582	3258
Proposed	724	2217	3832

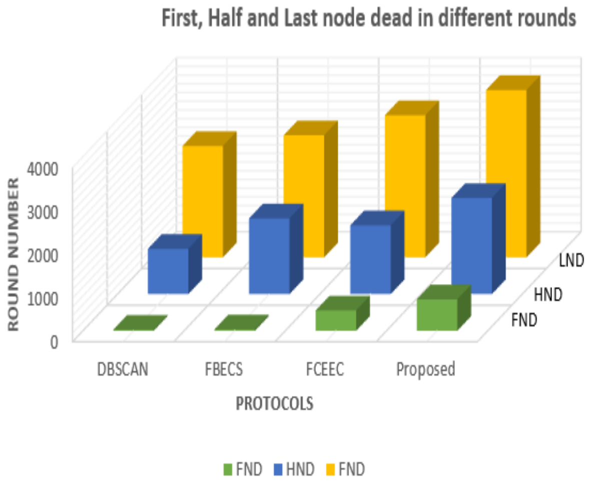

Fig. 5. FND, HND and LND in 1200 nodes

Table 3. FND, HND and LND in different rounds for 600 nodes

Schemes	FND	HND	LND
DBSCAN	16	1019	1913
FBECS	15	1264	2386
FCEEC	462	1451	2586
Proposed	694	2104	2983

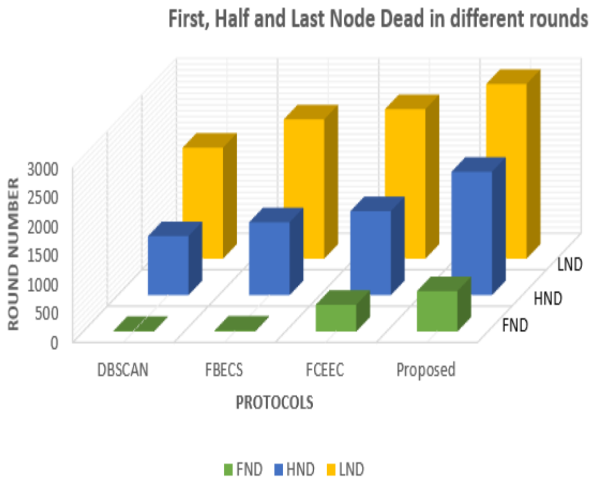

Fig. 6. FND, HND and LND in 600 nodes

5.4. Performance evaluation based on Dead nodes

Figure-7 and Figure-8 illustrate graphs that display the relationship between the number of rounds and the number of dead nodes in deployments consisting of 1200 and 600 sensor nodes respectively. We have compared the outcomes of our proposed protocol with those of existing protocols such as FBECS, DBSCAN and FCEEC. As evident from Figure-7 and Figure-8, our proposed protocol exhibits significantly fewer dead nodes across various rounds compared to the other schemes. Our scheme outperforms in terms of dead nodes in both scenarios, dense deployment of 1200 nodes as well as light deployment of 600 nodes. This superior performance can be attributed to the CH change factor and the size of the CH. The unequal clustering plays a crucial role in balancing the energy consumption of the nodes by uniform distribution of overhead CH role. Consequently, the nodes closer to the base station (BS) experience an extended lifespan. This mitigates the energy hole problem which restricts transmission distance to a threshold value, thereby conserving the transmission energy of the nodes and prolonging the network's lifetime.

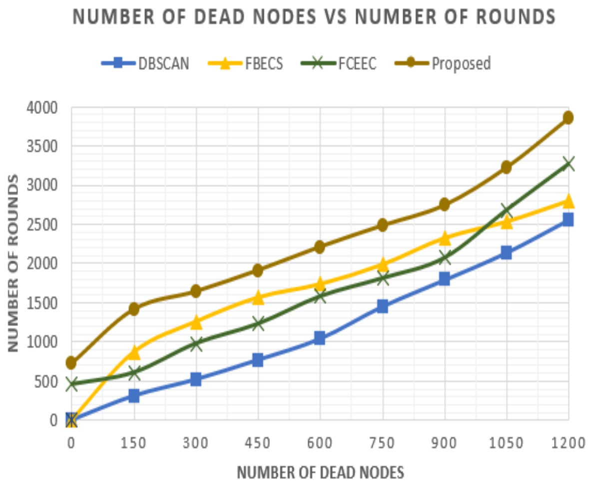

Fig. 7. Dead nodes vs Round numbers in 1200 nodes

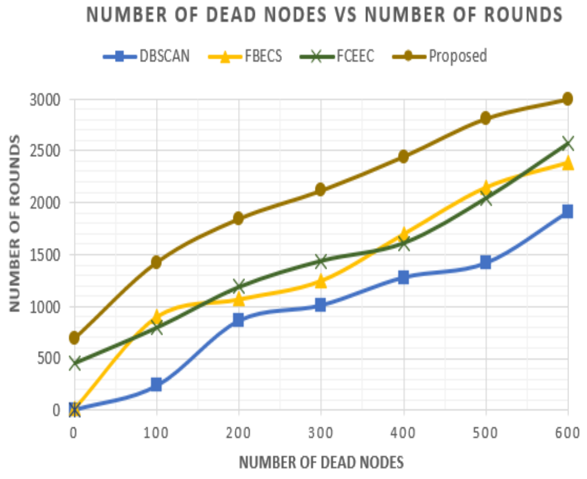

Fig. 8. Dead nodes vs Round numbers in 1200 nodes

5.5. Performance evaluation based on Residual energy

Figure-9 and Figure-10 depict the residual energy of the network after each round considering deployment of 1200 and 600 nodes respectively. The comparison in these figures demonstrates that the residual energy of the network surpasses that of the existing protocols in both deployment scenarios in any round. This can be attributed to fewer nodes becoming inactive in the corresponding round. The efficient selection of cluster size and the data collection process facilitated by the MDC play a crucial role in achieving this outcome. By enabling direct data transmission from CHs, the MDC effectively reduces the number of large distance transmissions resulting in substantial energy savings.

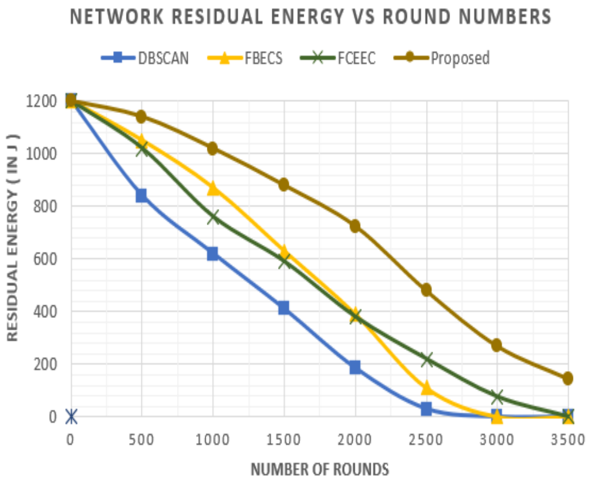

Fig. 9. Residual energy vs Round numbers in 1200 nodes

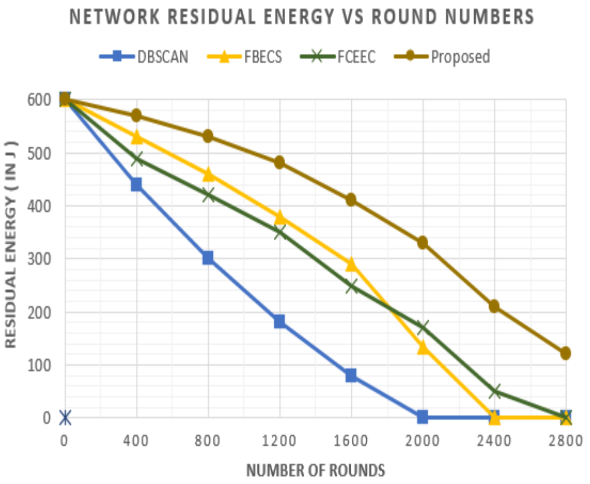

Fig. 10. Residual energy vs Round numbers in 600 nodes

6. Conclusion and Future Works

There are various reasons for better performance of the proposed protocol over existing protocols. It uses an unequal clustering approach where the size of the clusters near the BS is bigger as compared to the far away clusters. The bigger cluster associates more numbers of nodes due to that the higher number of nodes participated in the CH election. It has improved the lifetime of these nodes which lead to reduction in occurrence of energy hole. Due to centralized nature of the proposed protocol, sensor nodes play a minimal role in CH selection and route discovery. This minimizes energy consumption for nodes tasked with overhead duties. The protocol restricts the transmission range for any node in the network to D_0 which ensures energy depletion of sensor node at rate of d^2 which is remarkably less than d^4. The protocol ensures uniform energy consumption and data traffic in the entire network resulting in reduction of energy hole problem. Use of MDC in the protocol saves energy of nodes near to APs which extends the life of nearer nodes. The change of CH based on the CH change factor (CHC) balances the energy consumption of nodes throughout the network. All these factors all together saves the energy of sensor nodes that provides larger network lifespan and stable network. The simulation results demonstrate that the lifetime of the entire network is approximately 3200 rounds showcasing the superiority of our scheme over other approaches.

In future, we will try to analyse the other movement patterns of the MDC with different speeds in order to increase network lifespan to much more extend.

Author contributions

Bhaskar Prince: Conceptualization, Methodology, Software and writing the original draft. Prabhat Kumar: Data curation, original draft preparation, Software, Validation. Sunil Kumar Singh: Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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