

Energy Efficient Multi-Sink Hybrid Data gathering Framework for Smart Agriculture Monitoring System in Wireless Sensor Network

Sanjay Kumar Biswal¹, Sampa Sahoo^{2*}, Prabhudutta Mohanty³

¹Research Scholar, Department of Computer Science and Engineering, C.V. Raman Global University, Odisha- 752054, India

Email Id: sanjaybiswalit@gmail.com

²Associate Professor, Department of Computer Science and Engineering, C.V. Raman Global University, Odisha- 752054, India

Email Id: sampa.sahoo@cgu-odisha.ac.in

³Post Graduate, Department of Computer Science, Lecturer, Govt. (Auto) College, Rourkela, Odisha- 752054, India

Email Id: prabhudutta.mohanty@gmail.com

Cite this paper as: Sanjay Kumar Biswal , Sampa Sahoo, Prabhudutta Mohanty, (2025) Energy Efficient Multi-Sink Hybrid Data gathering Framework for Smart Agriculture Monitoring System in Wireless Sensor Network. *Journal of Neonatal Surgery*, 14 (32s), 2721-2736.

ABSTRACT

Wireless Sensor Network (WSN) is a key emerging technology helps in providing efficient and reliable solutions for modernizing agricultural farming with minimal Human involvement. This approach has become more defined and evidence-based data gathering approach in refining throughput by elevating usage of resource. The proposed approach presents a Multi-Sink Hybrid Data-gathering WSN-based framework for the smart agriculture Monitoring system with minimal energy consumption. At first, an optimized node deployment strategy is used to divide the sensing field into logical cells. Each cell has a leader node designed for sensing and communication activity. The primary objective of the projected approach is to reduce traffic overhead while monitoring sensing entities like temperature, soil moisture, and humidity of the soil for irrigation thereby minimizing energy conservation of the sensor network. Over the years small sensor nodes have been designed to monitor environmental conditions to reduce energy consumption. The adoption of new clustering technology & optimization of routing protocols led to an increase in the battery lifetime in WSN. The proposed framework adopts a load balancing scheme, the Silent and Zero Start (SZS) approach exploits redundant data communication to increase energy conservation. We also adopted a modified acknowledgment scheme that helps to achieve reliability during communication. The performance analysis of the proposed framework shows a better result than some existing smart agriculture monitoring systems

Keywords: Smart farming, Wireless Sensor Network, Data redundancy & fusion, Energy efficiency Strategy, Multi-Sink Communication.

1. INTRODUCTION

Agriculture contributes from food safety to economic prosperity in the society. The use of high-yield varieties of crops increases production and aims to mitigate the food requirement for the increasing population. To increase the production of crops in limited cultivated land high fertilizers and pesticides are used. This leads to soil contamination and health issues in modern society [4-5, 9]. Furthermore, the environment is one of the principal factors that impact the productivity of agriculture. Agriculture contributes to the greenhouse effect in crops and soil while attempting to mitigate food risks [1,2,7]. The emphasis is paid to the research for adopting modern technology to increase agricultural production at a lower cost. Recent analysis indicates that advanced technology in agriculture can boost the annual growth rate by 20% [8]. This modern approach to agriculture is called precision agriculture (PA) [3,18,29]. In precision agriculture, farmers can effectively observe, measure, and respond to variability both within and between fields, thereby reducing the risks of environmental pollution [3,19].

Although technologies have significantly improved agricultural production, it suffers many challenges. Some of these are listed below.

A water crisis caused by insufficient rainfall, leading to dry land unsuitable for cultivation.

Water logging due to flood irrigation, higher rainfall, or flood.

Chemical fertilizers used in the agriculture field plummet soil quality.

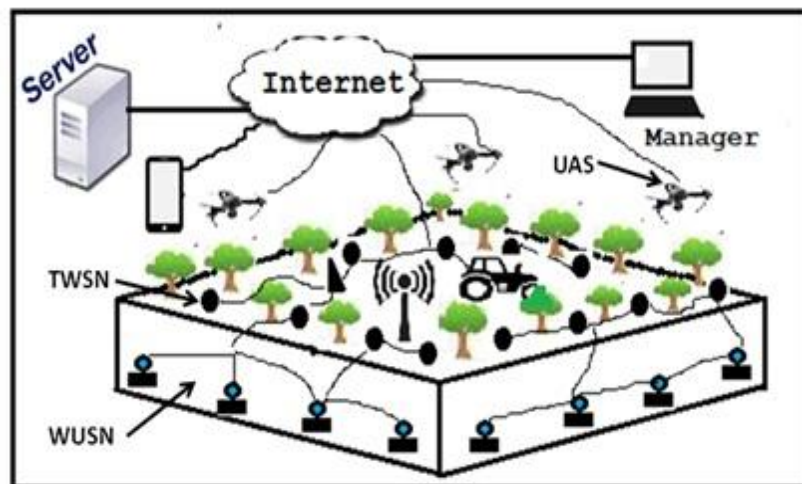
The growth of weeds in agricultural fields that hinder plant development, necessitating their removal.

The technological advancement in the field of Internet of Things (IoT), Wireless Sensor Networks (WSNs), Cloud computing, and Big data analytics are frequently used in Smart farming [1,4,5,9,14,16,17]. These technologies collectively deliver suitable scope to forecast, process, and scrutinise the circumstances to solve the above-mentioned problems. Sensing location collects relevant data and transmits them to the base transceiver station (BTS) for further analysis and decision-making regarding various parameters such as humidity, temperature, soil moisture, pH value, water supply quantity [30], etc. By effectively managing these parameters, the quantity and quality of crop yields can be improved, while optimizing the consumption of natural resources during farming. The sensor technology is used to measure pollution and climate change data to create a more sustainable farm with accurate predictions based on informed decisions. Therefore, maintaining network communication and lengthening the duration of WSNs is a critical concern. WSN also finds its application in diverse research areas, such as engineering [11,21,22], science [21-23], healthcare [24-28], and agriculture [25, 26]. However, a major constraint for any sensor network is its limited resources, which include processing speed, storage capacity, and communication bandwidth [28-31].

Figure 1, shows the monitoring system inspired by architecture proposed in [11]. The three parts of architecture are Wireless Underground Sensor Network (WUSN), Terrestrial Wireless Network (TWSN), and unmanned aerial System (UAS).

The details of these components are given below.

Figure 1. General Architecture of Smart agricultural monitoring system



Wireless Underground Sensor Network (WUSN): - In WUSN, sensor nodes are inside the soil. These sensor nodes have a limited communication radius. High communication frequencies suffer from attenuation, while lower frequencies suffer from soil penetration. These sensors are higher-cost, have larger antennas, and consume more energy than TWSNs [31-36].

Terrestrial Wireless Sensor Networks (TWSN): - In TWSN, Sensor nodes are mounted on the soil to collect information and act as intermediate nodes that transmit WUSN information to the gateway for further processing [21-26]. They can be mounted anywhere over the ground, and their communication range is greater than that of underground sensors. The Antenna size is smaller, energy consumption is lower, and cost is less than that of WUSNS.

Unmanned Aerial System (UAS): -In UAS, Unmanned Aerial Vehicles are equipped with multi-spectral cameras that can collect information and monitor crop growth with the help of IoT devices [4-7]. Mostly drones are used as UAS. The UAV needs to be in the line of sight with a distance of 1000 meters and must adhere to the rules for the use of UAV in a country.

The lifespan of a sensor network depends on how much energy its sensor nodes consume. Data communication between nodes consumes more energy and quickly drains the energy. When a sensor node's energy is exhausted, the battery must be replaced, or the node is considered dead. The dead node creates routing holes [29-33] that interrupt communication. Battery replacement may not be a feasible solution for critical applications. Further, underground sensor nodes of the WUSN are difficult to replace. Sensors often produce redundant data during their operation, and the transmission of this data further increases energy consumption and network traffic. The high traffic load leads to a packet drop, necessitating the retransmission of these lost packets. This retransmission significantly escalates energy consumption [29-34].

This research contributes by assessing the performance of WSNs in the agriculture sector and developing a multi-sink hybrid data-gathering framework for an agriculture monitoring system. First, we propose a node deployment scheme that helps to optimize the total nodes needed to deploy in the sensing region. The sensing field is divided into logical cells, with leader nodes coordinating sensing and communication activities. Second, a multi-sink communication scheme is implemented to minimize traffic overhead and improve energy efficiency in the sensor network. Third, we employ a load-balancing approach called the Silent and Zero Start (SZS) method, which uses redundant data to conserve energy further. We also adopted a modified acknowledgment scheme that helps to achieve reliability during communication.

The paper is structured into five main segments where Segment 2 outlines related works, Segment 3 focuses on the proposed framework of a Multi-Sink hybrid data-gathering framework for the smart agriculture monitoring system. Section 4 shows the simulation results and Segment 5 concludes the paper and summaries some future advices of innovation.

RELATED WORK

Numerous methodologies have been recommended in clustering, multi-sink, and load balancing to enhance network performance. However, one of the biggest challenges remains the optimal energy utilization of resource-constrained sensor nodes due to their high energy consumption during the routing process. The lifecycle of a WSN depends on the energy capacity & effective use of sensor nodes. To tackle the problem, many researchers have efficiently designed routing algorithms/protocols to prolong the network lifetime of sensor networks. Some existing routing approaches proposed by researchers are analyzed based on network dynamics, location information, data centrality, path redundancy, and QoS requirements.

Cluster Based Routing Protocol

The Sensor nodes organize themselves into small groups called clusters. One of the sensor nodes in the group is designated as Cluster Head (CH). The Cluster Head (CH) is responsible for collecting data from the group, refining it, and transmitting it to the Base Station (BS). In [18,25], the authors proposed the Low Energy Adaptive Clustering Hierarchy (LEACH), a self-organizing and adaptive routing protocol. It selects a cluster head based on the energy level greater than a computed threshold value. However, the remaining energy of the nodes is not considered when selecting Cluster Heads. Since communication with the Base Station is single-hop, each deployed sensor consumes more energy. A three-tier hierarchical routing protocol Energy Aware Routing (EAR) for cluster-based sensor Networks is discussed in [13-18]. It forms clusters based on energy consumption and performance metrics, maintaining the tree structure until the root node fails to save energy. However, its limitations include unequal cluster distribution, overloaded Cluster Heads, and the complexity of finding energy-efficient routes, which is computationally expensive for small sensor nodes. Hybrid Energy Efficient Distributed Clustering (HEED) discussed in [13-19] creates a cluster by adopting the basic scheme of LEACH along with residual energy, node density, and degree of the node to balance the network power. Its main goal is to extend the network lifetime by balancing energy consumption. However, limitations include uneven energy usage, early node failure, and inadequate coverage in dense deployments. Small Minimum Energy Communication Network (MECN) [13] finds an energy-efficient sub-network using low-power GPS. For every node, it identifies a region that consists of nodes within its surrounding area. Its small size leads to a limited coverage area, which is vulnerable to a single point of failure and maintaining connectivity. Energy Optimization Routing using Improve Artificial Bee Colony (EOR- iABC) [11,26,37] is an improved artificial bee colony optimization algorithm used to select the CH in a fixed time. It uses local search strategies to minimize the delay convergence. For large-scale WSN, the Grenade Explosion Method (GEM) and Cauchy operators are used for dynamic search from one region to another region. It suffers in handling complex network topologies to find the most efficient route, especially when dealing with intricate network structures.

Hybrid Hierarchical Routing Protocols

In the Hybrid hierarchical routing Protocols, the routing of sensed data and data gathering in the sensing field is performed by creating a hybrid structure from any of the structures, i.e., chain, Tree, Cluster, or grid. Chain Cluster-based Mixed routing (CCM) [25,31] creates chain-based routing like PEGASIS for connection during data transmission. Clusters are needed like LEACH where chain heads are interconnected for data transmission. The voted cluster head will fuse the data that is received from inter and intra connection, then transmit the fuse data to BS. Its hybrid nature complicates network setup and maintenance, with potential performance degradation if chain creation is not optimized. Additionally, it is vulnerable to a single point of failure if the chain head node fails. In Grid PEAGASIS [25] protocol, the sensing area is divided into small grids, and each grid selects a start node and end node. The start node connects one grid with the next grid by connecting the end node of the next grid. In each grid, the chain is created using a greedy algorithm to connect grids and select the head node for data transmission. It reduces the length of the data transmission path. However, it cannot avoid delay and redundant data. Position-based Chain Clustering Routing protocol (PCCR) [40] is designed for narrow strip area applications where traditional routing protocol cannot be applied. It divides the sensing region into a belt-shaped region cluster. Cluster Head (CH) is nominated based on node position and remaining energy. They are connected in a chain-like structure for data forwarding to the Base Station (BS)[36-40]. The Protocol faces high computational overhead due to complex location calculations, susceptibility to node failures, and challenges in maintaining accurate location information, especially in areas

with poor GPS reception.

Proposed Framework

In the Projected structure, we suggest a node deployment scheme to optimize the number of nodes needed to deploy for the sensing field. A multi-sink communication scheme is adopted to reduce the traffic overhead and increase energy conservation for the entire sensor network. We also proposed a modified acknowledgment scheme to achieve reliability during communication. The different phases of the proposed framework are discussed below.

Multi-sink Node Deployment Scheme

The entire sensing area is divided into cells for node deployment. The cell follows a logical hexagonal structure, allowing for efficient coverage of the sensing field. Due to the minimal gaps between hexagonal cells, coverage holes are significantly reduced [30]. The proposed approach calculates the total cells necessary to cover the sensing field. Based on the number of cells, sensor nodes (WUSN and TWSN) are deployed in the sensing field. Figure 2 shows the hexagonal cells that cover a sensing field. At first, the Sink node position is selected in the sensing field. After the sink node position is found, cells are marked for data gathering and transmitting to respective sink nodes [39-41]. The number of sink deployments is directly proportional to the network deployment cost [17]. Thus, an optimal multi-sink node deployment strategy is proposed to minimize the network deployment cost. The multi-sink data communication also supports to lessen the traffic load of the sensor network in the agriculture field.

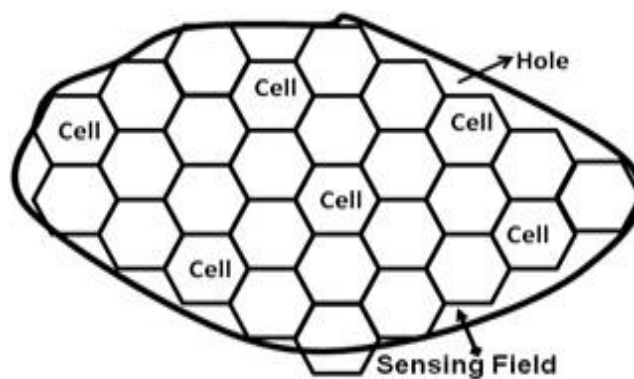
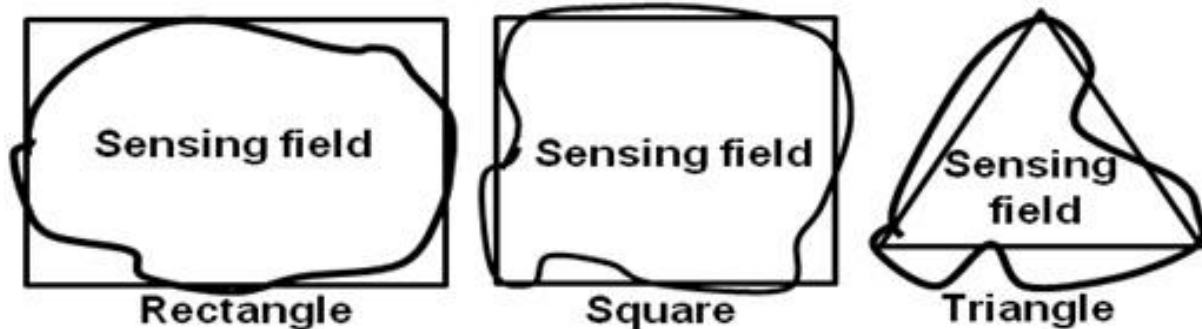


Figure 2. Hexagonal cells that covering a sensing field

In the sink node deployment strategy, minimum numbers of sink nodes are positioned in the sensing region. Selecting nodes far away from each other is beneficial for traffic load balancing and energy management. A good node deployment strategy can further increase the network life span [22] and cover the entire sensing field [30]. Before node deployment, the area of



the sensing field is calculated, and a minimum bounding polygon (such as a rectangle, square, or triangle) is chosen to fit the sensing area as closely as possible, as illustrated in Figure 3.

Figure 3. Polygon covering a Sensing field

The proposed multi-sink node deployment strategy utilizes a rectangular structure. The aim is to select the multi-sinks as far apart as possible to enable an even distribution of the network load [13,17]. In a rectangle, the endpoints of the diagonals are the maximum distance apart from each other. Thus, we choose the two endpoints of each diagonal that are farthest apart, at a distance of R_d . The first diagonal (P1, P2) intersects the sensing field perimeter at the point (IP1, IP2). The second diagonal (P3, P4) intersects the sensing field perimeter at the point (IP3, IP4) as shown in Figure 4.

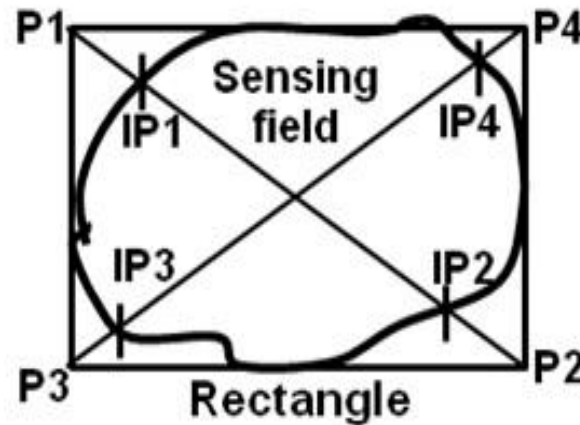


Figure 4. Intersection point of the Sensing field

The algorithm for selection of Sink node is stated in algorithm 1. The distance between diagonal end point and intersection point of Sensing field of both sides of the diagonal is required to ascertain the Sink Positions of the Sensing Area. Each intersecting distance at each side of the diagonal is calculated. In the above scenario the distance between (P1, IP1), (P2, IP2), (P3, IP3) and (P4, IP4) is calculated using equation 1 as discussed in [20].

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \text{----- (1)}$$

In the above equation, d is the distance among two coordinate points (x_1, y_1) and (x_2, y_2) . Applying the above equation the distances d_1, d_2, d_3 , and d_4 for the co-ordinate points (P1, IP1), (P2, IP2), (P3, IP3) and (P4, IP4) are computed respectively. The distance of two coordinate points of each diagonal is calculated for deployment of Sink node.

Based on d_1, d_2, d_3 , and d_4 , select the diagonal (D_{select}) that covers the maximum distance in the sensing field using Equation

$$D_{\text{select}} = \min\{(d_1 + d_2), (d_3 + d_4)\} \text{----- (2)}$$

After the diagonal (D_{select}) is selected, the sinks are fixed at the meeting point of the diagonal. The first sink is positioned at the coordinate point of the first intersection point. The second sink is deployed in the coordinate position of the second intersection point.

Algorithm 1: Sink Node Selection Algorithm

Inputs: Rectangle sensing field, two diagonals (P1, P2) and (P3, P4)

Output: Sink node coordinates (x_f, y_f) and (x_s, y_s)

Find two intersection points (IP1, IP2) and (IP3, IP4) of the sensing field on diagonal (P1, P2) and (P3, P4), respectively.

Compute distances d_1, d_2, d_3, d_4 for (P1, IP1), (P2, IP2), (P3, IP3) and (P4, IP4) using equation 1, respectively.

If $(d_1 + d_2) \leq (d_3 + d_4)$, (Equation 2) $x_f = x_{IP1}$, $y_f = y_{IP1}$ and $x_s = x_{IP2}$, $y_s = y_{IP2}$.

Else $x_f = x_{IP3}$, $y_f = y_{IP3}$ and $x_s = x_{IP4}$, $y_s = y_{IP4}$

Hexagonal Cell Division of the Sensing Field

Once the sink node positions are set, a hexagon is formed at each sink's location, consisting of six equilateral triangles. Here, Sh is the side of the equilateral triangle and the side of the hexagon. The side of the equilateral triangle is equal to the sensing distance of the sensor node ($Sh = S_d$). The coordinate point of the height of the equilateral triangle on the sink is the center of the hexagon. From the center point (c) to the endpoint of the base of perpendicular (A, B) joined to form the equilateral

triangle. The first equilateral triangle formed is assigned a zone number one. After the first equilateral triangle, at the base point of triangles, A and B 60° angles are formed along Sd distance, and these points are joined with center (C) to form the rest of the equilateral triangle. Figure 5 shows how to create the cell at the sink point. The triangle formed after the first triangle is numbered as zone two, and so on. When a new triangle is formed, the zone number is computed as the previous zone number+1.

Once the first hexagon is formed, at every edge of the hexagon (except the sink edge) the height is drawn using equation E3. At every height, the center point (C) is found, and the endpoint of the base of height (A, B) is joined to form the equilateral triangle. Figure 5 shows how to construct the rest of the hexagonal cell after the first hexagonal cell. The hexagonal cell formation continues till the cell edge is greater or equal to half of the selected diagonal (Dselect).

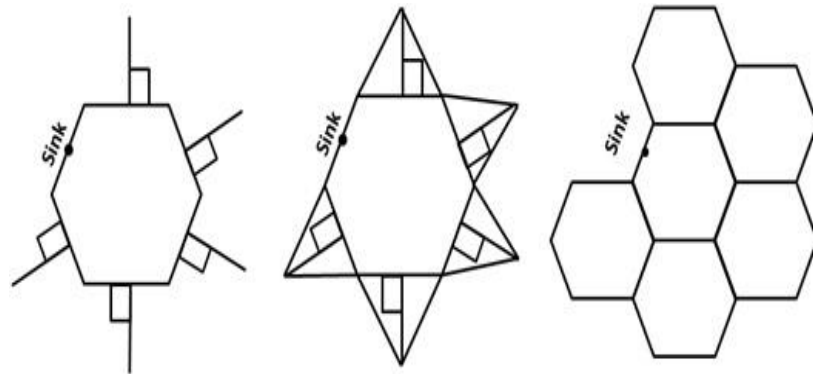
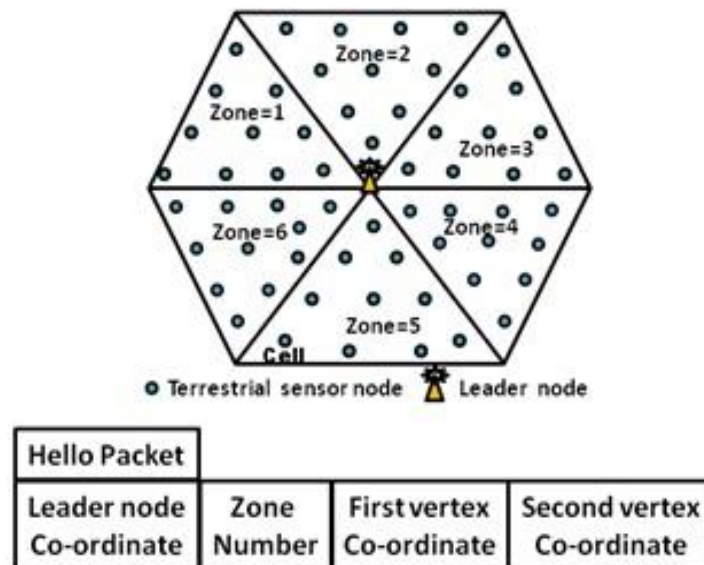


Figure 5. Step of hexagon cell formation in sensing field

Node Deployment Policy for Selection of Co-Ordinate Position of TWSN

In the proposed framework, we use both random and manual node deployment. First, hexagonal cells are formed to cover the sensing field. A sensor node, called the leader node, is placed at the center of each hexagon to collect and aggregate data.



Leader nodes are manually placed based on computed coordinates, while other sensor nodes are deployed randomly. After the deployment, each leader node broadcasts a "hello" packet containing its coordinates, the zone number, and the coordinates of the next endpoint. Figure 6 illustrates the format of the hello packet.

Figure 6. Hello Packet format

After receiving the hello packet, the terrestrial sensor node checks its position. If nodes are inside the triangular zone, set the zone number and join the leader node. Once a sensor node is associated with a triangular zone, it goes to sleep mode to avoid unnecessary overhearing. This process continues till all sensor nodes of a cell are associated with one of the six triangles of a hexagonal cell. If a sensor node is at the edge of the triangle, then the sensor will join the zone from which it receives the hello message first. It selects the zone of the boundary sensor node based on the first received hello message as shown in Figure 7. The procedure of selecting sensor node placements is explained in Algorithm 2.

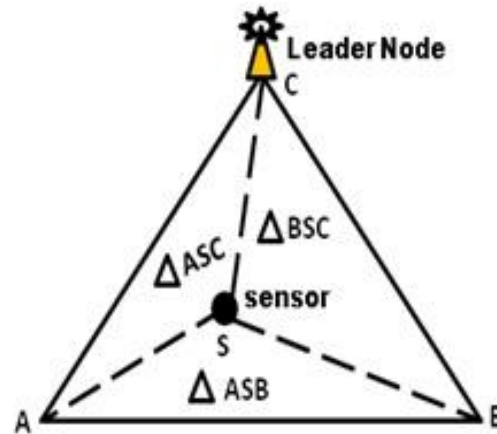


Figure 7. Node selection on a Triangle

Algorithm 2: Sensor Node Place Selection

Inputs: Triangle ABC, leader node

Output: Position of Sensor Node (Inside or Outside)

Find Area of the triangle ABC as A_T , triangle ASB as A_1 , triangle ASC as A_2 , triangle BSC as A_3 .

If $(A_T = (A_1 + A_2 + A_3))$ then sensor is inside the Zone. Set zone number and Go to sleep mode.

Else If $((A_1 = 0) \text{ or } (A_2 = 0) \text{ or } (A_3 = 0))$ then sensor is on the boundary Zone. Set zone number and Go to sleep mode.

Else sensor is Outside the Zone. Wait for the next broadcast by leader node.

Selection of the Co-ordinate position of a WUSN

After the leader node location is fixed, select the position of the sensor nodes deployed for the UWSN. The underground sensor node position is computed using Equation 3. The underground sensor nodes are manually positioned in a triangular zone of the cell in the sensing field according to the computed coordinate position.

$$\begin{aligned} UGS_{xi} &= l_{xi} + \frac{1}{2} \left(\frac{S_h \sqrt{3}}{2} \right) = l_{xi} + \frac{S_h \sqrt{3}}{4} \\ UGS_{yi} &= l_{yi} + \frac{1}{2} \left(\frac{S_h \sqrt{3}}{2} \right) = l_{yi} + \frac{S_h \sqrt{3}}{4} \end{aligned} \quad (3)$$

In Equation 3, the UGS_{xi} , UGS_{yi} is the coordinate of the underground sensor node. l_{xi}, l_{yi} is the coordinate of the leader node of the i th hexagon. Figure 8 shows the leader node and WUS node position in a hexagonal cell.

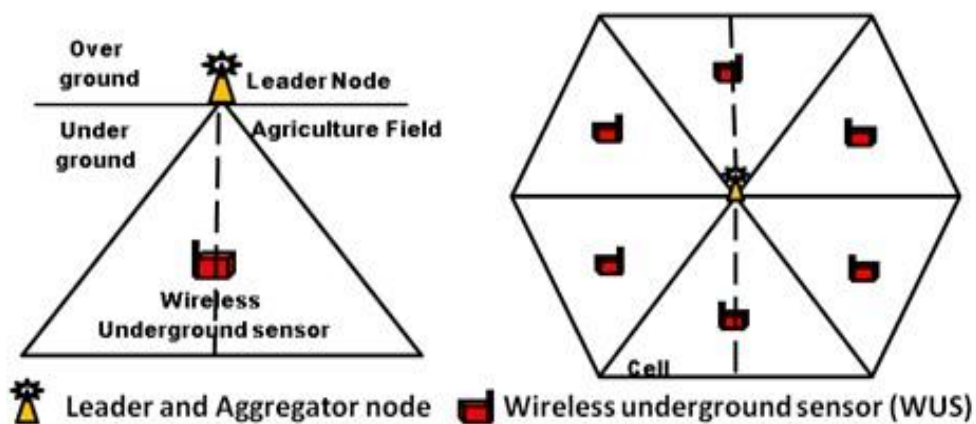


Figure 8. Leader node and WUS node position in the Cell

Traffic Management

The proposed protocol divides traffic into aerial and terrestrial. UAVs generate aerial traffic, which is sent directly to the base station, avoiding interference with terrestrial traffic. UAV sensors can be recharged, while TWSN and WUSN sensors have limited resources. WUSN sensors, buried underground and left unattended for long periods, require efficient battery

management during communication.

In the agriculture application, data redundancy is inherited [23] by nature due to slow changes in phenomena. We exploit this phenomenon during data communication to conserve more energy. After the zone of the cell is formed sensor nodes of each zone set their zone number, and set a schedule to actively sense the phenomena and transmit them to the leader node. We adopt an even-odd traffic management policy for the cells. In the even-odd traffic management policy the even and odd number of zones alternatively carry out their sensing and transmission activity. For example, the odd number of zones, i.e., 1, 3, and 5 first sense their data and transmit it to the leader node. After that, an even number of zones, i.e., 2, 4, and 6 transmit their sensed data to the leader node in the second round of communication. The second round of communication is initiated after a random waiting time (R_{WT}) to avoid collision and interference. The R_{WT} is computed using Equation 4 where Z_n is the zone number and P_{delay} is propagation delay.

$$R_{WT} = Z_n + 2 \times P_{delay} \text{ ----- (4)}$$

The cell leader nodes form a tree-like hierarchy to collect the data from the cell, aggregate them, and transmit them to the upper level. The tree's root is the sink node, which receives data from leader nodes and forwards it to the information processing center for user actions. The data collection tree is formed during cell formation initiated by the sink node with the help of cell leader nodes. The number of data collection trees depends on the number of sink nodes deployed in the sensing field. Figure 09 shows the data collection tree of the cell leader nodes for the two sink nodes in the sensing field.

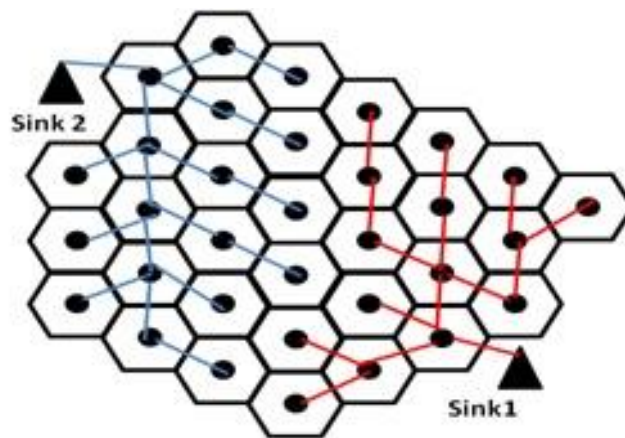


Figure 9. Data collection tree for the cell leader nodes

Load balancing Mechanism

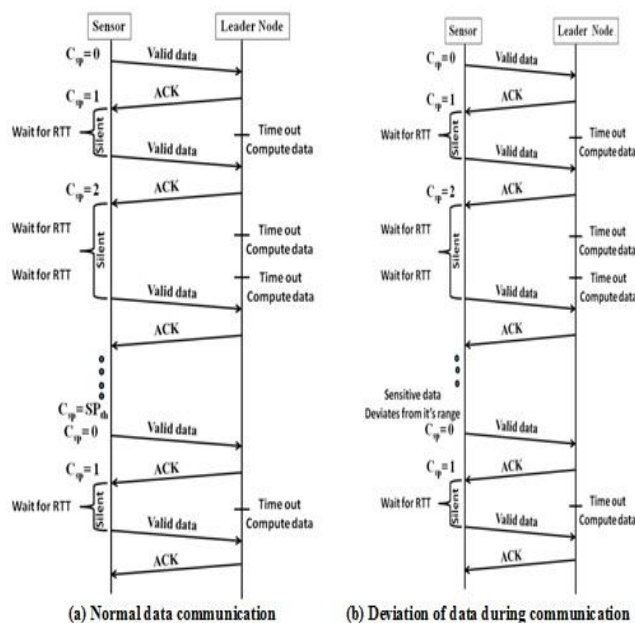


Figure 10. Silent and Zero Start (SZS)

Data transmission in WSNs uses more energy than processing. Additionally, when an event occurs, data flow and network traffic increase [13]. As traffic increases in a resource-constrained network, the risk of congestion also rises. Congestion leads to data packet loss in the network, and the lost data packets trigger the retransmission. Retransmitting data uses more energy and shortens network life. To save energy, we use selective data transmission [15]. We classify the data as sensitive data, non-sensitive data, and control data for selective data forwarding to avoid unnecessary energy consumption. Sensitive data are real-time and pose a risk if they deviate from normal values. Non-sensitive data are non-real-time and stay within the expected range. Control data help maintain the network and are exchanged periodically.

Data transmission in WSNs uses more energy than processing. Additionally, when an event occurs, data flow and network traffic increase [13]. As traffic increases in a resource-constrained network, the risk of congestion also rises. Congestion leads to data packet loss in the network, and the lost data packets trigger the retransmission. Retransmitting data uses more energy and shortens network life. To save energy, we use selective data transmission [15]. We classify the data as control data, sensitive data & non-sensitive data for selective data forwarding to avoid unnecessary energy consumption. Sensitive data are real-time and pose a risk if they deviate from normal values. Non-sensitive data are non-real-time and stay within the expected range. Control data help maintain the network and are exchanged periodically.

The proposed protocol allows user to set and select their sensitive and non-sensitive data based on the application. The load of the network can be balanced by the Silent and Zero Start (SZS) approach. The proposed load balance approach exploits the inheritance feature of the agriculture application. The sensing environment slowly changes and produces duplicate data with time. In the proposed approach, data is validated before transmission. If it is out of range, it is considered valid and sent to the receiver. If the sensed data is within the range, then the data transmission is deferred for one round trip time by keeping the source silent. The data transmission continues in the silent mode to minimize the redundant data transmission. Every sensor node maintains a counter to count the transmission rounds. Initially, the counter is set as zero. If data is out of range, it starts transmission again and resets the counter to zero. The proposed protocol sets a user-defined threshold for the counter. If the counter reaches the threshold, it starts the communication from the beginning by adjusting the counter to zero. The threshold for the counter is used to avoid misinterpreting a long period of silence. A sensor node transmits data when the counter reaches a threshold, even without a deviation, preventing confusion between a dead node and a silent phase. Figure 10 illustrates ASZS data transmission in both normal and deviation scenarios.

The SZS policy for data forwarding works in four Phases

Communication Phase: - The Phase where sensor nodes communicate their Sensed data to the cell head which is leader node. The leader node transmits the aggregated data collected from the sensor nodes to the next level leader node until it reaches the sink node.

Silent Phase: - Here the sensor node skips data communication to the leader node to conserve energy.

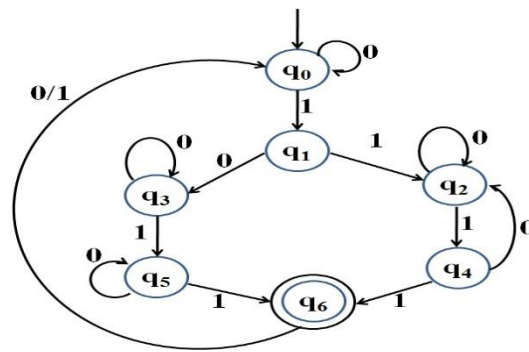
Data Computation Phase: - This phase where the leader node computes the sensitive and non-sensitive data not transmitted from the sensor node. The leader node computes these data from the previously received data of a node. This computation occurs when a timeout occurs for the node to receive data at the leader node end ($D_{curr} = D_{prev}$).

Data Validation Phase

In this phase, sensed data is authenticated for data communication. If the authentication is successful, the data is communicated to the destination; otherwise, it enters a silent phase. If the information is sensed for the first time, it is authenticated as true. Data sensed within the defined range is considered redundant for transmission, whereas data outside this range is classified as unique data. The non-redundant data is validated as accurate for every time it is sensed. Redundant data after the threshold time is valid for transmission; otherwise, it is false. When a sensor node first senses the environment, it enters the communication phase.

In data sensing phase, the node checks its sensed data and if the data is within range, it starts a silent phase followed by a data calculating phase. In the first silent phase, it holds back for one round-trip time (RTT). After silent phase is over, the next sensed data is transmitted to the destination by initiating the communication phase, whether the data is within the range or not. In the next sensing round, the node enters a silent phase for two RTTs. This process continues, increasing the silent phase duration by one after each communication phase. The number of silent phases is reset to a user-defined threshold value (SP_{th}) based on application requirements. If the silent phases reach SP_{th}, the data is transmitted as if it were the first communication phase. Every sensor node upholds a counter to calculate the number of Silent phases (CSP). This counter starts at zero, and each time the CSP meets the SP_{th} value, it is reset to zero during data communication. If data is not inside its range then it will break the chain of silence and start transmission from the beginning. It transfers the data to the end user by setting the CSP counter to zero.

Figure 11, shows the deterministic finite automata (DFA) of the ASZS policy.



1 = State change due to success of a phase.

0 = State change due to unsuccessful of a phase.

q₀ = Sensing Phase.

q₁ = Data validation phase.

q₂ = Data transmission phase.

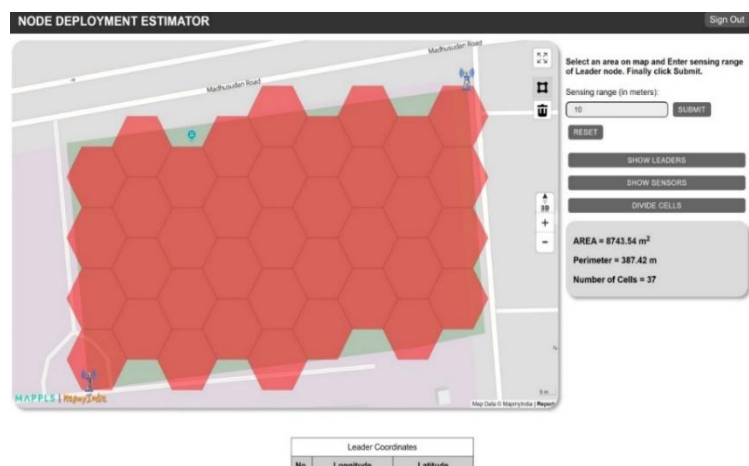
q₃ = Silent phase.

q₄ = Acknowledge for receive data.

q₅ = Data computation phase.

q₆ = Final State (Communication Success).

Figure 11. Deterministic Finite Automata of ASZS Policy



Performance Analysis

In this portion, we inspect our projected framework on various quantitative parameters. We develop software that estimates the node deployment in a practical sensing field. It computes the cell structure, sink position, leader node position in the cell, and sensor node position in the cell and partition the cells according to the sink nodes. We develop the software using Google Maps, HTML, CSS, and JavaScript. The developed software implements our node deployment strategy.

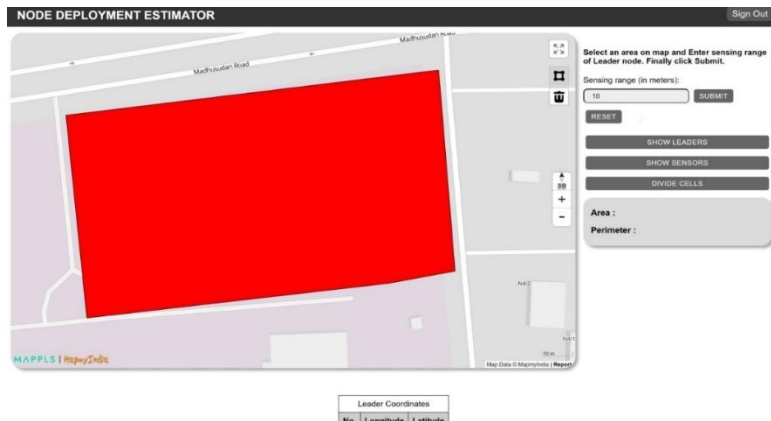


Figure 12. Deployment of Sensing Node in the Sensing Field

Figure 13. Selection of Sensing range & Leader Node

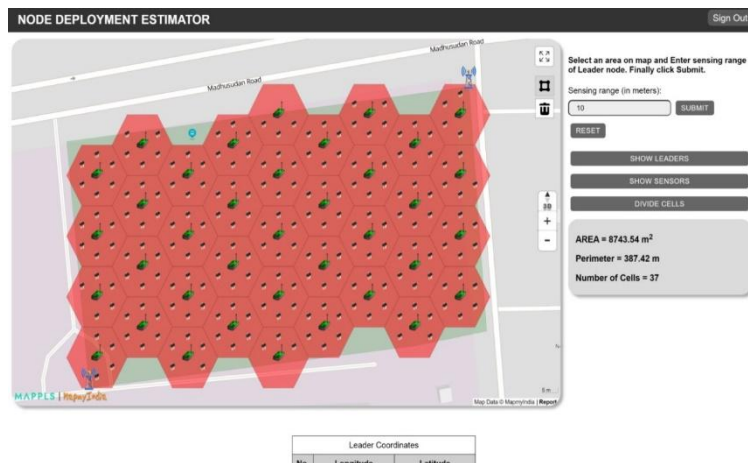


Figure 14. Sensor node position within the cell

Figure 12 shows how we select a sensing area from Google Maps. After selecting the sensing area, the selected area is divided into hexagonal cells, and the sink position is shown in Figure 13. In Figure 14, the leader node for each cell is selected. Once the leader node is selected the sensing node for each cell is selected. Figure 15 shows the sensor node position inside every cell. Figure 16 shows how the cells are associated with respective sinks in the sensing field. After node deployment, the performance of the projected protocol is evaluated in terms of energy consumption, packet delivery ratio, delay, network lifetime routing overhead, etc. The proposed protocol's performance is evaluated through a simulation in NS-2.30 to compare it with existing routing protocols.



Figure 15. Cells associated with Sink

Table 1 outlines the simulation parameters of the proposed protocol. A total of 400 sensor nodes are deployed in a 500×500

m² area. Each sensor node transmits data at 200 kbps with a transmission range of 40 m and a sensing range of 50 m. The sensed data and control packets are both 60 bytes long. Each sensor node is assigned an preliminary energy of 0.6J. The energy consumption is 50 nJ/bit for both transmission and reception. The energy spent in sensing, aggregation, and radio amplification is 0.083J/s, 5nJ/bit/signal, and 10pJ/bit/m² respectively. Events are generated randomly every 3 seconds in the sensing field. Data Packets with the same event ID (EID) are aggregated, and each node can store up to 65 data packets in its buffer. The sensing area is assigned random sensing consistency in each simulation. The simulation runs 25 times for 35 seconds, and the average value of the runs is considered for optimal results.

Table 1. Simulation Parameters

Area of Sensor field	500X500m ²
Number of Sensor nodes	400
Packet length	60 bytes
Buffer length	65 Packets
Initial Node energy	70 J
Bandwidth	200Kb/s
Sensing Length	50m
Radio Range	40m
Propagation Model	Two Ray
Eelec	50nJ/bit
Esense	0.083J/s
Eagg	5nJ/bit/signal
Eamp	10pJ/bit/m ²

The Performance of the projected protocol is compared with some existing routing protocols EOR-iABC [10,25,36], EEGDG [22], and PCCR [25]. The simulation results are analyzed based on average energy consumption, miss ratio, and end-to-end delay [27-31]. The miss ratio is calculated as the percentage of packets not delivered to the base station (BS) on time and discarded in delay-sensitive applications by setting a Time-To-Deadline (TTD) for each packet. The end-to-end delay is measured as the time from when a packet is generated by the source until it reaches the destination.

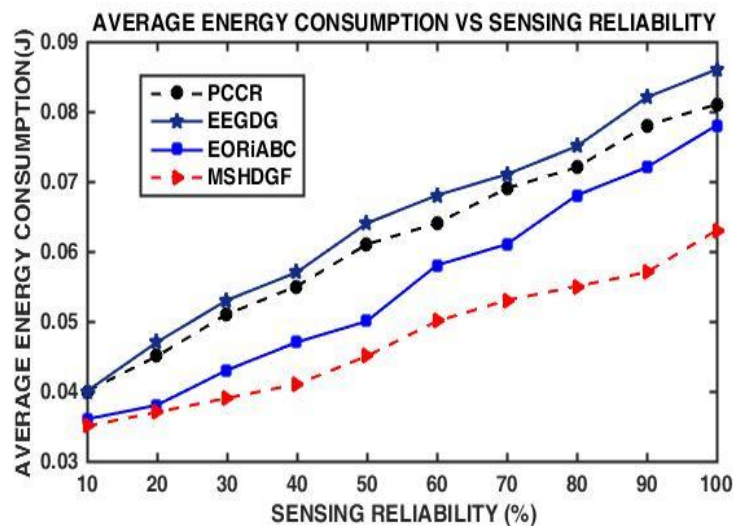


Figure 16. Average Energy Consumption at different sensing reliability

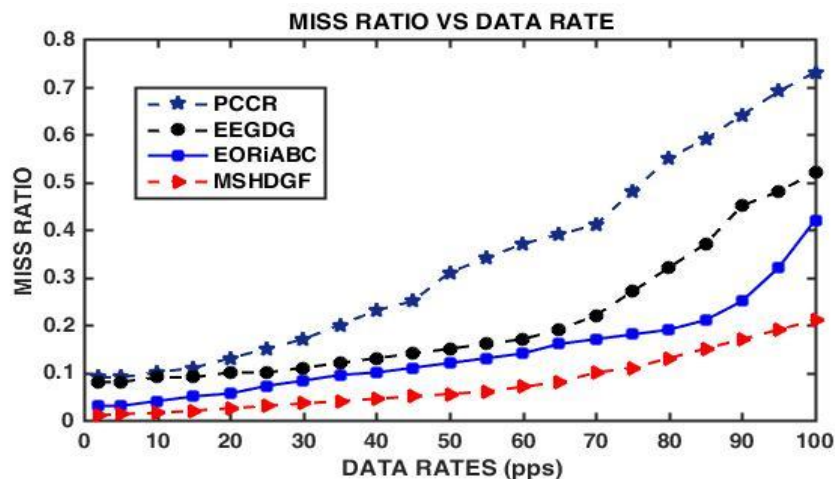


Figure 17. Average Miss Ratio Vs Data rate

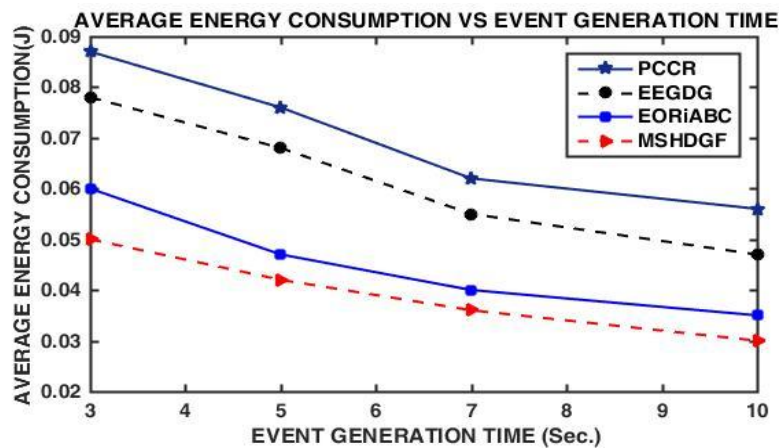


Figure 18. Average Energy Consumption vs Event Generation Time

Figure 16 to Figure 18 show a comparison of the average energy consumption of the proposed MSHDGF protocol with EOR-iABC, EEGDG, and PCCR protocols for varying data rate, sensing reliability, and event generation time respectively. It is observed that MSHDGF conserves more energy than EOR-iABC, EEGDG, and PCCR with the increase in data rate, sensing reliability, and event generation time respectively. The MSHDGF protocol outperforms other proposed protocols due to its selective data forwarding, reducing the burden of transmitting all sensed data packets to neighbours and the base station (BS). Additionally, dividing the network into multiple sinks minimizes transmission distances, leading to lower energy consumption compared to other protocols. With an increase in data rate, the data redundancy also increases. While other protocols either transmit redundant data or aggregate it, resulting in higher energy consumption, MSHDGF selectively forwards redundant data, optimizing energy usage. Figure 16 illustrates that average energy consumption increases as sensing reliability in sub-regions rises from 10 to 100. This is because higher sensing reliability requires a greater sensing frequency, leading to increased data transmission.

Although all protocols experience increased data transmission, MSHDGF outperforms them due to the ASZS technique used during data transmission. Furthermore, increasing the event generation time from 3 to 10 slows down data production in the network, reducing the data transmission rate and network congestion. This allows MSHDGF to achieve better performance compared to existing protocols.

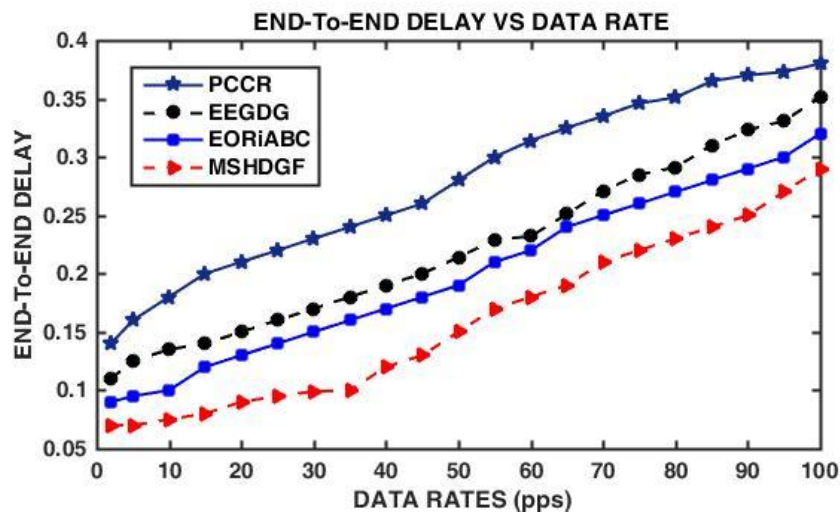


Figure 19. End-to-End delays at different data rate

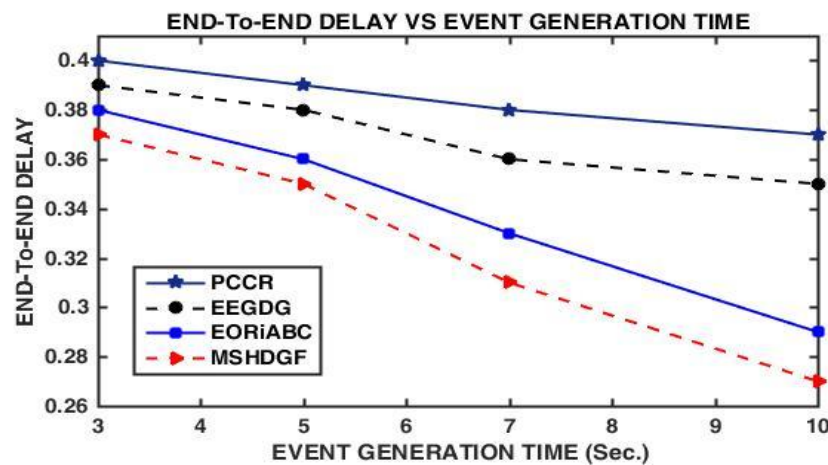


Figure 20. End-to-End delays with different event generation time

An increase in data rate leads to more transmissions in the network, resulting in higher congestion and packet loss. This packet loss further triggers retransmissions, increasing the miss ratio and end-to-end delay. MSHDGF processes data at the receiving end instead of transmitting it from the source node, effectively reducing both the miss ratio and end-to-end delay, as shown in Figures 17. Additionally, increasing the event generation time decreases transmission load and network congestion. Figures 19 and Figure 20 illustrate the end-to-end delay at changed data rates and event generation times, respectively.

2. CONCLUSION & FUTURE WORK

In this paper, we propose a multi-sink hybrid data gathering framework (MSHDGF) for the agriculture monitoring system. The multi-sink communication scheme reduces the traffic overhead and increases energy conservation for the entire sensor network. The proposed even-odd traffic management policy for the cells balances the traffic load and conserves energy during communication. The proposed framework adopts a load balancing scheme Silent and Zero Start (SZS) approach that exploits redundant data communication to increase energy conservation. This prototype approach can be used in agriculture to monitor environmental conditions to improve crop quality and yield for precision agriculture, irrigation scheduling, etc. In forthcoming, the anticipated approach can be enhanced by integrating Artificial Intelligence (AI) and the Internet of Things (IoT) into wireless sensor networks (WSNs). This integration can enable autonomous and intelligent operations, optimizing energy efficiency, network speed, and data transmission for cost-effective smart farming.

REFERENCES

- [1] J. Tong, S. Shou and H. Wang, "A Dictionary-Enhanced Clustering Compressive Sensing Routing Protocol for Large-Scale WSNs," in IEEE Sensors Journal, vol. 25, no. 4, pp. 7445-7456, 15 Feb.15, 2025, doi:

10.1109/JSEN.2025.3525759.

- [2] T. A. Abose, V. Tekulapally, D. C. Kejela, K. T. Megersa, S. T. Daka and K. A. Jember, "Optimized Cluster Routing Protocol With Energy-Sustainable Mechanisms for Wireless Sensor Networks," in IEEE Access, vol. 12, pp. 99661-99671, 2024, doi: 10.1109/ACCESS.2024.3429645.
- [3] E. M. Manuel, V. Pankajakshan and M. T. Mohan, "Efficient Strategies for Signal Aggregation in Low-Power Wireless Sensor Networks with Discrete Transmission Ranges," in IEEE Sensors Letters, vol. 7, no. 3, pp. 1-4, March 2023, Art no. 7500304, doi: 10.1109/LSENS.2023.3250432.
- [4] E. M. Manuel, V. Pankajakshan and M. T. Mohan, "Efficient Strategies for Signal Aggregation in Low-Power Wireless Sensor Networks With Discrete Transmission Ranges," in IEEE Sensors Letters, vol. 7, no. 3, pp. 1-4, March 2023, Art no. 7500304, doi: 10.1109/LSENS.2023.3250432.
- [5] Ingle, Pramod U., Avinash P. Ingle, Rafael R. Philippini, and Silvio S. da Silva. "Emerging role of nanotechnology in precision farming." In *Nanotechnology in Agriculture and Agroecosystems*, pp. 71-91. Elsevier, 2023.
- [6] Morchid, Abdennabi, Rachid El Alami, Aeshah A. Raezah, and YassineSabbar. "Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges." *Ain Shams Engineering Journal* (2023): 102509.
- [7] Benyezza, Hamza, MounirBouhedda, Reda Kara, and SamiaRebouch. "Smart platform based on IoT and WSN for monitoring and control of a greenhouse in the context of precision agriculture." *Internet of Things* 23 (2023): 100830.
- [8] Asharani, M., and H. R. Roopashree. "A Survey Paper: An Energy and Secure Aware Routing Protocol for Wireless Sensor Network." *SN Computer Science* 4, no. 3 (2023): 219.
- [9] Thabit, Fatma N., and Ali RA Moursy. "Sensors Efficiency in Smart Management of the Environmental Resources." In *Handbook of Nanosensors: Materials and Technological Applications*, pp. 1-40. Cham: Springer Nature Switzerland, 2023.
- [10] Rivera, Antonio, Pedro Ponce, Omar Mata, Arturo Molina, and Alan Meier. "Local weather station design and development for cost-effective environmental monitoring and real-time data sharing." *Sensors* 23, no. 22 (2023): 9060.
- [11] Prakash, Chander, Lakhwinder Pal Singh, Ajay Gupta, and Shiv Kumar Lohan. "Advancements in smart farming: A comprehensive review of IoT, wireless communication, sensors, and hardware for agricultural automation." *Sensors and Actuators A: Physical* (2023): 114605.
- [12] Rajak, Prem, AbhratanuGanguly, SatadalAdhikary, and Suchandra Bhattacharya. "Internet of Things and smart sensors in agriculture: Scopes and challenges." *Journal of Agriculture and Food Research* 14 (2023): 100776.
- [13] Santhosh, G., and K. V. Prasad. "Energy optimization routing for hierarchical cluster based WSN using artificial bee colony." *Measurement: Sensors* 29 (2023): 100848.
- [14] Wang, Jun, DongxuLuo, FunanPeng, Weiru Chen, Jun Liu, and Hualiang Zhang. "Wireless Sensor deployment optimization based on cost, coverage, connectivity, and load balancing." *International Journal of Sensor Networks* 41, no. 2 (2023): 126-135.
- [15] Bouarourou, Soukaina, AbderrahimZannou, El HabibNfaoui, and AbdelhakBoulaalam. "An efficient model-based clustering via joint multiple sink placement for WSNs." *Future Internet* 15, no. 2 (2023): 75.
- [16] Raj, E. FantinIrudaya, M. Appadurai, and K. Athiappan. "dasion farming in modern agriculture." In *Smart Agriculture Automation Using Advanced Technologies: Data Analytics and Machine Learning, Cloud Architecture, Automation and IoT*, pp. 61-87. Singapore: Springer Singapore, 2022.
- [17] Li, Jianpo, Qing Han, and Wenting Wang. "Characteristics analysis and suppression strategy of energy hole in wireless sensor networks." *Ad Hoc Networks* 135 (2022): 102938.
- [18] Shovon, Iftekharul Islam, and Seokjoo Shin. "Survey on multi-path routing protocols of underwater wireless sensor networks: Advancement and applications." *Electronics* 11, no. 21 (2022): 3467.
- [19] Khan, Nawab, Ram L. Ray, GhulamRazaSargani, Muhammad Ihtisham, Muhammad Khayyam, and Sohaib Ismail. "Current progress and future prospects of agriculture technology: Gateway to sustainable agriculture." *Sustainability* 13, no. 9 (2021): 4883.
- [20] Martos, Vanesa, Ali Ahmad, Pedro Cartujo, and Javier Ordoñez. "Ensuring agricultural sustainability through remote sensing in the era of agriculture 5.0." *Applied Sciences* 11, no. 13 (2021): 5911.
- [21] X. Fu, H. Yao and Y. Yang, "Modeling and Optimizing the Cascading Robustness of Multisink Wireless Sensor Networks," in *IEEE Transactions on Reliability*, vol. 70, no. 1, pp. 121-133, March 2021, doi:

10.1109/TR.2020.3024797.

- [22] Lloret, Jaime, Sandra Sendra, Laura Garcia, and Jose M. Jimenez. "A wireless sensor network deployment for soil moisture monitoring in precision agriculture." *Sensors* 21, no. 21 (2021): 7243.
- [23] J. Singh, S. S. Yadav, V. Kanungo, Yogita and V. Pal, "A Node Overhaul Scheme for Energy Efficient Clustering in Wireless Sensor Networks," in *IEEE Sensors Letters*, vol. 5, no. 4, pp. 1-4, April 2021, Art no. 7500604, doi: 10.1109/LSSENS.2021.3068184.
- [24] Yemeni, Zaid, Haibin Wang, Waleed M. Ismael, Yanan Wang, and Zhengming Chen. "Reliable spatial and temporal data redundancy reduction approach for WSN." *Computer Networks* 185 (2021): 107701.
- [25] Rady, Asmaa, EL-Sayed M. El-Rabaie, Mona Shokair, and Nariman Abdel-Salam. "Comprehensive survey of routing protocols for Mobile Wireless Sensor Networks." *International Journal of Communication Systems* 34, no. 15 (2021): e4942.
- [26] Gupta, Preeti, SachinTripathi, and Samayveer Singh. " Energy-efficient routing protocols for cluster-based heterogeneous wireless sensor network (HetWSN)—strategies and challenges: a review." *Data Analytics and Management: Proceedings of ICDAM* (2021): 853-878.
- [27] Sahar, Gul, Kamalrulnizam Bin Abu Bakar, Fatima TulZuhra, Sabit Rahim, TehminaBibi, and Syed Hamid HussainMadni. "Data redundancy reduction for energy-efficiency in wireless sensor networks: A comprehensive review." *IEEE Access* 9 (2021): 157859-157888.
- [28] Shukry, Suzan. "Stable routing and energy-conserved data transmission over wireless sensor networks." *EURASIP Journal on Wireless Communications and Networking* 2021, no. 1 (2021): 36.
- [29] Chan, Louie, Karina Gomez Chavez, Heiko Rudolph, and AkramHourani. "Hierarchical routing protocols for wireless sensor network: A compressive survey." *Wireless Networks* 26 (2020): 3291-3314.
- [30] Wan, Hang, Michael David, and William Derigent. "Energy-efficient chain-based data gathering applied to communicating concrete." *International Journal of Distributed Sensor Networks* 16, no. 8 (2020): 1550147720939028.
- [31] Sharma, Abhishek, PankhuriVanjani, Nikhil Paliwal, Chathuranga M. WijerathnaBasnayaka, DushanthaNalin K. Jayakody, Hwang-Cheng Wang, and P. Muthuchidambaranathan. "Communication and networking technologies for UAVs: A survey." *Journal of Network and Computer Applications* 168 (2020): 102739.
- [32] Khalaf, Osamah Ibrahim, and GhaidaMuttasharAbdulsahib. "Energy efficient routing and reliable data transmission protocol in WSN." *Int. J. Advance Soft Compu.Appl* 12, no. 3 (2020): 45-53.
- [33] A. A. Chauhan and S. K. Udgate, "Load Balancing in Wireless Sensor Networks using Multiple Cluster Heads," 2020 IEEE-HYDCON, Hyderabad, India, 2020, pp. 1-7, doi: 10.1109/HYDCON48903.2020.9242754.
- [34] Tripathi, Abhishek D., Richa Mishra, Kamlesh K. Maurya, Ram B. Singh, and Douglas W. Wilson. "Estimates for world population and global food availability for global health. "In The role of functional food security in global health, pp. 3-24. Academic Press, 2019.
- [35] Thakur, Divyansh, Yugal Kumar, Arvind Kumar, and Pradeep Kumar Singh. "Applicability of wireless sensor networks in precision agriculture: A review." *Wireless Personal Communications* 107 (2019): 471-512.
- [36] A. Singh and A. Nagaraju, "Energy Efficient Optimal Path based coded transmission for multi-sink and multi-hop WSN," 2018 Second International Conference on Green Computing and Internet of Things (ICGCIoT), Bangalore, India, 2018, pp. 129-132, doi: 10.1109/ICGCIoT.2018.8752993.
- [37] Aetesam, Hazique, and ItuSnigdh. "A comparative analysis of flat, hierarchical and location-based routing in wireless sensor networks." *Wireless Personal Communications* 97 (2017): 5201-5211.
- [38] Dang, Devarshi, and GaganDhawan. "Survey on Tree Based Energy Balanced Routing Protocols in WSNs." *International Journal of Recent Research Aspects* 4, no. 1 (2017).
- [39] A.K.Singh, S.Rajoriya, S.Nikhil, and T.K.Jain, "Design constraint in single-hop and multi-hop wireless sensor network using different network model architecture.", In *International Conference on Computing, Communication & Automation*, IEEE (2015): 436-441.
- [40] Cumming, Graeme S., Andreas Buerkert, Ellen M. Hoffmann, Eva Schlecht, Stephan von Cramon-Taubadel, and TejaTscharntke. "Implications of agricultural transitions and urbanization for ecosystem services." *Nature* 515, no. 7525 (2014): 50-57.
- [41] K. Singh and A. K. Daniel, "Load Balancing in Region Based Clustering for Heterogeneous Environment in WSNs Using AI Techniques," 2015 Fifth International Conference on Advanced Computing & Communication Technologies, Haryana, India, 2015, pp. 641-646, doi:10.1109/ACCT.2015.101.