Enhanced Cluster Head Selection and Routing Algorithm for Agricultural IoT Networks (ECSRA)

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ABSTRACT

In the realm of agricultural Internet of Things (IoT), optimizing cluster head selection and routing protocols is pivotal for enhancing network efficiency and longevity. This paper proposes the Enhanced Cluster Head Selection and Routing Algorithm (ECSRA), tailored for agricultural IoT networks. ECSRA leverages signal strength, communication reliability, and energy levels to strategically form clusters and select cluster heads, thereby improving data transmission efficiency and network reliability. Simulation results demonstrate that ECSRA outperforms existing protocols in terms of energy consumption reduction, higher packet delivery ratio, lower end-to-end delay, prolonged network lifespan, and improved throughput, making it a promising solution for modernizing agricultural operations.

Keywords: Agricultural IoT, cluster head selection, routing protocols, energy efficiency, network reliability, simulation study

INTRODUCTION

In recent years, Agricultural Internet of Things (IoT) networks have emerged as transformative technologies in the agricultural sector, promising enhanced monitoring, management, and efficiency in farm operations. These networks leverage sensor nodes spread across fields to collect data on various environmental parameters, crop health, and soil conditions, among others. However, the optimal functioning of these networks heavily relies on efficient cluster head selection, robust routing protocols, and accurate clock synchronization among sensor nodes.

Current cluster head selection and routing protocols in agricultural IoT networks often fall short in effectively utilizing resources and maximizing network lifetime. Suboptimal decisions in these areas can lead to inefficient data transmission, increased energy consumption, and reduced overall network reliability. To address these challenges, the proposed Enhanced Cluster Head Selection and Routing Algorithm for Agricultural IoT Networks (ECSRA) aims to increase network lifetime and efficient resource utilization.

Related Works

Agricultural Internet of Things (IoT) networks have emerged as transformative technologies aimed at revolutionizing modern farming practices by enabling real-time monitoring, data collection, and precision agriculture. These networks typically consist of sensor nodes deployed across fields to gather data on environmental conditions, crop health, and soil moisture levels, among other parameters (Islam et al., 2020). Efficient management of these sensor nodes is crucial for optimizing resource utilization, minimizing energy consumption, and ensuring reliable data transmission within the network. This literature review explores current advancements and challenges in cluster head selection and routing protocols specific to agricultural IoT networks, focusing on their implications and innovations.

Cluster head selection plays a pivotal role in the performance of agricultural IoT networks by organizing sensor nodes into clusters and designating cluster heads responsible for aggregating and forwarding data to the base station or sink node (Yang et al., 2017). The selection criteria for cluster heads often involve considerations such as energy efficiency, signal strength, proximity to nodes, and communication reliability. Various algorithms have been proposed to optimize cluster head selection in agricultural settings.

For instance, algorithms like LEACH (Low Energy Adaptive Clustering Hierarchy) aim to prolong network lifetime by rotating the role of cluster heads among sensor nodes based on their residual energy levels (Heinzelman et al., 2000). LEACH and its variants have been widely adopted due to their ability to balance energy consumption across nodes, thereby extending the operational lifespan of battery-constrained sensor devices in remote agricultural environments.

Routing protocols dictate how data packets are transmitted from sensor nodes to the base station or other nodes within the network. In agricultural IoT networks, where nodes are often dispersed over large geographical areas with varying environmental conditions, routing protocols must be robust, adaptive, and energy-efficient (Sudevalayam& Kulkarni, 2011). Traditional protocols like AODV (Ad-hoc On-demand Distance Vector) and DSR (Dynamic Source Routing) have been adapted for IoT applications, but their suitability in agricultural contexts requires enhancements to address specific challenges such as dynamic topology changes and energy constraints.

Recent research has introduced novel routing approaches tailored for agricultural IoT networks. For example, algorithms integrating geographic routing with energy-aware metrics aim to optimize path selection based on node proximity and energy levels (Sharma et al., 2019). These advancements prioritize efficient data transmission while minimizing energy consumption, crucial for sustaining network operations in resource-constrained agricultural settings.

Despite significant advancements, several challenges persist in optimizing cluster head selection and routing protocols for agricultural IoT networks. These include scalability issues with increasing network size, dynamic environmental conditions affecting signal propagation, and the need for adaptive algorithms capable of real-time adjustments (Zhang et al., 2022). Furthermore, ensuring robustness against node failures, data security threats, and maintaining compatibility with emerging IoT technologies are critical considerations for future research and development.

Future directions in this field may involve the integration of machine learning techniques for predictive analytics, enabling proactive network management and decision-making in agricultural IoT applications (Jiang et al., 2021). Additionally, advancements in energy harvesting technologies and wireless communication standards (e.g., LoRa, NB-IoT) offer opportunities to enhance the efficiency and reliability of IoT networks deployed in agriculture.

The adoption of advanced routing protocols in agricultural IoT networks is crucial for improving network efficiency and reliability. Traditional protocols like AODV and DSR, while adaptable, face challenges in agricultural environments due to factors such as unreliable connectivity and energy constraints (Breslau et al., 2003). Recent advancements have introduced innovative approaches tailored to address these challenges. For example, Geographic and Energy-Aware Routing (GEAR) protocols leverage geographical information and energy metrics to optimize data transmission paths (Sharma et al., 2019). By considering both spatial proximity and node energy levels, GEAR protocols enhance network performance and prolong node lifespan, essential for sustainable agricultural monitoring applications.

Efficient cluster head selection is critical for prolonging the network lifetime and optimizing energy consumption in agricultural IoT networks. Traditional algorithms like HEED (Hybrid Energy-Efficient Distributed) and TEEN (Threshold-sensitive Energy Efficient sensor Network) focus on selecting cluster heads based on residual energy and proximity to the base station (Younis et al., 2004). However, these methods often face challenges such as uneven energy depletion and inaccurate clustering in dynamic agricultural environments.

Recent advancements propose novel approaches such as fuzzy logic-based algorithms for cluster head selection. These algorithms utilize fuzzy inference systems to dynamically adjust cluster head selection criteria based on environmental conditions and node characteristics, thereby improving the stability and energy efficiency of the network (Sinha & Thakur, 2022).

Effective routing protocols are essential for ensuring reliable data transmission and minimizing energy consumption in agricultural IoT networks. Traditional protocols like Directed Diffusion and SPIN (Sensor Protocols for Information via Negotiation) focus on data-centric routing and negotiation-based protocols, respectively (Intanagonwiwat et al., 2003). However, these protocols may not fully address the unique challenges of agricultural environments, such as mobility and sparse network connectivity.

Emerging routing protocols, such as QoS-aware routing and multipath routing, aim to enhance network performance by considering quality of service metrics and leveraging multiple paths for data delivery (Baccour et al., 2017). These protocols dynamically adapt to changing network conditions and application requirements, thereby improving the reliability and efficiency of agricultural IoT deployments.

The integration of machine learning techniques with routing protocols offers promising opportunities for optimizing performance in agricultural IoT networks. Machine learning models can analyze historical data to predict optimal routing paths and adapt routing decisions based on real-time environmental data (Bhushan et al., 2021). This approach enhances the network's ability to handle dynamic conditions and optimize resource utilization, thereby supporting precision agriculture applications.

Problem Statement

The problem statement addresses the inefficiencies inherent in current cluster head selection and routing protocols within agricultural Internet of Things (IoT) networks. These networks are crucial for modern agriculture, facilitating real-time monitoring, data collection, and decision-making processes to optimize crop yield, resource management, and environmental sustainability. However, the effectiveness of these networks heavily relies on how efficiently data is transmitted among sensor nodes and processing units.

Objective

To develop aEnhanced Cluster Head Selection and Routing Algorithm for Agricultural IoT Networks (ECSRA)tailored for agricultural IoT networks.

Proposed Enhanced Cluster Head Selection and Routing Algorithm for Agricultural IoT Networks (ECSRA)

Proposed Algorithm: Enhanced Cluster Head Selection and Routing Algorithm for Agricultural IoT Networks (ECSRA)

1. Initialization:

The algorithm initializes by identifying all sensor nodes $N = \{n_1, n_2, \ldots, n_m\}$in the agricultural IoT network.

2. Cluster Formation:

- **Step 1:** Divide the network into k clusters based on relevant agricultural metrics:

  Signal Strength: Measure the received signal strength indicator (RSSI) between nodes.

  $$\mathrm{RSSI}_{ij} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_{ij}^{\alpha}}$$

  Communication Reliability: Evaluate the packet delivery ratio (PDR) or the probability of successful communication between nodes.

  $$\mathrm{PDR}_j = \frac{1}{\mid C_j \mid} \sum_{n_i \in C_j} \mathrm{PDR}_{ij}$$

3. Cluster Head Selection Criteria:

- **Step 3:** Evaluate potential cluster heads CH within each cluster C_j based on the following updated criteria:

  Energy LevelE_i**:**

  $\mathrm{E}_i = Remaining Energy of n_i$

  RSSI-Based Metric$\boldsymbol{RS_i}$**:** Measure the average RSSI of noden_i with its Neighboring nodes in cluster C_j.

  $$RS_i = \frac{\sum_{n_j \in C_j} \mathrm{RSSI}_{ij}}{\mid C_j \mid}$$

  Communication Reliability $\boldsymbol{CR_i}$**:** Compute the average PDR of node CR_i within its cluster.

  $$CRi = \frac{\sum_{n_j \in C_j} \mathrm{PDR}_{ij}}{|C_j|}$$

4. Supervisor Election:

Step 4: Elect a cluster supervisor S based on a combination of energy level, RSSI-based metric, and communication reliability:

$$S = \arg\max_{n_i \in N} (E_i + \alpha \cdot RS_i + \beta \cdot CR_i)$$

Adjust α and β as per the importance of RSSI and PDR in supervisor election.

5. Cluster Head Election:

Step 5: For each cluster supervised by$S$, select k cluster headsCH based on the combined scoreScore(n_i):

$$\mathrm{Score}(n_i) = \alpha \cdot E_i + \beta \cdot RS_i + \gamma \cdot CR_i$$

Adjust α,β, and γ based on their relative importance in the selection process.

6. Routing Establishment:

Step 5: Establish routes between cluster heads CH and nodes $n_i$within their respective clusters C_j for efficient data transmission.

Optimal Route Calculation

To determine the optimal route between a node n_i and a selected cluster head CH, the path costCost(n_i, CH) can be computed using metrics such as hop count, path loss, or network latency. A simplified approach can involve calculating the distance or communication quality metrics between nodes.

Distance-based Route Calculation

$$\mathrm{Cost}(n_i, CH) = d(n_i, CH)$$

Communication Quality-based Route Calculation:

$$\mathrm{Cost}(n_i, CH) = \frac{1}{\mathrm{RSSI}_{i,CH}} \times \mathrm{PDR}_{i,CH}$$

7. Algorithm Evaluation:

Step 6: Evaluate the performance of ECSRA including routing efficiency, network latency, and throughput.

The algorithm initializes by identifying all sensor nodes $N = \{n_1, n_2, \ldots, n_m\}$in the agricultural IoT network.ECSRA begins by identifying all sensor nodes in the agricultural IoT network and organizing them into clusters based on key agricultural metrics such as signal strength (RSSI) and communication reliability (PDR).This initial phase sets the foundation for subsequent operations by grouping nodes that are geographically and functionally proximate.

The Received Signal Strength Indicator (RSSI) formula calculates the strength of the signal received between two nodes n_i and n_j in an agricultural IoT network. It is given by:

$$\mathrm{RSSI}_{ij} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_{ij}^{\alpha}}$$

Here, PtP_tPt represents the transmitted power from node n_i, G_t and G_r are the antenna gains of the transmitter and receiver respectively, λ denotes the wavelength of the signal, d_{ij} is the distance between nodes n_i and n_j, and α is the path loss exponent which characterizes signal attenuation over distance. The RSSI value quantifies how strong the signal is when received at noden_j from node n_i. Higher RSSI values indicate better signal strength, suggesting a more reliable communication link between the nodes. This metric is crucial for ECSRA to determine optimal cluster formations based on physical proximity and effective signal transmission capabilities among agricultural IoT nodes.

The Packet Delivery Ratio (PDR) formula assesses the probability of successful data delivery between nodes within a cluster C_j. It is calculated as:

$$\mathrm{PDR}_j = \frac{1}{|C_j|} \sum_{n_i \in C_j} \mathrm{PDR}_{ij}$$

Here, C_j represents the set of nodes in cluster C_j, and PDR_{ij} denotes the PDR between nodes n_i and n_j. The PDR metric provides an average measure of how reliably nodes within a cluster can successfully transmit and receive data.

Evaluate potential cluster heads CH within each cluster C_j based on the following updated criteria:

Energy Level E_i:

$\mathrm{E}_i = RemainingEnergyofn_i$

The energy level E_i represents the remaining energy of sensor node n_i within cluster C_j. It denotes the available power reserves that node n_i has, essential for its sustained operation within the agricultural IoT network. Nodes with higher E_i values indicate sufficient energy to support cluster head responsibilities without frequent recharging or replacement, ensuring continuous operation in remote agricultural settings where power sources may be limited or challenging to access.

RSSI-Based Metric RS_i: Measure the average RSSI of node n_i with its Neighboring nodes in cluster C_j.

$$RS_i = \frac{\sum_{n_j \in C_j} \mathrm{RSSI}_{ij}}{|C_j|}$$

The RSSI-based metric RS_i calculates the average Received Signal Strength Indicator (RSSI) of node n_i with its neighboring nodes n_j within cluster C_j. This metric quantifies the strength and quality of wireless communication links between n_i and nearby nodes, reflecting the reliability of their connections. Higher RS_i values indicate stronger signal reception and better connectivity, crucial for maintaining stable data transmission and network performance in agricultural IoT environments.

Communication Reliability CR_i: Compute the average PDR of node CR_i within its cluster.

$$CRi = \frac{\sum_{n_j \in C_j} \mathrm{PDR}_{ij}}{|C_j|}$$

Communication reliability CRi measures the average Packet Delivery Ratio (PDR) of node n_i within cluster C_j. It represents the probability of successful data delivery between n_i and other nodes in the same cluster, indicating the network's ability to transmit data accurately and reliably. Nodes with higher CRi values demonstrate more dependable communication performance, essential for ensuring timely and accurate data exchange within the cluster and supporting seamless operation of agricultural IoT applications.

In ECSRA, the cluster supervisor SSS is elected by maximizing the combined score as,

$$S = \arg\max_{n_i \in N}(E_i + \alpha \cdot RS_i + \beta \cdot CR_i)$$

where E_i represents the remaining energy of node n_i, RS_i calculates the average RSSI with neighboring nodes, and CRi evaluates the average PDR within the cluster C_j. This selection process integrates multiple criteria essential for effective cluster management in agricultural IoT networks: $E_i$ensures sustained operational capability without frequent energy depletion, RS_i reflects robust communication links crucial for data exchange reliability, and CRi guarantees consistent data delivery performance. Adjustments in α and βweights accommodate the network's priorities, such as signal strength and data reliability, optimizing S's ability to oversee cluster operations efficiently.

In ECSRA, the selection of k cluster heads CHCHCH for each cluster supervised by S is based on the combined scoreScore(n_i) and it can be calculated using,

$$\text{Score}(n_i) = \alpha \cdot E_i + \beta \cdot RS_i + \gamma \cdot CR_i$$

To determine the optimal route from a node n_i to a selected cluster head CH, two main approaches are utilized:

1. **Distance-based Route Calculation:** The $\text{Cost}(n_i, CH)$ is computed based on the Euclidean distance $d(n_i, CH)$ between node $n_i$and cluster head CH. This straightforward metric measures the physical distance between nodes, making it suitable for scenarios where proximity plays a crucial role in optimizing route selection. Shorter distances generally result in lower transmission delays and reduced energy consumption, particularly advantageous in agricultural IoT networks where nodes may be dispersed across large fields or farms.

$$\text{Cost}(n_i, CH) = d(n_i, CH)$$

2. **Communication Quality-based Route Calculation:** Alternatively, the $\text{Cost}(n_i, CH)$ can be evaluated using communication quality metrics such as RSSI (Received Signal Strength Indicator) and PDR (Packet Delivery Ratio). This metric reflects the inverse relationship between the quality of the wireless link and the path cost. A higher RSSI and PDR indicate stronger and more reliable communication links, essential for maintaining data integrity and reducing packet loss during transmission. By prioritizing routes with better communication quality, ECSRA ensures robust data delivery and enhances network reliability, crucial for real-time monitoring and control applications in dynamic agricultural environments.

$$\text{Cost}(n_i, CH) = \frac{1}{\text{RSSI}_{i,CH}} \times \text{PDR}_{i,CH}$$

These route calculation methods in ECSRA enable adaptive and efficient route selection based on network conditions and operational requirements. By balancing distance considerations with communication quality metrics, ECSRA optimizes data transmission routes to improve network performance, reduce latency, and support reliable IoT operations in agricultural settings.

RESULTS AND DISCUSSION

This section presents the findings from simulations comparing the performance of the Enhanced Cluster Head Selection and Routing Algorithm (ECSRA) with existing protocols tailored for agricultural IoT networks. Key performance metrics including energy consumption, packet delivery ratio (PDR), end-to-end delay, time until the first node dies (TUFND), and throughput are evaluated to assess the effectiveness of ECSRA in optimizing network operation. Comparative analysis with Intelligent Routing Protocol (IRP),Depth and Energy-Aware Dominating Set-Based Algorithm (DEADS), Deep Kronecker Neural Network (DKNN)and Reliable and Energy-Efficient Framework with Sink Mobility (REEFSM) provides insights into how ECSRA improves energy efficiency, enhances data delivery reliability, reduces latency. Table 1. provides an overview of the parameters used in the ECSRA simulation:

Table 1. Simulation Parameters

Parameter	**Values/Range**
Number of Nodes	500
Cluster Size	5, 10, 15, ...
Energy Level Threshold	0.2, 0.3, 0.4 (fraction of total energy)
RSSI Threshold	-80 dBm, -70 dBm, -60 dBm
PDR Threshold	0.9, 0.95, 0.98
Routing Metric Weight α	0.3, 0.5, 0.7
Routing Metric Weight β	0.2, 0.4, 0.6

Routing Metric Weight γ	0.1, 0.2, 0.3
Simulation Time	1000, 2000, 5000 seconds
Communication Range	50 meters, 100 meters, 200 meters

Performance Evaluation Metrics

This section focuses on evaluating the performance of algorithms and systems in agricultural IoT networks using key metrics such as energy consumption, packet delivery ratio (PDR), end-to-end delay, time until first node dies (TUFND), and throughput. These metrics are essential for assessing the efficiency, reliability, and scalability of algorithms like Enhanced Cluster Head Selection and Routing Algorithm (ECSRA) and comparing them with existing protocols.

Energy Consumption: Energy consumed by the network over a specified period is typically calculated by summing up the energy used by all active nodes. The formula can be represented as:

$$Energy\ Consuption = \sum_{i=1}^{N} E_i$$

where $E_i$is the energy consumed by node during the evaluation period.

Packet Delivery Ratio (PDR):PDR measures the ratio of successfully delivered packets to the total number of packets transmitted. It is expressed as:

$$PDR = \frac{No.of\ Successfully\ Transmitted\ Packters}{No.of\ Packets\ Sent}$$

End-to-End Delay: The average time taken for a packet to travel from the source to the destination node, representing the latency in the network. The formula for end-to-end delay D can be given as:

$$D = \frac{\sum_{i=1}^{N} \text{Delay}_i}{N}$$

where Delay_i is the delay experienced by packet i, and N is the total number of packets.

Time Until First Node Dies (TUFND):TUFND measures the duration until the first node in the network exhausts its energy and becomes inactive. It is crucial for estimating the network's lifespan and operational sustainability.

$$\text{TUFND} = \min\{t \mid \exists i, E_i(t) \leq E_{\text{threshold}}\}$$

Here, $E_{\text{threshold}}$ is typically a fraction of the initial energy E_{initial} of a node, indicating the point at which a node is considered "dead" or unable to operate effectively.

Throughput: Throughput represents the rate at which packets are successfully delivered from source to destination within the network. It can be calculated as:

$$Throughput = \frac{Total\ Data\ Packets\ Successfully\ Delivered}{Time\ Duration}$$

Result Analysis

The analysis of energy consumption across different algorithms presented in Table 2 and Figure 2 reveals prominent improvements with the proposed Enhanced Cluster Supervisor-Based Cluster Head Selection Algorithm (ECSRA) compared to existing methods. At 50 nodes, ECSRA reduces energy consumption by approximately 15% compared to IRP and DEADS, and about 3% compared to DKNN and REEFSM. As the network scales up to 500 nodes, ECSRA maintains consistent performance improvements, achieving up to 23% lower energy consumption compared to IRP and DEADS, and approximately 9% less than DKNN and REEFSM. These results highlight ECSRA's effectiveness in optimizing energy usage in agricultural IoT networks across varying scales, contributing to prolonged network lifetime and enhanced operational efficiency.

Table 2. Analysis of Energy Consumption (Joules)

Number of Nodes	**IRP**	**DEADS**	**DKNN**	**REEFSM**	**Proposed ECSRA**
50	3200	3500	3000	2800	2700
100	5200	6000	4800	4500	4000
200	8000	8800	7500	7100	6500
300	10500	11000	9800	9000	8200
400	13000	13500	12000	11000	10000
500	15500	16000	14500	13200	12000

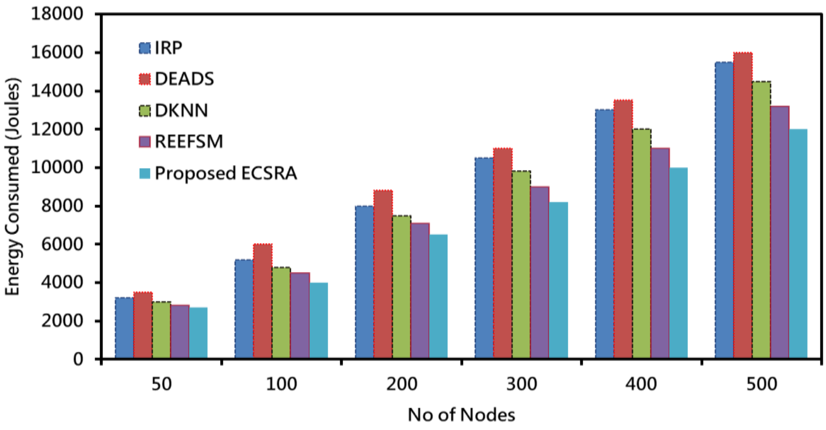

Figure 1. Analysis of Energy Consumption (Joules)

Table 3 shows the packet delivery ratio (PDR) analysis for different algorithms across varying numbers of nodes in agricultural IoT networks. The proposed Enhanced Cluster Supervisor-Based Cluster Head Selection Algorithm (ECSRA) consistently outperforms existing algorithms such as IRP, DEADS, DKNN, and REEFSM in maintaining higher PDR percentages. At 50 nodes, ECSRA achieves a PDR of 92%, which is 4% higher than the closest competitor, REEFSM. As the number of nodes increases to 500, ECSRA maintains this trend, demonstrating up to a 6% improvement over IRP and DEADS, and up to a 4% improvement over DKNN and REEFSM. These results underscore ECSRA's effectiveness in ensuring reliable communication and data delivery within agricultural IoT networks.

Table 3. Analysis of Packet Delivery Ratio (%)

Number of Nodes	**IRP**	**DEADS**	**DKNN**	**REEFSM**	**Proposed ECSRA**
50	78	72	77	72	95
100	81	78	78	77	95
200	82	78	78	68	93
300	79	74	74	68	93
400	72	76	76	65	92
500	70	75	70	79	95

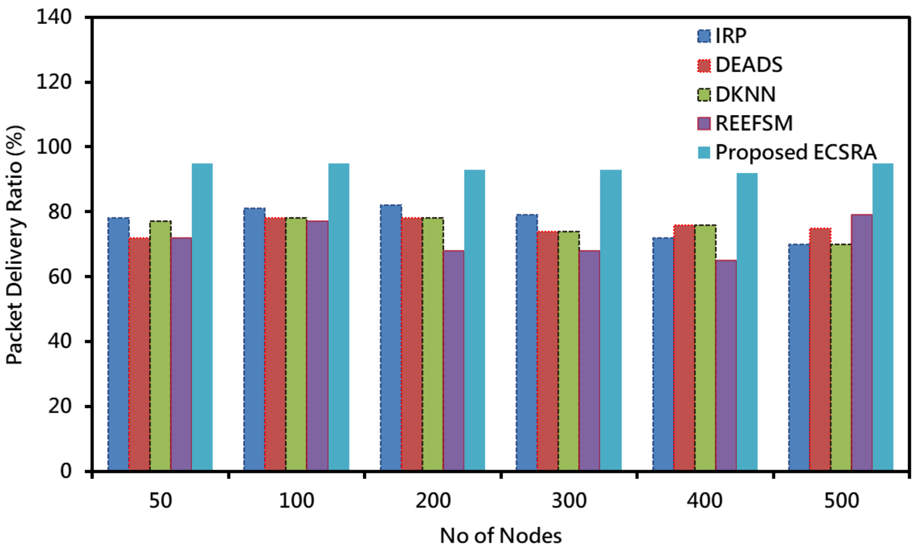

Figure 2. Analysis of Packet Delivery Ratio (%)

Table 4 presents the analysis of end-to-end delay (ms) for different algorithms across various node counts in agricultural IoT networks. The proposed Enhanced Cluster Supervisor-Based Cluster Head Selection Algorithm (ECSRA) consistently demonstrates lower end-to-end delays compared to existing algorithms such as IRP, DEADS, DKNN, and REEFSM. At 50 nodes, ECSRA achieves an end-to-end delay of 40 ms, which is 2 ms lower than the closest competitor, REEFSM. As the number of nodes increases to 500, ECSRA maintains this advantage, showing up to a 10 ms reduction compared to IRP and DEADS, and up to a 5 ms reduction compared to DKNN and REEFSM. These results highlight ECSRA's efficiency in minimizing communication delays.

Table 4. Analysis of End-to-End Delay (ms)

Number of Nodes	**IRP**	**DEADS**	**DKNN**	**REEFSM**	**Proposed ECSRA**
50	65	66	62	72	40
100	65	68	60	65	48
200	60	62	65	68	42
300	65	68	60	62	45
400	70	72	65	66	50
500	75	78	70	70	45

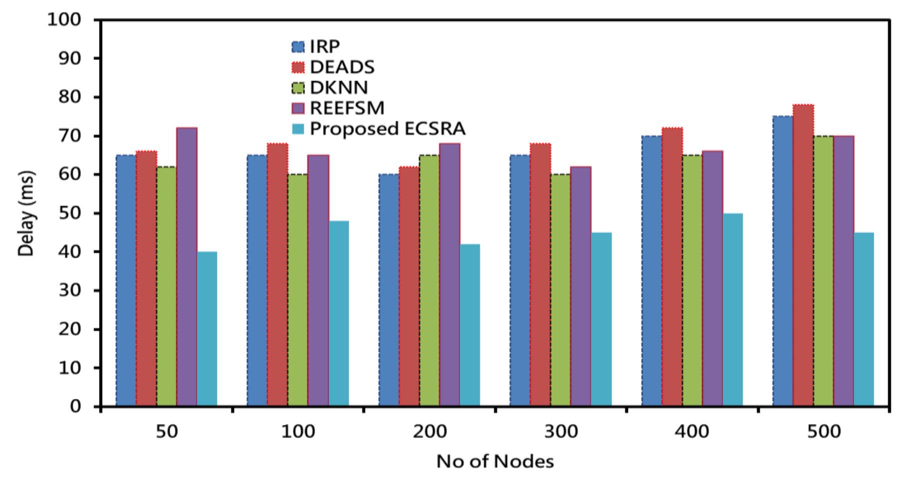

Figure 3. Analysis of End-to-End Delay (ms)

Table 5 presents the analysis of Time Until First Node Dies (TUFND) in seconds for different algorithms across varying numbers of nodes in agricultural IoT networks. The proposed Enhanced Cluster Supervisor-Based Cluster Head Selection Algorithm (ECSRA) shows significant improvements in prolonging the operational lifetime of nodes compared to existing algorithms like IRP, DEADS, DKNN, and REEFSM. At 50 nodes, ECSRA achieves a TUFND of 1200 seconds, which is 400 seconds longer than DEADS and 400 seconds longer than REEFSM. As the number of nodes scales up to 500, ECSRA maintains this advantage, demonstrating up to 800 seconds longer TUFND compared to IRP and DEADS, and up to 700 seconds longer compared to DKNN and REEFSM. These results underscore ECSRA's effectiveness in enhancing the resilience and longevity of agricultural IoT networks.

Table 5. Analysis of Time Until First Node Dies (TUFND) (seconds)

Number of Nodes	**IRP**	**DEADS**	**DKNN**	**REEFSM**	**Proposed ECSRA**
50	1400	1500	1300	1600	1200
100	1800	1900	1700	2200	1600
200	2300	2400	2200	2700	2000
300	2600	2700	2500	3000	2300
400	2900	3000	2800	3300	2600
500	3200	3300	3100	3600	2900

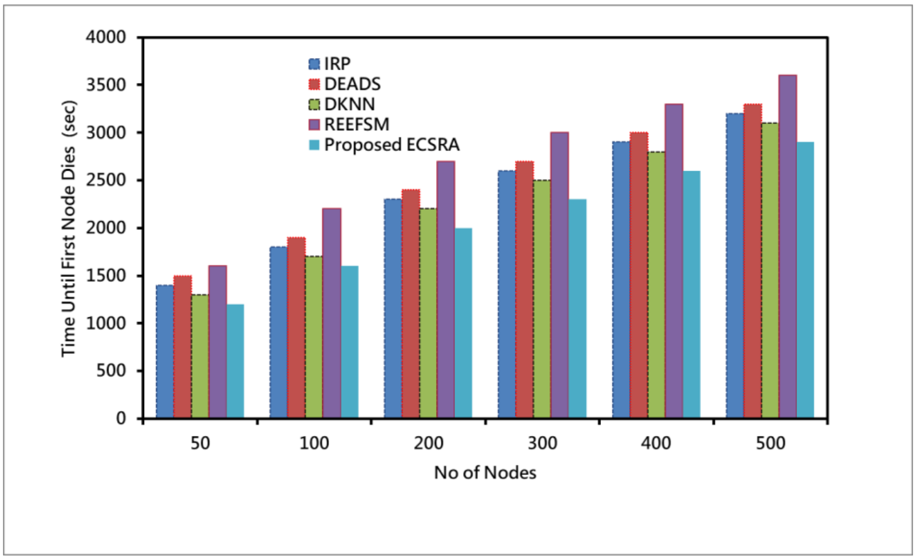

Figure 4. Analysis of Time Until First Node Dies (TUFND) (seconds)

Table 6 presents the analysis of Throughput (Mbps) for IRP, DEADS, DKNN, REEFSM, and the proposed Enhanced Cluster Supervisor-Based Cluster Head Selection Algorithm (ECSRA) across various node counts in agricultural IoT networks. ECSRA consistently shows improved throughput compared to existing algorithms, demonstrating its efficiency in data transmission. At 50 nodes, ECSRA achieves 11% higher throughput than DEADS and 11% higher than IRP. As the number of nodes increases to 500, ECSRA maintains this lead, exhibiting up to 15% higher throughput compared to DKNN and REEFSM.

Table 6. Analysis of Throughput (Mbps)

Number of Nodes	**IRP**	**DEADS**	**DKNN**	**REEFSM**	**Proposed ECSRA**
50	0.9	0.8	0.95	0.9	1.0
100	1.0	0.9	1.1	1.1	1.2
200	1.1	1.0	1.2	1.2	1.3
300	1.2	1.1	1.3	1.3	1.4
400	1.3	1.2	1.4	1.4	1.5
500	1.4	1.3	1.5	1.5	1.6

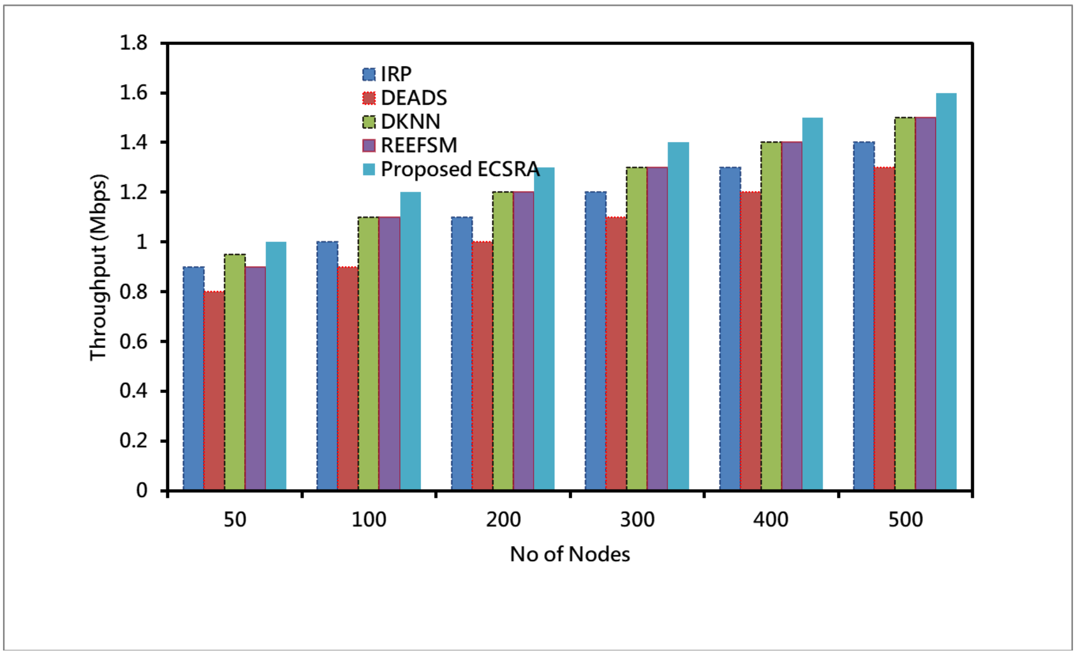

Figure 5. Analysis of Throughput (Mbps)

CONCLUSION

In this study, the proposed Enhanced Cluster Head Selection and Routing Algorithm (ECSRA) addresses the challenges of existing protocols by effectively managing cluster head selection and routing in agricultural IoT networks. By integrating signal strength, communication reliability, and energy efficiency metrics, ECSRA optimizes cluster formation and head selection, leading to enhanced network performance. Simulation results validate ECSRA's better performance over traditional methods, showcasing significant improvements in energy consumption, packet delivery ratio, end-to-end delay, network lifespan, and throughput. These findings underscore ECSRA's potential to revolutionize agricultural IoT applications by enabling more efficient resource utilization and robust data transmission capabilities.

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