# Improved Developed Distributed Energy Efficient Clustering for Precision Agriculture enabled by Wireless Sensor Networks

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## ABSTRACT
Routing protocols are crucial in agricultural WSNs, enabling efficient data exchange and communication. However, energy consumption is a major constraint. The Developed Distributed Energy-Efficient Clustering (DDEEC) scheme has limitations, including neglecting average distance between nodes and the Base Station (BS) and wasting of energy by idle nodes. To address this, a modified DDEEC scheme, Improved Developed Distributed Energy Efficient Clustering (IDDEEC) is proposed. The new scheme, incorporates residual energy, average energy of the network, distance between cluster head (CH) and BS, and average distance between nodes and BS in CH selection. Inter-cluster multi-hop communication and sleep/wake schemes are also introduced in the new scheme. MATLAB R2018a simulations show the proposed scheme outperforms TDEEC and DDEEC in throughput, residual energy, and network lifetime whiles DDEEC provided better stability period. However, the proposed system is still suitable for precision agriculture applications than other two schemes.

## General Terms
Algorithm enhancement

## Keywords
Residual energy, Average distance, Average energy

## 1. INTRODUCTION
Precision agriculture leverages modern technologies to increase the efficiency and sustainability of agricultural activities. Wireless Sensor Networks (WSNs) are one of the core components that facilitate real-time monitoring of agro-ecological conditions. These systems consist of multiple distributed sensor nodes that are battery-powered and deployed across vast fields [1]. The task of these sensor nodes is to send the sensed data to the base station (BS) where the information can be retrieved for analysis. In the area of WSNs, major research is carried out to cut down the energy consumption with the help of efficient routing protocols so as to retain the connectivity of the network to the maximum extent possible [2]. Majority of the energy efficient routing techniques use the concept of clustering to minimize the energy usage and enhance the overall network lifetime. In clustering technique all the sensor nodes will not participate in data transmission instead the cluster head will be responsible for the data transmission. This reduces the energy usage of the sensor nodes [3]. However, this can lead to hot spot issues as the cluster heads

will continuously participate in data transmission and dies off fast; especially those near the BS [4]. Also, clusters that are far from base station still suffer from large amount of energy for directly transmit their cluster data back to base station as in the case of DDEEC protocol. Therefore, multi-hop routing was introduced to reduce energy dissipation of cluster heads that far away from base station by relaying data through nearer cluster heads [5]. Duty cycling is mainly focused on the networking subsystem. The most effective energy-conserving operation is putting the radio transceiver in the (low-power) sleep mode whenever communication is not required. Ideally, the radio should be switched off as soon as there is no more data to send/receive and should be resumed as soon as a new data packet becomes ready. In this way, nodes alternate between active and sleep periods depending on network activity [6]. The study of literature shows that several heterogeneous cluster-based routing protocols have been proposed in agriculture. Authors in [7], discussed the significance of routing protocols in extending network lifetime, optimizing energy use, and ensuring reliable data transmission in wireless sensor network. It further evaluates the performance of these algorithms under real-world farming scenarios. Comparative analyses, tabular data, and schematic figures are included to demonstrate the impact of various techniques. This work aims to guide researchers and engineers in developing sustainable IoT-based smart farming systems. Also, various multi-hop protocols have been proposed in Literature.

Qing et al. [8] introduced the Distributed Energy Efficient Clustering Protocol (DEEC) for multi-level and 2-level heterogeneous WSNs. In DEEC, cluster heads are elected based on the ratio of a node's residual energy to the network's average energy, favoring high-energy nodes (advanced nodes). This approach enhances stability and prolongs network lifetime in heterogeneous settings. A robust hybrid routing method for heterogeneous WSN which adaptively combines clustering and multi-hop communication methods has been suggested in [9]. In the scheme, the nodes placed near to sink perform a multihop network (multi-hop zone) and nodes far away from sink perform clusters. Also, the researchers approximately analyze spatial boundary between both methods. Simulation results show that the new scheme approach significantly increases network lifetime in comparison with pure clustering and multi-hop communication methods. Saini and Sharma [10] proposed the TDEEC (Threshold Distributed Energy Efficient Clustering) protocol, an energy-efficient cluster head scheme for heterogeneous WSNs that modifies a node's threshold value

for cluster head selection. Simulations indicate TDEEC outperforms other protocols. Elbhiri et al. [11], proposed and evaluated a Developed Distributed Energy-Efficient Clustering (DDEEC) scheme for heterogeneous wireless sensor networks. DDEEC dynamically adjusts cluster head election probability, outperforming Stable Election Protocol (SEP) by 30% and Distributed Energy-Efficient Clustering (DEEC) by 15% in network lifetime and first node death. Authors in [12] explained a research scenario of multi-hop communication where one node may help other node to transmit data. The average energy efficiency under Rayleigh fading channels was derived and compare with single-hop communication. The proposed system performed better than the existing scheme in terms of extension of network lifetime. The author in [13] examined a hierarchical clustered network with two-level heterogeneous sensor nodes, proposing an enhanced multi-hop DEEC routing protocol. Simulation results indicate the protocol outperforms DEEC in terms of First Dead Node (FDN), energy consumption, and packet transmission. Energy-efficient multi-hop routing with Unequal Clustering approach (EMUC) is discussed by Assari et al. [14]. The scheme creates clusters of different sizes, which depend on the distance between the sensor node and the base station. Multi-hop communication approach was adopted to relay data to the base station. The implementation of multi-hop mode to transmit data to the base station reduces the energy cost of transmission over long distances. The effectiveness of this approach is validated through performed simulations, which prove that EMUC balances energy consumption between sensor nodes, mitigates the hotspots problem, saves more energy and significantly extends the network lifetime. In [15], Rajab proposed a genetic algorithm-based multi-hop routing which provides the optimized routes for data operations and improves the lifetime of wireless sensor networks by saving energy. The performance of the genetic algorithm is compared with the TEEN algorithm and results showed that the proposed scheme performed better than the existing scheme. An enhanced Heterogeneous Gateway-based Energy-Aware multi-hop routing protocol (HMGEAR) has been described by authors in [16]. The suggested routing scheme is based on the heterogeneous nodes that were introduced in the existing scheme, modification of the election probabilities of the cluster heads and introduction of multi-hop communication strategy in all the regions of the network. Simulation results showed that the new scheme performed better than the existing scheme in terms of stability period, throughputs, residual energy, and the lifetime of the network. Bazar and Sharma [17] propose an energy-efficient routing protocol for heterogeneous WSNs, selecting cluster heads based on residual energy. The protocol uses multi-hopping and sub-clustering techniques, with high-energy nodes becoming cluster heads and transmitting data to the base station. Simulations in MATLAB 2022b show improved network lifetime (75-80% increase), alive nodes, and data packets transmitted to the sink, outperforming O-LEACH, EEE-LEACH, Z-SEP, and LEACH protocols. Jalalinejad et al. [18] proposed a multi-hop clustering and renewable energy-based routing protocol for Energy Harvesting Wireless Sensor Networks (EH-WSNs) to address the limitations of conventional WSN routing methods that neglect Energy Harvesting. The protocol uses centralized and decentralized clustering based on energy conditions and harvested energy, operating in three phases: cluster formation, data transmission, and centralized management. Evaluation across three scenarios shows the approach reduces network energy consumption and increases node operational lifespan, outperforming AEHAC, CRBS, HUCL, and EADUC in energy levels, efficiency, stability, and live nodes. A reactive heterogeneous routing scheme called the Enhanced Zonal Stable Election protocol (EZ-SEP) is proposed by authors in [19]. In this scheme, clustering techniques has been introduced in all the Zones. The election probabilities of the cluster heads have been modified to take into account the residual energy and relative distance of nodes from the base station. This is to ensure that the energetic heads that can transmit data to the Base station are selected. The scheme furthermore, introduced inter-cluster multi-hop communication to ensure effective energy distribution among the nodes while using hard and soft thresholds to reduce unnecessary data transmission to the Base station. Simulation was conducted to evaluate the performance of the new scheme using MatLab R2018a, and the results showed that EZ-SEP outperformed Zonal SEP in terms of coverage, throughput, stability period, residual energy and network lifetime. The remainder of this work is arranged as follows: In **Section 2**, explained the Materials/Methods, while the Simulation Results and Analysis are discussed in **Section 3**, and the conclusion is drawn in **Section 4**

## 2. MATERIAL AND METHODS

MatLab R2018a was employed to measure the effectiveness of the proposed algorithm and the existing algorithm.

## 2.1 Existing Scheme

In [11], authors proposed the Developed Distributed Energy-Efficient Clustering (DDEEC) scheme, which builds upon the DEEC approach. DDEEC refines the cluster head (CH) selection process by taking into account both the residual energy of individual nodes and the network's average energy. Nodes with residual energy above the network average have a higher likelihood of becoming CHs. Otherwise, the probability is adjusted proportionally to the ratio of the node's residual energy to the network's average energy.

The data transmission in DDEEC follows a similar process to DEEC. Normal nodes send their sensed data to their respective cluster heads (CHs), which aggregate the data and forward it to the base station (BS) using either single-hop or multi-hop communication.

However, DDEEC's CH selection approach has limitations. It only considers residual energy and network average energy, overlooking node distance to the BS. This can lead to selecting distant nodes as CHs, increasing energy consumption. Additionally, all nodes remain active even without data to transmit, wasting energy. The protocol also lacks inter-cluster multi-hop communication, which could help conserve energy for nodes far from the BS.

The DDEEC scheme implements the same strategy as in [8] in terms of estimating the average energy of the networks and the CH selection algorithm which is based on the residual energy. The average energy, $\overline{E}(r)$ of rth round of the network used in [8] is given by Equation (1)

$$\overline{E(r)} = \frac{1}{N}\left(E_{total}\left(1 - \frac{r}{R}\right)\right) \qquad (1)$$

where $R$ denote the total rounds of the network lifetime and is defined by Equation (2)

$$R = \frac{E_{total}}{E_{round}} \qquad (2)$$

$E_{round}$ is the total energy dissipated in the network during a round.

In order to balance the selection of CHs in both the advanced and normal nodes at a point where their residual energy difference is not so great, DDEEC introduced    a threshold

residual energy value $Th_{REV}$. Under this $Th_{REV}$ all nodes, the advanced and normal nodes must have the same probability to be cluster head. Therefore, the cluster head election will be balanced and more equitable

The election probabilities of both normal ($p_{nrm}$) and the advance nodes ($p_{adv}$) as explained in [DDeec] are given by Equation (3)    For Normal nodes $E_i(r) > Th_{REV}$.

$$P_i = \begin{cases} \dfrac{p_{opt} \times E_i(r)}{(1+am) \times \overline{E(r)}} \\ \dfrac{(1+a) \times p_{opt} \times E_i(r)}{(1+am) \times \overline{E(r)}} \\ c \dfrac{(1+a) \times p_{opt} \times E_i(r)}{(1+am) \times \overline{E(r)}} \end{cases} \quad (3)$$

Where $Th_{REV}$ is a threshold residual energy value, and $C$, is a real positive variable which control directly the clusters head number.

## 2.2 Proposed Scheme

We propose the Improved Developed Distributed Energy Efficient Clustering (IDDEEC) scheme, which builds upon the network phases of the original DDEEC [11] but introduces key enhancements. Our scheme assumes the base station (BS) is distant from the sensing field, making distance a crucial factor. Cluster heads (CHs) are selected based on residual energy, average network energy, distance between CHs and the BS, and average node-BS distance. This approach favors energetic nodes closer to the BS, reducing energy consumption. To address scalability, we introduce inter-cluster multi-hop communication, enabling distant nodes to relay reports to the BS through multiple CHs. Additionally, a node sleep/wake-up mechanism suggested by [20] is implemented, allowing nodes to switch modes and conserve energy while periodically waking up to check for data or transmit.

The election probabilities of both normal ($p_{nrm}$) and the advance nodes ($p_{adv}$) in the new system are given by Equation (4)

$$P_i = \begin{cases} \dfrac{p_{opt} \times E_i(r) \times D_{CH\_BS}}{(1+am) \times \overline{E(r)} \times \overline{D_{Node\_BS}}} & \text{For Normal nodes } E_i(r) > Th_{REV}. \\ \dfrac{(1+a) \times p_{opt} \times E_i(r) \times D_{CH\_BS}}{(1+am) \times \overline{E(r)} \times \overline{D_{Node\_BS}}} & \text{For Adv normal nodes } E_i(r) > Th_{REV}. \\ c \dfrac{(1+a) \times p_{opt} \times E_i(r) \times D_{CH\_BS}}{(1+am) \times \overline{E(r)} \times \overline{D_{Node\_BS}}} & \text{For Adv \& Normal nodes } E_i(r) \leq Th_{REV}. \end{cases}$$

$$(4)$$

Where the Distance of CH to the BS, $D_{CH\_BS}$ is given by Equation (5)

$$D_{CH\_BS} = \sqrt{(X_{CH} - X_{BS})^2 + (Y_{CH} - Y_{BS})^2} \qquad 5)$$

The average distance of all nodes to the BS, is given by Equation (6)

$$\overline{D_{Node\_BS}} = \frac{1}{N} \sum_{i=1}^{N} D_{Node\_BS} \qquad 6)$$

**Table 1: Proposed algorithm1**

| Proposed algorithm 1 |
|---|
| **Algorithm 1**<br>// Initialize nodes<br>FOR EACH node i:<br>SET n(i).position and n(i).energy<br><br>FOR EACH round:<br>// CH Selection |

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| |
|---|
| FOR EACH node i:<br>Calculate election probability:<br>P(i) = (E_i / E_r) * ($D_{CH\_BS}$ / $\overline{D_{Node\_BS}}$<br>SELECT nodes with highest P(i) as CHs<br><br>// Cluster Formation<br>FOR EACH non-CH node j:<br>ASSIGN j to nearest CH<br>SEND data to CH<br><br>// Data Transmission<br>FOR EACH CH k:<br>IF distance($D_{CH\_BS}$) > $\overline{D_{Node\_BS}}$<br>SEND data to nearest CH in adjacent cluster<br>ELSE:<br>SEND data directly to BS |

**Table 2: Applied algorithm**

| Proposed algorithm 2 |
|---|
| **Algorithm 2**<br>// Initialize all nodes to Wake-up status<br>SET all nodes.status = WAKE-UP<br><br>FOR EACH node i:<br>IF n(i).energy > threshold AND n(i).status ==<br>WAKE-UP:<br>// Check neighboring nodes<br>FOR EACH node j ≠ i:<br>IF n(j).status == WAKE-UP AND distance(n(i),<br>n(j)) ≤ $\overline{D_{Node\_BS}}$ :<br>// Apply off-duty eligibility rule<br>APPLY off-duty eligibility rule<br>IF n(i) is eligible to sleep:<br>// Put node i to sleep and select a replacement<br>n(i).status = SLEEP<br>SELECT replacement node (if needed)<br>replacement_node.status = WAKE-UP |

## 3. RESULTS AND DISCUSSION

The proposed scheme, DDEEC and TDEEC [10] protocols were simulated in MATLAB R2018a to compare the performance of these protocols. A 100-node network was randomly deployed in a 100m x 100m area, with 20% advanced nodes. The BS was placed far from the BS at (50m, 200m), and all nodes were stationary. The performance metrics used in our comparison are: the number of alive and dead nodes, the number of sent packets to the base station and the residual energy of nodes. See Table 3 for simulation parameters.

**Table 3: Simulation Parameters**

| Parameters | Values |
|---|---|
| Network field | (100,100) |
| Number of nodes | 100 |

| | |
|---|---|
| Number of normal nodes | 80 |
| Number of advanced nodes | 20 |
| Initial energy of normal nodes($E_0$) | 0.5J |
| $E_{elec}$ | 50Nj/bit |
| $E_{fs}$ | 10Nj/bit/m$^2$ |
| $E_{mp}$ | 0.0013Pj/ bit/m$^2$ |
| $P_{opt}$ | 0.1 |
| M | 0.5 |
| A | 1.5 |

The following metrics are used to assess the two protocols

## 3.1 Network Lifetime

The performance of the proposed protocol is illustrated in Fig 1, which shows the number of alive nodes versus rounds. The results indicate that the proposed protocol sustains alive nodes for a longer period, up to 7500 rounds, with a relatively stable period, thereby prolonging the network lifetime. In comparison to DDEEC and TDEEC protocols, the proposed protocol increases node lifetime. This improvement is attributed to the modified CHs selection technique and the use of inter-cluster multi-hop communication, which reduces long-distance data transmission to the BS, resulting in lower energy consumption. In contrast, DDEEC shows a better stability period initially but sustains alive nodes for only 2500 rounds, while TDEEC sustains alive nodes for 2000 rounds. The poor performance of these existing schemes can be attributed to the absence of energy conservation techniques such as effective cluster selections and the placement of the BS far from the sensing area, for which these schemes were not designed for. However, DDEEC shows better performance than TDEEC in terms of sustaining alive nodes.
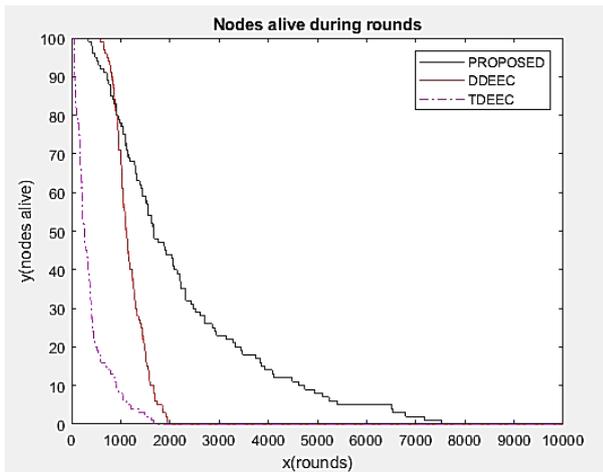


**Fig 1: Number of Alive Nodes per rounds**

The number of dead nodes versus rounds is shown in Fig 2, which clearly indicates that the proposed algorithm has the lowest number of dead nodes compared to DDEEC and TDEEC protocols. This is attributed to the energy-reducing strategies employed in the proposed scheme, including CH

selection based on residual energy and distance, where nodes with higher energy and proximity to the BS are chosen as CHs, and a sleep and wake approach. The absence of these strategies in the existing schemes has led to a higher death rate. Additionally, the schemes' struggle to transmit data to the distant BS has contributed to their faster energy declining. However, DDEEC outperformed that of TDEEC in terms of reducing number of dead nodes.
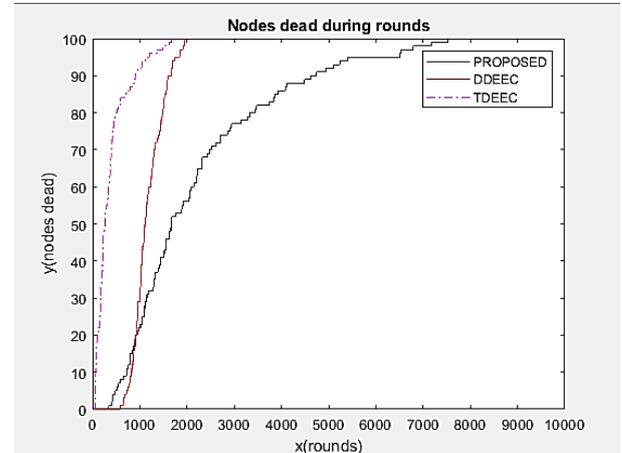


**Fig 2: Number of Dead Nodes per rounds**

## 3.2 Throughput

Fig 3 illustrates the number of packets sent to the base station versus rounds and this is crucial for assessing network performance, capacity, and efficiency. The results shows that the proposed scheme outperforms DDEEC and TDEEC protocols in terms of packet transmission. This is due to the strategic selection of CHs, which are more energetic and proximal to the BS, enabling efficient data transmission. Additionally, nodes in remote areas can easily transmit data to nearby CHs, which then forward it to the BS. In contrast, the existing schemes struggle to send data to the distant BS because distance or average distance is not considered in selecting the CHs. So distant nodes are selected as CHs which will not have the power to transmit data to the BS efficiently. Thus, resulting in reduced packet transmission to the BS. However, TDEEC performs better than DDEEC in terms of data transmission to the BS.
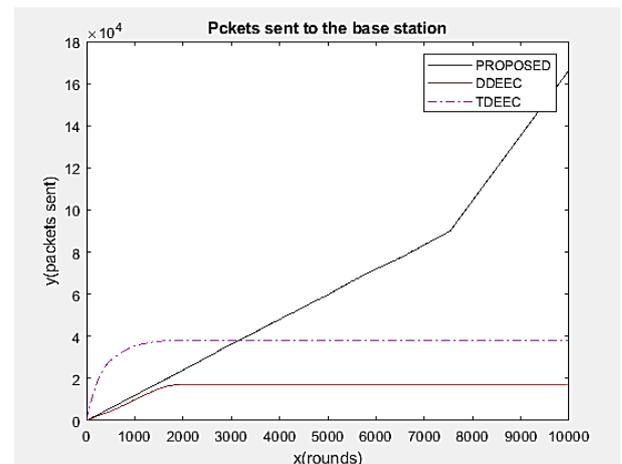


**Fig 3: Throughput per number of rounds**

## 3.3 Residual Energy

Fig 4 shows the average energy consumption versus rounds, highlighting the effectiveness of the proposed energy-efficient

cluster-based routing scheme. The proposed system exhibits the lowest energy consumption compared to DDEEC and TDEEC protocols, which is crucial for prolonging network lifetime. Three key factors contribute to this achievement:

- Energy and distance-based CH selection, which prevents weak and distant nodes from becoming CHs, conserving energy.

- Inter-cluster multi-hop communication, which reduces energy consumption by allowing CHs to send data via intermediate nodes when the distance to the BS exceeds the average distance.

- Sleep/wake techniques, which enable nodes to alternate between active and sleep states based on specific criteria, minimizing energy waste.

In contrast, the existing schemes lack these energy-saving strategies, leading to higher energy consumption despite selecting CHs based on residual energy. However, DDEEC perform better than TDEEC.
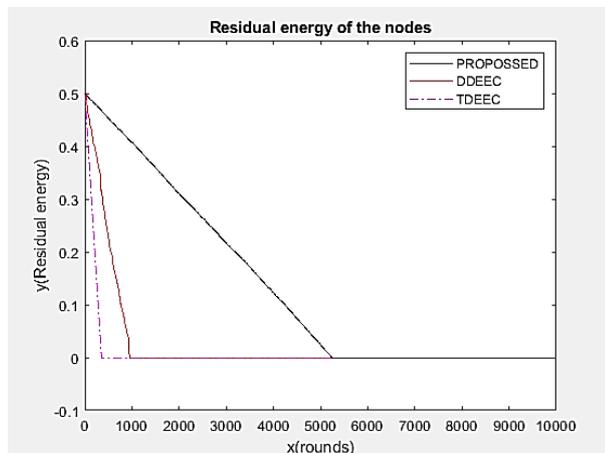


**Fig 4 : Residual energy per number of rounds**

## 4. CONCLUSION

In recent years, Wireless Sensor Networks (WSNs) have gained significant research attention, with network lifetime being a crucial parameter. To address this, an energy-efficient routing protocol is essential. This review paper proposes an Improved Developed Distributed Energy Efficient Clustering (IDDEEC) scheme, which incorporates three processes. The first process involves selecting Cluster Heads (CHs) based on residual energy and average distance /distance to the Base Station (BS). Nodes with plenty of energy and closer to the BS are chosen to handle data aggregation and transmission efficiently. The second process involves multi-hop communication between clusters which lets far-off nodes transmit data through intermediates. Finally, sleep/wake-up mechanisms which let idle nodes rest and wake up when it is time to transmit data.

Simulated in MATLAB R2018a, IDDEEC outperforms DDEEC and TDEEC protocols in network lifetime, throughput, and energy consumption. DDEEC performs better in stability period than all the algorithms, better network lifetime and energy consumption than TDEEC while TDEEC shows better throughputs than DDEEC. Based on these results, the proposed scheme is better suited for precision agriculture farming compared to DDEEC and TDEEC

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