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# Improving the Reliability of Wireless Sensor Network Assisted IoT Network with a Cluster-Based Chain-Tree Routing Protocol

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**Abstract**

The primary objective of designing routing protocols for Wireless Sensor Networks (WSNs) is to extend the network lifetime by optimizing the use of the limited battery energy of the sensor nodes. To improve conservation of energy and longevity of the network in WSNs, this study proposes a Cluster-based Chain-Tree Routing Protocol (CCTRP). Integrating tree based chain and cluster routing methods in WSNs is the primary objective of this study. This new CCTRP adopts a sector-based vertical network-partitioning scheme that divides network into sectors and it again vertically partitions the nodes too form various size of clusters. Then, Minimum Spanning Tree (MST) is created based on the kruskal's Algorithm through a Chain Leader (CL) node serving as the receiver and chain is formed from CLs of last level cluster to Base Station (BS) in each sector. Using the BS, remaining energy and distance to the next CL node, CCTRP determines the Cluster Leader (CL) or Chain CL node in each cluster. For data transport, it also selects the shortest paths. When the energy that remains in the node is ready to be exhausted, the transition is executed according to this protocol. This results in a significant improvement of the average network lifespan. Finally, the CCTRP protocol outperforms the current protocols in terms of network performance, according to the simulation results.

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**Keywords:** WSN; Routing; Chain based routing; clustering; Vertical network partitioning; Minimum spanning tree

## 1. Introduction

As the Internet of Things (IoT) continues to gain traction, WSNs will play an increasingly important role in many different industries, including those dealing with environmental monitoring, agriculture, urban planning, industrial automation and healthcare, among many others [1]. WSN assisted IoT is a system in which the Internet of Things (IoT) uses the features of a wireless sensor network (WSN) to gather and send data from different physical surroundings. This network can be constructed using large numbers of spatially dispersed autonomous sensors like temperature, sound, pressure, etc., which sense environmental data and transfer it to the BS [2]. Despite their broad applicability, several limitations, particularly in energy depletion, intrinsically constrain WSNs longevity. Usually, WSNs spend the majority of their energy on communication, which far balances the energy spent on data processing [3].

Therefore, improving the network's lifetime requires the creation of energy-efficient routing algorithms. To address this challenge, earlier strategies, such as direct communication, shortest path data transfer, and basic clustering processes, have been widely used [4]. The design of these strategies primarily motivated by reducing energy consumption and increasing network lifespan. However, these strategies were unsuitable in large-scale deployment situations that demand long network operational periods. Furthermore, they frequently fall short of properly balancing the needs for stability and scalability in the network. For example, nodes engaged in long-distance transmission may experience rapid energy depletion due to flat routing methods. Similar to this, clustering strategies may result in nodes using different amounts of energy, which could hasten network partitioning and shorten the network's lifespan overall [5].

In WSN, one of the most popular clustering algorithms is LEACH, which assigns a control node the role of CH and splits the nodes into clusters. The CH's job is to gather data packets from the cluster's nodes that aren't CHs [6]. The CH aggregates data to guarantee its security and reliability before sending it to the BS. By sending data packets to their respective CHs, the remaining nodes help LEACH save energy and extend the lifespan of the network. However, because to the greater workload and longer communication distances with the BS, the CHs' batteries may deplete more rapidly. Distributing the CH duty to other nodes at random will help keep the network's energy consumption in check. In contrast to LEACH, centralized LEACH (LEACH-C) uses the BS for CH selection and cluster construction [7]. Because of this, a block-based clustering technique can discover the maximum number of clusters in each cycle without requiring any additional control messages. In addition, LEACH has issues with nodes communicating across vast distances. As a solution, tree-based clustering protocols were developed, in which each cluster node builds a tree according to the distance from its member nodes to its CH [8]. A network partitioning-based routing methodology called hierarchical chain-based routing was proposed to extend the life of sensors. This method uses the shortest path algorithm in a chain structure [9]. In order to gather data and send it to the BS through multi-hop transmission, the CHs established a minimal spanning tree. For intra-cluster communication, these protocols used many spanning trees to cut down on energy usage from long links. Nevertheless, the extensive broadcasting of hello messages during spanning tree development necessitated additional energy for these protocols. Chosen the optimal number of clusters was difficult because CHs were randomly selected based on statistical possibilities. In particular, data transmission between clusters, from CHs to BS, requires energy-intensive single-hop communication across long networks.

As a result, researchers have proposed the PEGASIS technique, which employs a greedy algorithm to construct an extensive network of nodes before choosing one to serve as the CH in charge of data transmission and fusion [10]. On the other hand, PEGASIS has issues with long distances to the BS and an excess of the chosen CH. In order to lessen the load on WSNs' power supplies, researchers proposed the Power Efficiency Grid-Chain Routing Protocol (PEGCP) [11], which employs a chain transmission approach and divides the network in virtual cells. Its network lifetime and energy efficiency were both improved over LEACH, however, there are some weaknesses. The unpredictability of node deployment and cell division makes it impossible for PEGCP to ensure that smart sensor devices will have uniform energy usage and the single-chain algorithm may lead to extended communications. Hence, instead of sending data directly to the BS, researchers came up with hierarchical chain-based routing protocols that allow data transport through a sequential relay of nodes [12]. Although these protocols were robust, they were nevertheless vulnerable to the effects of node failures, which can disrupt or even destroy a network. To prevent this vulnerability, network partitioning has been adopted with this protocol, which involves segmenting the network into small subnetworks [13]. This protocol ensures that the core network architecture continues to perform properly by reducing the impact of failed nodes and keeping data transmission distances to a minimum. The routing methods that rely on chains may have significant transmission overhead and delays, regardless of their benefits.

To improve energy efficiency and network longevity, this work aims to build a new cluster-based chain-tree based routing protocol called CCTRP. It will integrate tree based chain and cluster routing methods in WSNs. A novel routing method is introduced that merges the benefits of tree based and chain based topologies to optimize network efficiency. This strategy drastically reduces distances transmitted and lengths of chains. It improves network performance by reducing latency using parallel-operating clusters, which speed up data processing and transmission. Furthermore, a novel approach to network partitioning is introduced for optimal load balancing, which solves important problems in network management by making resource distribution equitable and improving system dependability and resilience. The key points are as follows:

1. This new CCTRP adopts a sector-based vertical network-partitioning scheme that divides network into clusters through the formation of angle based sectors and vertical partitioning. The vertical partition of network regions crosses each sectors vertically and form cluster regions.
2. To determine the Cluster Leader (CL) or Chain CL node in each cluster, CCTRP considers the duration until reaching the BS and remaining energy.
3. Then, a cluster's minimal spanning tree is constructed from CL nodes using Kruskal's Algorithm, which is serving as receiver and a chain is formed between clusters through CL nodes up to Base Station (BS). Moreover, it chooses the short links for data transfer.
4. In a TDMA schedule, each active node in the network is assigned a specific amount of time to transmit data in a predetermined order and avoid data collisions. Every CL in the network collects information from its offspring and sends it, together with its own data, to the BS.
5. The transition is executed according to this protocol when the energy that remains in the node is nearly depleted. As a result, the average network longevity is significantly improved.

Here is the remaining content of the paper: The relevant literature is reviewed in Section 2. Part 3 provides an overview of the CCTRP, while Part 4 evaluates its performance in relation to prior research. The study is summarized and further enhancements are detailed in Section 5.

## 2. Literature Survey

While designing hierarchical routing techniques, protocols can accommodate WSNs with either multi-hop or single-hop communication modes, and various network types. Hierarchical routing protocols, which fall into one of three categories—block-based, chain-based, or tree-based—have been the focus of prior studies aimed at enhancing their energy efficiency. This section discusses recent studies related to these protocols.

Qiao et al. [14] developed a Random Projection-Polar Coordinate-Chain Routing (RPC) protocol. This protocol incorporates polar coordinates for node localization, a chain structure for route establishment, and random projection for compressed data collecting. For less extensive networks, it was proposed a four-quadrant chain routing algorithm that takes polar angle and polar radius into account. For more extensive networks, a routing method was employed that combined the inner circle and sector. Then, for every sector, the sink received the weighted total of the random projections for every row of the applicable measurement matrix. The signal reconstruction is complete since the sink has combined all measurements from all divisions. However, in more extensive networks, the sectors will get quite small. It is important to consider neighbouring regions when evaluating the routes set up within the sectors, since they might not be the best option.

Aziz et al. [15] presented an efficient energy routing system. To make the network last longer, it uses a combination of a chain generation mechanism and data fusion, a compression method that shrinks data packets before sending them to the base station. Nevertheless, data compression prior to transmission increases the computational cost at nodes. While working on WSN-assisted IoT, Firdous et al. [16] introduced PERC, a routing protocol that relies on clustering and uses the K-means clustering algorithm to group nodes into clusters. Geographical location and remaining energy of the nodes determined the principal CH and other CHs. Energy consumption can be decreased and the network's lifespan can be extended. There is no guarantee of minimal power consumption with single-hop intra-cluster transfer.

For longer network lifetime, Zhang et al. [17] suggested HTC-RDC, a routing system that combines tree based and clustering techniques. In order to facilitate multi hop communication between the base station and sensing nodes, this protocol constructs a tree structure. However, it allowed obstructions in the specified area, leading to significant energy use. For optimal data transport in WSNs enabled by the Internet of Things (IoT). Altowaijri [18] created an Efficient Multi-hop Routing Protocol (EMRP) that uses a rank based next hop selection technique. To get the best ranking for choosing the right data transfer route, it compared the remaining energy in every node to its connectivity degree. However, there was very little PDR.

In order for WSNs to offer continuous coverage of the target area through decentralized modulation of data transmission, Han et al. [19] developed an adaptive hierarchical-clustering routing protocol known as HCEH-UC. The original goal of developing a routing system based on hierarchical clustering was to reduce nodes' power consumption. Continuous target coverage is made possible by the development of a distributed alternation of operating modes that adaptively controls the number of nodes in the energy-harvesting mode. On the other hand, clustering with it is rather time-consuming.

Somauroo & Bassoo [20] presented PEGASIS that utilizes a genetic algorithm for chain creation instead of a greedy technique. Nevertheless, the mean energy consumption per node each round remained at higher levels. The weights for CH selection were established through trial and error, leading to significant time complexity.

## 3. Methodology

The suggested algorithm follows a detailed methodology, broken down into six key stages: network architecture, energy usage model, system initialization, leader selection process, construction of a data transmission with Minimal Spanning Tree (MST). A block diagram illustrating this framework is provided in Figure 1. Increasing the longevity and decreasing the energy consumption of Wireless Sensor Networks (WSNs) relies on each step.

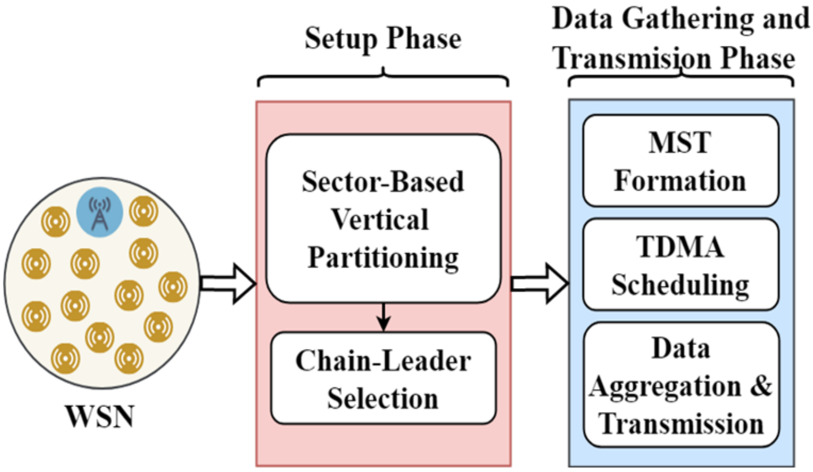

**Figure 1.** Schematic Representation of the Suggested Model

### A. Network Model

In a typical scenario, when $N$ sensor nodes are evenly distributed across an area of A square meters, the probability distribution density function, denoted as $\rho(x, y)$, is given by the following equation1:

$$\rho(x,y) = \frac{1}{(A^2/nc)} \tag{1}$$

where $nc$ represents the number of clusters. The average area assigned to each sensor node is calculated as in equation2:

$$A_{node} = \frac{A^2}{N} \tag{2}$$

The typical distance between any two nodes is given by:

$$d^2_{toNB} = \frac{A}{\sqrt{N}} \tag{3}$$

The average area occupied by each cluster can be approximated as [21]:

$$A_{cluster} = \frac{A^2}{nc} \tag{4}$$

Since the Cluster Head (CH) is situated in the middle of its sector, [21] determine the greatest distance between the CH and the cluster's furthest node:

$$d_{cluster-max} = \frac{A}{\sqrt{nc \times \pi}} \tag{5}$$

Equations 2 – 5 are used to form initial clusters. The sensor nodes are expected to be randomly distributed across a two dimensional sensor field in the simulation experiment. It will be continuously monitoring the environment and periodically transmitting the data they collect to a BS. It is assumed that the nodes will not be restricted by energy limitations.

### B. Model of Energy Consumption

Evaluating the energy efficiency of the proposed routing algorithms is based on mathematical expressions derived from this model, which guarantees that methods are grounded in real world operating circumstances. Both the transmitter and the receiver require energy to operate. To find the total amount of bits, use the following equation(6).

$$E_{\frac{Tx}{Rx}-elec} = E_{elec} \times \mathrm{K} \tag{6}$$

Here, $E_{elec}$ denotes the energy consumed per bit for transmission or reception. Both the distance δ and the quantity of bits being transferred in equation affect the amount of energy consumed by the amplifiers during transmission is mentioned in equation (7) and (8)

$$E_{Tx-amp} = \begin{cases} \varepsilon_{fs} * K \times \partial^2, \text{if } \partial < d_0 \\ \varepsilon_{mp} * K \times \partial^4, \text{if } \partial < d_0 \end{cases} \quad (7)$$

where“$d_0$” is the threshold given as

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (8)$$

The constants $\varepsilon_{fs}$ and $\varepsilon_{mp}$ find if the multipath or free-space fading model was applied. Thus, the sum of all energy required for transmission [22] is mentioned in equation (9)

$$E_{Tx} = \begin{cases} \varepsilon_{elec} * K + \varepsilon_{fs} \times K \times \partial^2, \text{if } \partial < d_0 \\ \varepsilon_{elec} * K + \varepsilon_{mp} \times K \times \partial^4, \text{if } \partial < d_0 \end{cases} \quad (9)$$

The energy consumed during reception includes the power required to operate the circuitry and to receive the incoming signal is in equation (10)

$$E_{Rx} = E_{elec} \times K \quad (10)$$

Thus, the whole amount of energy needed for data aggregation can be expressed as:

$$E_{DA-tot} = s \times k \times E_{da} \quad (11)$$

In this case, "$s$" stands for the total number of aggregated signals, while $E_{da}$ is the energy used per bit throughout aggregation in equation (11)

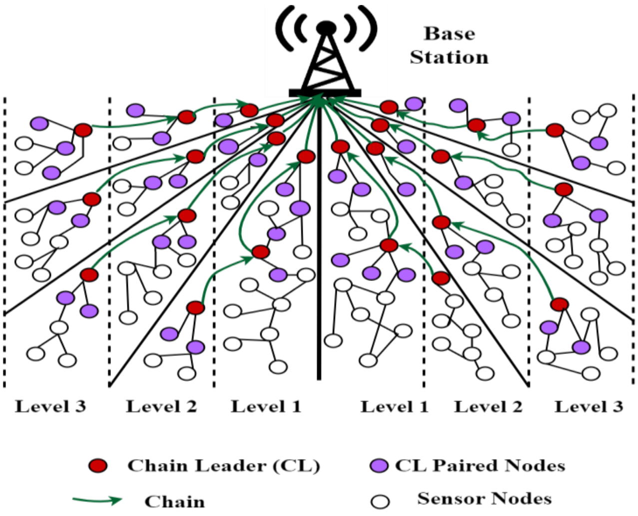

**Figure 2.** Sector-Based Vertical Network-Partitioning (Cluster Formation)

### C. Set-up Phase

The benefits of both tree based and LEACH centralized chain based routing schemes are brought together in this part by a Cluster-based Chain-Tree Routing Protocol (CCTRP). In order for the protocol to function during setup, there are three steps: One is Sector Division, which involves dividing the sensing area into clusters using vertical lines and sector boundaries. The second is Chain Leader (CL) Assignment, which involves choosing a leader for each cluster using criteria like residual energy and node distance to the BS. The third is Tree Construction, which involves creating routing trees using advanced algorithms. These trees may include one or more MSTs to optimize the transmission of data efficiency within the network.

Once this phase is complete, active nodes collect data and send it to the BS while keeping energy consumption to a minimum. The operational flow of CCTRP is shown in Figure 2 during a single round. It includes procedures such as sector division, leader selection, and the building of multi-hop routes based on MSTs. The BS to reduce the network’s total energy consumption coordinates all of these tasks. The setup phase involves selecting leader nodes for sectors and clusters using the following steps:

### (i) Sector division

Initially, nodes exchange HELLO messages with the Base Station (BS). The BS then partitions the entire sensing area into nc logical sectors, each corresponding to a cluster and the monitoring area is covered by unrealistic arcs. For this scenario, consider a network topology with 100 sensor nodes distributed across a 100 square meter area and the BS located at coordinates (50,100). The BS is assumed to be at the origin of the polar coordinate system (XOY), which the BS determines the angle φ for every node according to their locations, as follows in equation (12) and equation (13)

$$\omega = \arctan\left(\frac{Y}{X}\right)\frac{180}{\pi} \qquad (12)$$

Here, $X = |x - x_{BS}|, Y = |y - y_{BS}|$ and

$$\varphi = \begin{cases} \omega, & if\ Y > 0\ and\ X > 0 \\ \omega + 360, & if\ Y > 0\ and\ X < 0 \\ \omega + 180, & otherwise \end{cases} \qquad (13)$$

This is a two dimensional coordinate system where $x$, $y$, $x_{BS}$ and $y_{BS}$ are the node and BS positions, respectively. The BS then splits the sensing field into eight logical layers, with many uneven clusters in each. Every cluster has its own MST made up of linked nodes. Sector construction in the network is described in Algorithm 1 to guarantee a balanced distribution of nodes throughout the clusters.

**Algorithm 1 Sector Formation**

***Input***: *$N$ sensor nodes with positions $(x, y)$ and present energy levels.*

***Output:*** *$N$ nodes clustered into $nc$ distinct groups*

```
1. For each node $i$ from 1 to $N$, do:
   1.1. Acknowledge the BS with a HELLO message that includes its coordinates, remaining energy and unique ID.
2. Calculate the angle $\varphi$ for each node using eqs. (12) and (13).
3. Sort the nodes based on their angle $\varphi$ in ascending order.
4. Divide the network area into $nc$ sectors, with each sector containing approximately $N/nc$ nodes, based on the sorted $\varphi$ values, as illustrated in Figure 3.
5. For each sector $i$ from 1 to $nc$, do:
   5.1. Set $nnc = \{number\ of\ nodes\ in\ the\ i^{th} cluster\}$
   5.2. Sort the nodes in sector $i$ by their $y$-coordinate in non-decreasing order.
   5.3. For each level $j$ from 1 to $nl$, do:
      5.3.1. Apply the procedure in Algorithm 2.
6. Return: The distribution of $N/nc$ nodes into $nc$ sectors and a list of nodes within $np$ clusters.
```

### (ii) Vertical clustering

The method for creating clusters in the vertical clustering model is similar to that of horizontal clustering, with one significant distinction: the network is divided using the nodes' x-coordinates. This method requires maintaining a consistent y-coordinate for nodes within each cluster, effectively rotating the partitioning axis to create a vertical spatial distribution.

Consider the network operating in a $100 \times 100m^2$ area, where each node $n_i$ is located at coordinates $X_i, Y_i$. Vertical clustering creates partitions that run vertically across the region by using the BS to group nodes into clusters according to how close their x-coordinates are to one another. The network is divided into vertical segments, each containing nodes that are close to one another in terms of x-coordinate, but which may differ in their y-coordinates. This vertical division is depicted in Figure 2, showing how the network is segmented into vertical clusters within the $100 \times 100m^2$ region. This clustering strategy is based on mathematics that aims to minimize energy consumption during cluster communication by taking advantage of the physical proximity of nodes along the x axis. As a result, in a variety of deployment settings, vertical clustering improves energy efficiency and adds a new dimension to network segmentation.

The methodology for cluster formation in the vertical clustering paradigm is similar to that of horizontal clustering, with one key difference: the dependence on the x-coordinates of the nodes for network segmentation. By effectively inverting the partitioning axis to allow for an orthogonal view of spatial distribution, this method requires that each cluster maintain a uniform y-coordinate.

**Algorithm 2 Cluster formation**

**Input:** *There are $nc$ sectors and N sensor nodes, each with its own position (x, y) and energy level.*

**Output:** *N nodes clustered into $np$ distinct clusters*

```
Equally divide network region through vertical line in network region to form np clusters
Allocate $nnc/nl$ nodes at the j^th level to the corresponding j^th cluster, as illustrated in Figure 3.
return: $N/nc/np$ nodes in each of the $np$ clusters
```

### D. Chain Leader Selection

A subset of the sensor nodes is chosen to serve as Chain Leaders (CLs), whose responsibilities include cluster-level coordination and advanced processing. CLs collect data from the nodes, process it, and send it to the BS or sink node in an effort to lower the total energy consumption of communication. Every cluster has CLs that help with routing and data aggregation. Helping sensor nodes communicate with the next CL, they facilitate the efficient transfer of data within the cluster. For networks that use multi-hop communication or have many sensors deployed, CLs are chosen to help data get from one cluster to another or to fill in communication gaps. Data is sent from clusters to CLs, which then send it to the BS or other specified locations. Cluster member nodes are the other nodes in the cluster that aren't CLs. Every round, the CCTRP protocol uses these criteria to choose a CL for every cluster:

**An average of the residual ener gies $\left(\boldsymbol{ES_{avg}(j)}, \boldsymbol{EC_{avg}(j,l)}\right)$:** Prospective CL nodes must have a high average residual energy $j(ES(j))$ and an average residual energy of nodes in cluster $l$ of sector $j\left(EC_{avg}(j,l)\right)$ because they use more energy when sending data to the BS. These can be calculated using:

$$ES_{avg}(j) = \frac{1}{nnc}\sum_{i=1}^{nnc} E_{res}(i) \tag{14}$$

$$EC_{avg}(j,l) = \frac{1}{nnc}\sum_{i=1}^{nnc} E_{res}(i) \tag{15}$$

where $E_{res}(i)$ represents the remaining energy of the $i^{th}$ sensor node, and $nnc$ and $nnp$ is the quantity of nodes in the polygon or cluster.

**Distance to BS ($\boldsymbol{d_{toBS}}$):** The distance to the BS is an important factor, as longer transmission distances consume more energy. The CCTRP protocol uses the following fitness function to choose a CL in cluster $j$ that is both physically closer to the base station and has an average residual energy level higher than $ES_{avg}(j)$:

$$ff(i) = \frac{c_1 \times E_{res}(i)}{c_2 \times d_{toBS}(i,BS)} \tag{16}$$

where $d_{toBS}(i,BS)$ is determined as follows how far away node $i$ is from the BS:

$$d_{toBS}(i,BS) = \sqrt{(x_i - x_{BS})^2 + (y_i - y_{BS})^2} \tag{17}$$

The coefficients $c_1$ and $c_2$ represent the weight for energy and Euclidean distance, respectively, and can be adjusted based on the specific WSN model.

**Inter-level distance ($\boldsymbol{d_{toCL}}$):** The goal of this criterion is to reduce the distance between the CL and its parent node as much as possible within clusters, which reduces energy consumption and balances the load across CLs. A CL selects another CL as its parent node, considering both inter-cluster communication costs and the energy needed to communicate with the BS. The criterion for selecting the CL in each cluster is computed as:

$$sub_{CL}(i) = \frac{c_{@} \times E_{res}(i) \times nh}{10c_2 \times d_{toBS}(i,BS)} \tag{18}$$

where $nh$ is the count of nodes that are within communication range of the candidate CL.

A small number of CLs in CCTRP are in charge of sending aggregated data to the BS, which allows the remaining nodes to conserve energy. Placing the chosen CLs in close proximity to the BS will increase the network's lifespan. For a given round, a CL is chosen to become a chain-CL if either its distance from the BS is less than the average distance $D_{avg}$ from CLs to the BS or if it is located in a specific level zone. Among all CLs, the number of chosen chain-CLs is less than half. Where $D_{avg}$ is the average distance, it is computed as:

$$D_{avg}(r) = \frac{1}{nc}\sum_{i=1}^{nc} d(CL_i, BS) \quad (19)$$

The number of rounds for data transmission is determined by the following equation:

$$N_{round} = \frac{E_{init}}{ncE_{round}} \quad (20)$$

where $E_{init}$ is the initial energy and $E_{round}$ represents the energy consumed in each round.

**Algorithm 3: Selection of Chain Leaders**

***Input:*** *There are $nc$ clusters and np levels of sensor nodes, each with its own unique set of coordinates (x, y) and energy level.*

***Output:*** *List of CLs and Chain nodes in each cluster.*

```
1.  For each cluster $i$ from 1 to $nc$,
2.  Compute the mean energy of nodes in cluster $i$ using equation (14).
3.  Select the CL node with the highest fitness value from equation (16).
4.  Add the selected CL to the list of CLs.
5.  For each cluster $i$ from 1 to $nc$,
6.  For each level $j$ from 1 to $np$,
7.  Find the mean energy of the nodes at level $j$ using the formula (15).
8.  Select a CL node with the greatest possible cost function value from equation (18).
9.  Add the selected pair of CLs to the list of pair-CLs.
10. Compute the average distance $D_{avg}$ between all CLs and the BS using equation (19).
11. For each CL $i$ in the list of CLs,
12. If the distance from CL to BS $(d(CL, BS))$ is less than $D_{avg}$ or if the CL is in Level 1 or Level 2,
13. In the event that $nc/2$ is less than the count of chosen chain-CLs,
14. Add CL $i$ to the list of chain-CLs.
15. Compute the round size $t_{round}$ for this round based on the current configuration.
16. Return: List of CLs, pair-CLs, and relay-CLs.
```

## E. Data Gathering and Transmission

### (i) Minimum Spanning Tree Construction

In this suggested model, the network is initially divided into sectors, and CLs are chosen for each sector. A hierarchical two-level tree is constructed to optimize energy usage during data transmission. Through this hierarchical structure, sensor nodes are able to communicate both within and across sectors by continuously monitoring their environments and transmitting the collected data to the base station. According to the structure of the tree, the leaf nodes at the top of each MST send data to the matching pair-CLs. At the next level of the CL hierarchy, sub-CL nodes receive data packets that have been aggregated by parent nodes from their child nodes. The pair-CLs pass the aggregated data to their parent nodes, and the chain-CL nodes transmit all the data to the BS. After each cycle (denoted as $t_{round}$), the process restarts by reorganizing the clusters, redefining the polygons, reselecting CLs, chain-CLs, and sub-CLs, and rebuilding the two-level tree structure to optimize the data transmission for the next round.

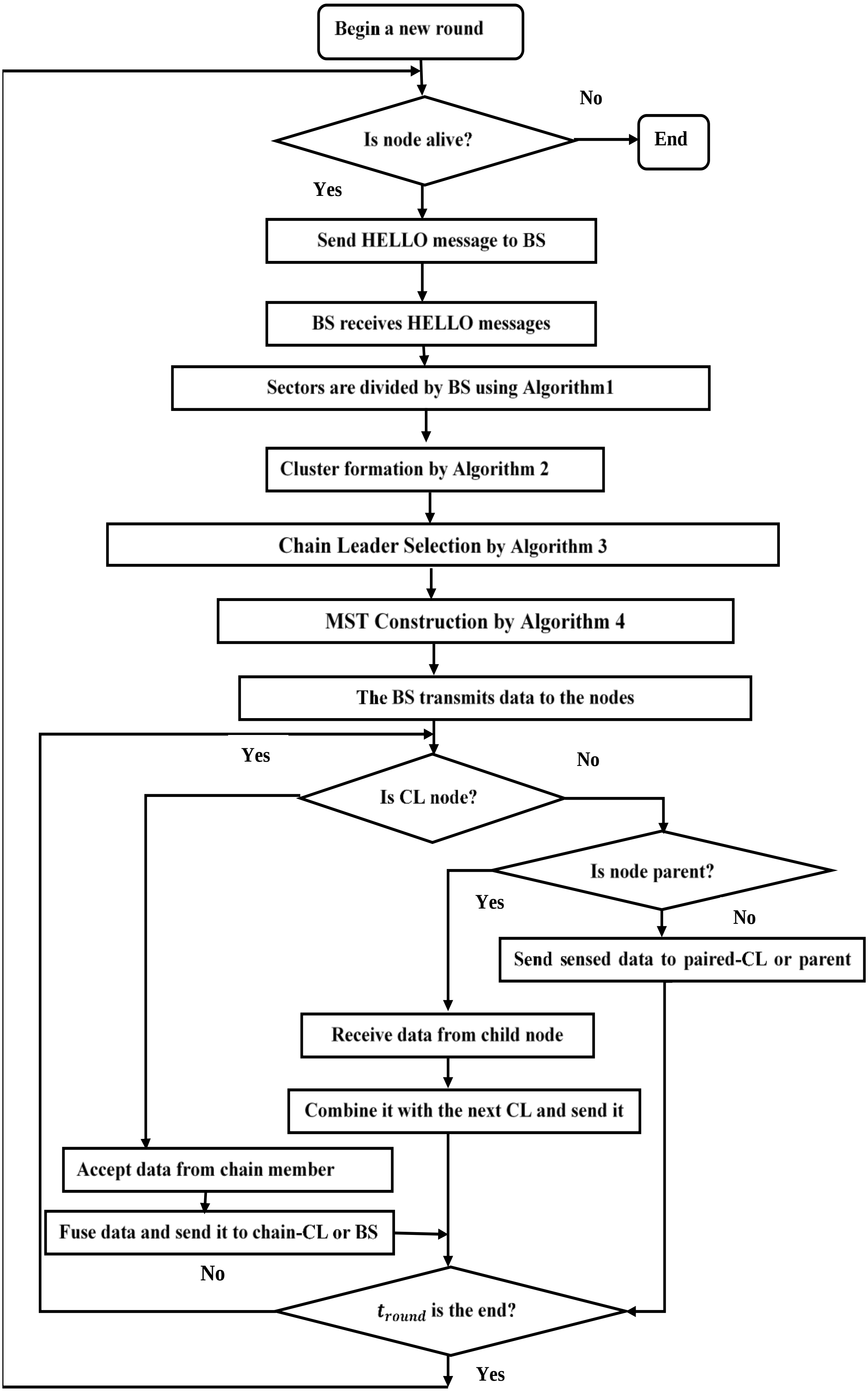

**Figure 3.** Flowchart of the proposed study

**Algorithm 4 MST formation**

```
Input: -$nnp$: The polygon's sensor node count and pair-CL.
       -$E_{dn}$: A collection of connections established by nodes within the cluster.
Output: Minimum Spanning Tree (MST) with pair-CL as the root.
Initialize count = 0;
Initialize edge index $edig = 0$;
Add pair-CL to MST: $MST = MST \cup \{pair - CL\}$;
Set pair-CL as the node at the root;
For every edge in $E_{dn}$, from the first edge to the overall amount of edges:
    Set $E_{dn}[i].selected = FALSE$;
Sort the list of edges in $E_{dn}$ in descending order of value.
While true:
    Select edge edig in $E_{dn}$, where $E_{dn}[edig].selected = FALSE$;
    Find the roots of $E_{dn}[edig].du$ and $E_{dn}[edig].dv$ (denoted as $d_u$ and $d_v$)
    if ($du$ and $dv$ represent two nodes on distinct trees) then
        Construct a tree union $d_u$ and $d_v$
        Mark $E_{dn}[edig].selected$ = TRUE;
        Increment count by 1.
    If count equals $nnp - 1$, break the loop.
For each edge $edig = 1$ to the number of edges in $E_{dn}$:
    If $E_{dn}[edig].selected = TRUE$ add it to the MST: $MST = MST \cup \{E_{dn}[edig].du, E_{dn}[edig].dv\}$;
Return the constructed MST
```

### (ii) TDMA scheduling

As part of this algorithm, the BS allots specific time slots to each network node that is actively transmitting data in order to avoid data collisions and maintain a consistent transmission order. This is made possible by implementing a TDMA schedule. To mathematically represent the scheduling, they can divide the network into cycles C and give each active node $i, j$ a unique time slot $T_i$ within each cycle, making sure that $T_i \neq T_j$ for any $i \neq j$.

## 4. Simulation Results

In this section, the effectiveness of the CCTRP in comparison to other protocols, including RPC [13], HTC-RDC [16], and HCEH-UC [18]. The simulation analysis is conducted using Python 3.7. Table 1 presents the parameters and their corresponding values utilized for simulating both the proposed and existing algorithms, which are used to assess performance.

**Table 1:** Simulation Parameters

| Parameters | Value |
|---|---|
| $E_{elec}$ | 50 nJ/bit |
| $N_{min}$ | 1 |
| $N_{req}$ | 2 |
| $T_{active}$ | 0.1 |

| | |
|---|---|
| $t_{min}$ | 0.3 |
| $t_{obs}$ | 0.3 |
| $\epsilon_{fs}$ | 10 pJ/bit/m$^2$ |
| $\epsilon_{mp}$ | 0.0013 pJ/bit/m$^4$ |
| Antenna category | Omni antenna |
| BS position | (250,500) |
| Channel category | Wireless channel |
| Energy used in data aggregation | 3 nJ/bit |
| Initial energy | 1.5 J |
| MAC layer | IEEE802.11 |
| MAC protocol | TDMA |
| Network topology | Flat grid |
| No. of clusters | 25 |
| No. of rounds | 100 |
| No. of sensor nodes | 500 |
| Packet size | 520 bytes |
| Propagation category | Two ray ground |
| Sensing region radius | 10 m |
| Simulation area | 1000×1000 m$^2$ |
| Runtime of the simulation | 200 sec |
| Source of traffic | Constant Bit Rate (CBR) |
| Uncertain region radius | 15 m |
| $\tau$ | 0.1 |

**Throughput:** It refers to the speed at which data is effectively transmitted from the nodes to a sink within a given period.

$$Throughput = \frac{No. of\ packets\ successfully\ delivered\ to\ the\ sink}{Time\ taken\ for\ delivery} \quad (21)$$

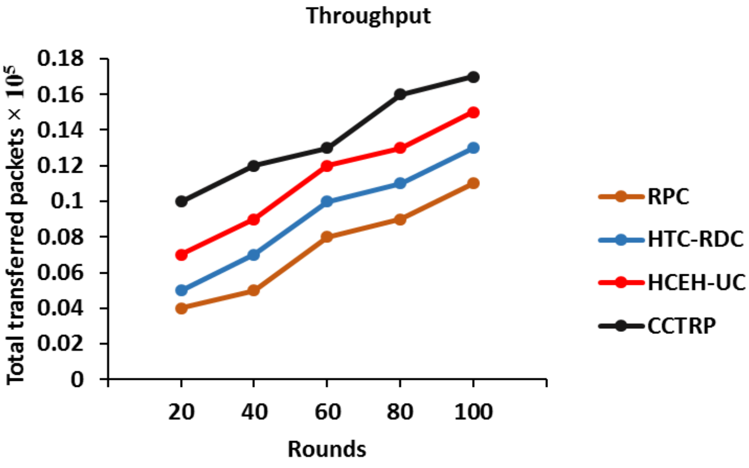

**Figure 4.** Total Transferred Packets vs. Rounds

As illustrated in Figure 4, different clustering routing methods are compared based on their throughput. When contrasted with other algorithms in WSNs, CCTRP outperforms the rest, achieving the highest data packet transfer to the BS. This results in reduced transmission costs and energy consumption in each cycle. As the lifespan of the network grows, so does the amount of data packets transmitted to the base station. Specifically, CCTRP transfers $0.17\times10^5$ packets to the BS over 100 rounds, while the RPC, HTC-RDC, and HCEH-UC algorithms transfer $0.11\times10^5$, $0.13\times10^5$, and $0.15\times10^5$ packets, respectively.

**Total Energy Utilization for Relaying:** It quantifies the energy consumed by each sensor node when receiving data from a neighboring CH node and transmitting it to the next CH or BS via a relay node (RN). The total energy can be expressed as:

$$E_{total} = \sum_{i=1}^{M} E_{overallT\_i} + E_{overallR\_i} \qquad (22)$$

In eq. (22), $M$ represents the total count of nodes, $E_{overallT_i}$ is the overall transmission energy used by node iii, and $E_{overallR_i}$ is the total energy consumed by node iii while receiving data from a neighboring node.

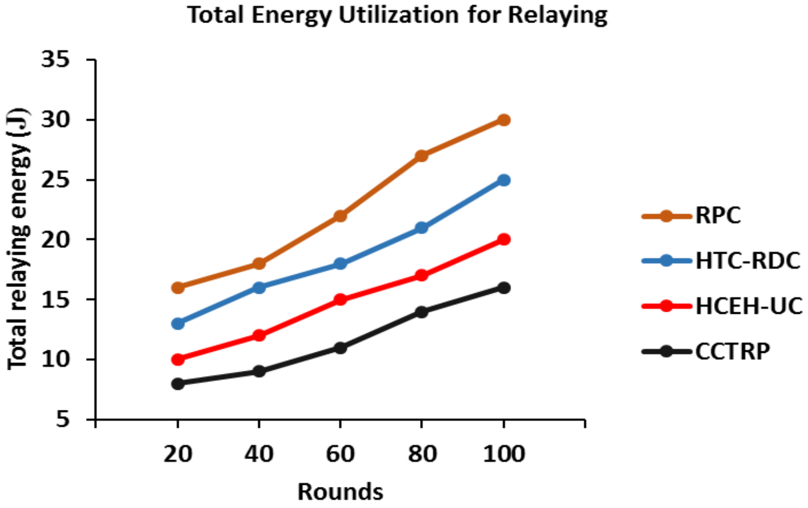

**Figure 5.** Total Relaying Energy vs. Rounds

Figure 5 illustrates the total energy consumption for relaying data across various clustering routing techniques over different round counts. The CCTRP algorithm significantly reduces the total relaying energy consumption compared to the RPC, HTC-RDC, and HCEH-UC algorithms, with reductions of 46.67%, 36%, and 20%, respectively.

**Network Energy Usage:** During the positioning phase, the network's energy utilization is calculated as the ratio of the nodes' energy consumption to the total available energy.

$$Network\ energy\ utilization = \frac{\sum_{i=1}^{M} E_{used\_i}}{\sum_{i=1}^{N} E_{initial\_i}} \qquad (23)$$

In Eq. (23), $E_{used_i}$ is the energy consumed by node iii during its operation, and $E_{initial_i}$ is the initial energy available to node $i$ before it is deployed in the network.

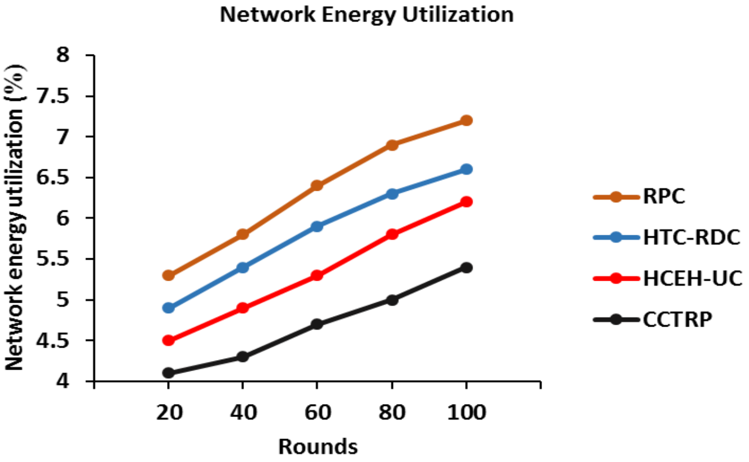

**Figure 6.** Network Energy Utilization vs. Rounds

Figure 6 illustrates the network energy utilization for different clustering routing techniques over varying round counts. The IDCSC algorithm, which employs a uniform energy consumption approach, demonstrates superior energy efficiency. When compared to the RPC, HTC-RDC, and HCEH-UC algorithms, the CCTRP reduces network energy consumption by 25%, 18.18%, and 12.9%, respectively.

**Network Lifetime:** Network lifetime refers to the duration during which the network remains functional before the first node's energy is depleted.

$$Network\ lifetime = \frac{Total\ energy\ available\ in\ the\ network}{Mean\ energy\ consumption\ per\ unit\ of\ period} \qquad (24)$$

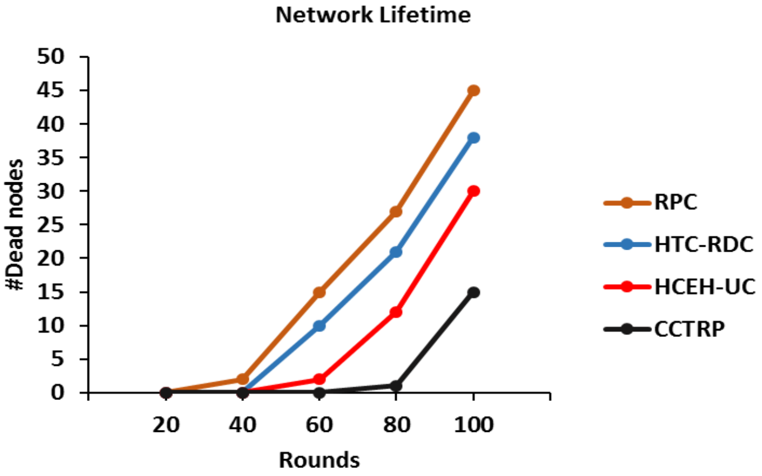

**Figure 7.** No. of Dead Nodes vs. Rounds

Figure 7 depicts the number of dead nodes over multiple rounds for various clustering routing techniques. After 100 rounds, the CCTRP significantly decreases the overall count of nodes when compared to other algorithms. Specifically, the CCTRP decreases the overall count of nodes by 66.67%, 60.53%, and 50% compared to RPC, HTC-RDC, and HCEH-UC, respectively.

**Delay**

Delay is the time taken for data to travel from source (S) to destination (D) within the network.

$$E2E\ delay = \frac{\sum_{i=1}^{p}(R_i - S_i)}{n} \qquad (25)$$

For each packet, $R_i$ is its reception time and $S_i$ is its transmission time; $p$ is the number of packets that made it to the BS successfully.

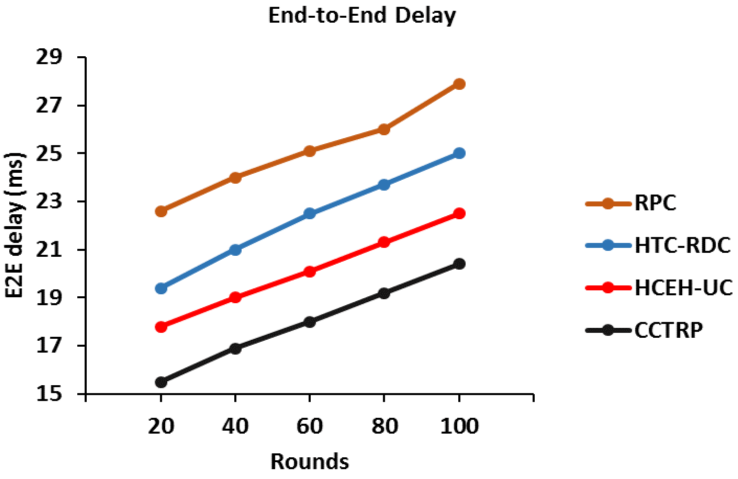

**Figure 8.** Rounds vs E2E Delay

Figure 8 displays a contrast between the E2E delays for different clustering routing techniques over multiple rounds. The analysis reveals that the IDCSC minimizes delay more effectively than other algorithms due to its optimized energy-efficient path selection for inter-cluster communication and its FDCA strategy for intra-cluster communication. Because of this, the IDCSC is able to find a perfect medium between delay and energy consumption. Consequently, the IDCSC algorithm exhibits a lower E2E delay over 100 rounds, with reductions of 29.66%, 26.88%, 18.4%, and 9.33% compared to EOR-iABC, CHHFO, EECHIGWO, and SCA-Levy, respectively.

## 5. Conclusion

This research introduces CCTRP, a novel energy efficient routing protocol that combines cluster based, tree based and chain based techniques to increase the nodes' lifespan in WSNs. The suggested approach disables redundant nodes that identify duplicate data in order to save energy. By reducing energy consumption associated with mode transitions, this routing approach increases the lifetime of the network by preventing nodes from frequently switching among active and sleep modes through a communication cycle. Furthermore, CL selection optimizes energy usage and operational lifetime of the network. Since nodes only communicate with their nearest parent node when employing a minimum spanning tree for routing, energy consumption is kept to a minimum. Based on the simulation results, CCTRP is the most energy-efficient and longest-lasting protocol currently available.

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