

An Enhanced Mobility-Aware Heed Clustering Algorithm For Wireless Sensor Networks

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Abstract Clustering strategies are frequently used in Wireless Sensor Networks (WSNs) to reduce energy consumption and accommodate the effective functioning of the network. The Hybrid Energy-Efficient Distributed (HEED) protocol is one of them, where residual energy and communication cost are considered as major factors to select cluster heads (CHs). However, HEED fails to consider node mobility as a significant constraint that is apparent in dynamic environments, causing unstable clusters and increases in energy consumption caused by frequent CH changeovers. In order to tackle this challenge, an enhanced version of Mobility-aware HEED (M-HEED) is introduced. This version will add an element of mobility to the process of choosing a CH, which is based on the speed of the nodes. Slower-moving nodes will be favoured as CHs. The goal is to reduce the number of times clusters are reformed and make them as consistent as possible. We compare the key performance indicators of HEED and M-HEED using the Packet Delivery Ratio (PDR), the CH lifespan, and the amount of energy used. The simulators show that M-HEED is a better option for mobile WSN settings because it is more stable, uses less energy, and sends data more consistently.

Index Terms– Wireless Sensor Networks (WSNs), Clustering Algorithm, Cluster Head (CH) Selection, Energy Efficiency, Network Lifetime, Mobility Factor, Sensor Node Stability.

1. INTRODUCTION

Wireless Sensor Networks have developed as a new strategy of monitoring and controlling physical environments[1]. It is made up of sensor nodes that are spatially distributed. WSNs find extensive uses in diverse applications and include industrial control, agriculture, surveillance in the military, environmental studies as well as disaster control. The capability of real time data collection, analysis and transmission that these networks exhibit enables decision making in mobile and often remote environments.. Energy efficiency[2] is one of the critical concern in WSNs. Sensor Nodes are predominantly powered by batteries [3]. Replacing or recharging these batteries is often impractical or even impossible, particularly in large-scale or inaccessible deployments, such as underwater or underground deployments. SNs are grouped into clusters using clustering protocols, which have been devised to overcome this difficulty. There is a Cluster Head in charge of each cluster. The Cluster Head is responsible for aggregating data from the member nodes of cluster and then transmitting this data to the Base station, hence reducing the overall energy consumption of the network. Among the various clustering protocols, the Hybrid Energy-Efficient Distributed (HEED) protocol has gained significant attention due to its ability to balance energy consumption and extending network lifetime. HEED protocol elects CHs on the basis of two parameters: residual energy of SNs and communication cost, ensuring that the nodes with high residual energy are prioritized for the role of CH. However, traditional HEED is designed for static networks and does not account for node mobility, which is a critical factor in many real-world applications. In dynamic network, SNs move within the network area rather than remaining stationary. This mobility poses numerous challenges:

1. **Frequent Cluster Reformation** : The movement of nodes within the network causes continuous topology changes, resulting in frequent reformation of cluster. This, in turn, rises the overhead of control messages and adversely affects network stability.
2. **Increased Energy Consumption** : the frequent reformation of clusters and continuous data transmission in dynamic network results in increased energy consumption, which consequently shortens the overall network lifetime.
3. **Reduced Data Delivery** : High mobility might result in packet loss and delays, lowering the reliability of data delivery to the BS.
4. Existing clustering protocols, such as HEED, are not designed to handle these challenges effectively. They assume a static network topology and do not incorporate mobility into the CH selection process. As a result, highly mobile nodes may be selected as CHs, leading to unstable clusters and increased energy consumption.

The increasing deployment of WSNs in dynamic situations has fuelled the demand for mobility-aware clustering methods. For instance:

Drone Networks : Drones used for surveillance or delivery operate in highly mobile environments, where traditional clustering protocols are ineffective

Vehicular Networks: SNs placed on vehicles travel at high speeds, necessitating a protocol that can adapt to rapid shifts in network topology.

Disaster Recovery : In disaster scenarios, sensor nodes may be deployed on moving vehicles or carried by first responders, necessitating a protocol that can handle mobility.

By incorporating mobility into the CH selection process, a mobility-aware clustering protocol can improve energy efficiency, extend network lifetime, and enhance the reliability of data delivery in mobile WSNs.

This paper propose M-HEED, a Mobility-Aware Hybrid Energy-Efficient Distributed clustering protocol , which extends the traditional HEED protocol to address the challenges of mobility in WSNs. The key contributions of this work are:

- **Mobility Factor :** A novel mobility factor f_{mob} is introduced to reduce the probability of highly mobile nodes becoming CHs.
- **Modified CH Selection :** The CH selection process considers both residual energy and node mobility, prioritizing the stable and energy-rich nodes for CH selection.
- **Improved Cluster Stability :** By reducing the frequency of cluster reformation, M-HEED enhances cluster stability and minimizes energy consumption.
- **Comprehensive Evaluation :** Extensive simulations are used to test M-HEED's performance, demonstrating its superiority over traditional HEED in mobile environments.

The remainder of this paper is organized as:

Section 2 provides a review of related work, focusing on existing clustering protocols and mobility-aware solutions. Section 3 describes the system model and assumptions used in this work. Section 4 provides a detailed description of the algorithm and cluster formation procedure for the proposed M-HEED protocol. The paper's conclusion and recommendations for future research are made in Section 5.

2. RELATED WORK

This section provides a summary of current clustering methods that are often used in WSNs, emphasising their workings, advantages, and disadvantages.

2.1. Clustering Protocols

Clustering protocols have been widely used in the context of WSNs to enhance energy efficiency and extend network lifetime [4]. These clustering protocols organize sensor nodes into clusters, where each cluster is headed by a cluster head which is responsible for data aggregation and transmission to the base station. Below, we discuss some of the most prominent clustering protocols with their limitations.

2.1.1. Low-Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is one of the foremost and most prominent clustering protocols for WSNs. LEACH over rounds, where each round is consist of a setup phase and a steady-state phase. In the setup phase, nodes probabilistically elect themselves as cluster heads based on their residual energy. The steady-state phase involves data transmission from member nodes to their cluster heads and then from cluster heads to their base stations[5], [6], [7].

Limitations:

- **Random CH Selection:** LEACH elects the cluster head using probabilistic method, which could lead to unequal energy utilisation throughout the network.
- **Static Network Assumption:** Since LEACH is intended for static networks and excludes node mobility, cluster reformation occurs repeatedly in mobile contexts.

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2.1.2. Hybrid Energy-Efficient Distributed Clustering (HEED)

HEED improves upon LEACH by selecting CHs based on both residual energy and communication cost. It uses a hybrid approach, where nodes with higher residual energy and lower communication cost are more likely to become CHs. This ensures a more uniform energy consumption and longer network lifetime [8].

Limitations:

- **No Mobility Consideration:** Like LEACH protocol, HEED too assumes a static network and does not incorporate mobility factor into the CH selection process.
- **Overhead:** The process of selecting a CH and forming a cluster again and over again adds extra overhead, especially in big networks.

2.1.3. Threshold-Sensitive Energy-Efficient Sensor Network Protocol (TEEN)

TEEN is designed for time-critical applications where sensor nodes transmit data only when certain thresholds are exceeded [9].

It uses a hierarchical clustering approach [10], with CHs responsible for aggregating and forwarding data to the BS.

Limitations:

- **Threshold Dependency:** TEEN's performance is highly dependent on the choice of thresholds, which may not be suitable for all applications.
- **No Mobility Support:** TEEN does not account for node mobility, making it unsuitable for dynamic environments.

2.1.4. Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

This protocol uses a chain-based approach, where nodes form a chain and take turns transmitting data to the BS [11], [12], [13]. This reduces the energy consumption of individual nodes and extends the network lifetime.

Limitations:

- **Chain Formation Overhead:** The process of forming and maintaining the chain introduces significant overhead, especially in large networks.
- **No Mobility Consideration:** PEGASIS is designed for static networks and does not handle node mobility effectively.

2.2. Mobility-Aware Protocols

To cope with the challenges associated with mobility in WSNs, a number of clustering procedures that are aware of mobility have been suggested. The goal of these protocols is to make clusters more stable and use less energy in changing circumstances.

2.2.1. Mobility-Based Clustering (MOBIC)

MOBIC is a mobility-aware clustering protocol that selects CHs based on their relative mobility [14]. It uses a mobility metric to identify stable nodes and elect them as CHs.

Limitations:

- **High Overhead:** MOBIC requires frequent exchange of control messages to calculate the mobility metric, leading to increased overhead.
- **Limited Scalability:** The protocol does not scale well to large networks due to its high computational complexity.

2.2.2. Mobility-Enhanced LEACH (M-LEACH)

M-LEACH extends the traditional LEACH protocol to handle node mobility by incorporating a mobility factor into the CH selection process [15]. It uses a probabilistic approach to select CHs based on their residual energy and mobility.

Limitations:

- **Probabilistic CH Selection:** Like LEACH, M-LEACH uses a probabilistic approach, which may result in uneven energy consumption.
- **Limited Performance Improvement:** The protocol provides only marginal improvements in cluster stability and energy efficiency.

2.2.3. Variant LEACH (V-LEACH)

V-LEACH introduces a backup CH to handle node mobility and improve cluster stability. The backup CH takes over the role of the primary CH if it moves out of range.

Limitations:

- **Increased Overhead:** The use of backup CHs increases the overhead of control messages and energy consumption.
- **Complexity:** The protocol introduces additional complexity in managing primary and backup CHs.

2.3. Limitations of Existing Clustering Protocols

Despite the advancements in clustering protocols, several limitations remain in the literature:

- **Lack of Mobility-Aware CH Selection:** Most existing protocols do not explicitly incorporate mobility into the CH selection process, leading to unstable clusters in mobile environments.
- **High Overhead:** Many mobility-aware protocols introduce significant overhead, reducing their scalability and energy efficiency.
- **Limited Performance Improvements:** Existing protocols provide only marginal improvements in cluster stability and energy efficiency, highlighting the need for more effective solutions.

2.4. Comparison of Clustering Protocols

Table 1 provides a side-by-side comparison of seven well-known clustering schemes, highlighting their primary cluster-head (CH) selection criteria, whether they support node mobility, and their relative performance in terms of energy efficiency and cluster stability. The entries for LEACH, HEED, TEEN and PEGASIS are drawn from foundational WSN studies [16], [17], [18], while those for MOBIC, M-LEACH and V-LEACH follow more recent mobility-focused investigations [14], [15]. The proposed M-HEED row is based on the mobility-augmented CH election mechanism detailed in this work. By comparing “Mobility Support” against “Energy Efficiency” and “Cluster Stability,” Table 1 illustrates how M-HEED attains both high energy efficiency and robust cluster structures in dynamic environments, outperforming most predecessors.

Table 1: Comparison of Clustering Protocols

Protocol	CH Selection Criteria	Mobility Support	Energy Efficiency	Cluster Stability
LEACH	Probabilistic	No	Moderate	Low
HEED[19]	Residual Energy, Communication Cost	No	High	Moderate
TEEN	Threshold-Based	No	Moderate	Low
PEGASIS	Chain-Based	No	High	Low
MOBIC	Mobility Metric	Yes	Moderate	High
M-LEACH	Residual Energy, Mobility	Yes	Moderate	Moderate
V-LEACH	Primary/Backup CH	Yes	Moderate	High
M-HEED	Residual Energy, Mobility	Yes	High	High

Table 2 presents a comparative analysis of mobility-aware clustering protocols for mobile wireless sensor networks, including MOBIC, M-LEACH, V-LEACH, and the proposed M-HEED. The comparison is based on protocol design characteristics as reported in existing literature, with a focus on the type of mobility metric used, communication overhead, scalability, and overall performance potential in dynamic network environments. These parameters were selected based on their relevance to performance in mobility-centric scenarios.

"The assessment is derived from a comprehensive review of each protocol's operational behaviour and design strategy, rather than from experimental simulation. This comparison helps establish a clear understanding of M-HEED's relative advantages, particularly in terms of reduced overhead and improved scalability. A full simulation-based performance evaluation is planned for future work to validate and expand upon these findings."

Table 2: Comparison of Mobility-Aware Protocols

Protocol	Mobility Metric	Overhead	Scalability	Performance Improvement
MOBIC	Relative Mobility	High	Low	Moderate
M-LEACH	Mobility Factor	Moderate	Moderate	Low
V-LEACH	Backup CH	High	Moderate	Moderate
M-HEED	Mobility Factor	Low	High	High

3. PROPOSED M-HEED PROTOCOL

The proposed M-HEED protocol addresses key limitations of existing clustering algorithms -specifically, the lack of mobility support, high communication overhead, and unstable cluster formations in dynamic environments—by incorporating a mobility factor into the cluster head (CH) selection process.

- **Prioritizes Stable Nodes:** Nodes with lower mobility are more likely to become CHs, improving cluster stability.
- **Reduces Overhead:** The protocol minimizes the overhead of control messages by using a hybrid approach for CH selection.
- **Improves Energy Efficiency:** By balancing energy consumption and reducing the frequency of cluster reformation, M-HEED extends the network lifetime.

M-HEED builds on the strengths of traditional HEED while addressing its limitations in mobile environments, making it a robust and efficient solution for mobile WSNs. By introducing **mobility factor** into the cluster head (CH) selection process, it is ensuring that nodes with lower mobility and higher residual energy are prioritized as CHs. This hybrid approach will not only extend the network lifetime but will also enhance cluster stability in mobile environments. M-HEED will operate in a distributed manner, requiring no global knowledge of the network. It will combine the strengths of probabilistic CH selection (inspired by HEED) with mobility-awareness, making it suitable for applications such as vehicular networks, wildlife tracking, and mobile IoT deployments. The protocol will consist of four key phases: (1) **Cluster Head Selection**, (2) **Cluster Formation**, (3) **Data Transmission**, and (4) **Re-clustering**. Each phase will be designed to minimize energy consumption while adapting to node mobility.

3.1. Mobility Factor

The **mobility factor** f_{mob} is a critical component of M-HEED, enabling the protocol to account for node mobility during CH selection. The mobility factor is defined as:

$$f_{mob} = \frac{1}{1 + velocity}$$

where:

The mobility factor f_{mob} , is a parameter which is designed to minimize the likelihood of selecting highly mobile nodes as Cluster Heads (CHs) in wireless sensor networks and Velocity refers to the rate at which a node changes its position over time within the network.

velocity represents the speed of the node, measured in meters per second (m/s).

3.1.1. Role of the Mobility Factor

The mobility factor inversely correlates with the node's velocity. A lower velocity results in a higher f_{mob} , increasing the likelihood of the node being selected as a CH. Conversely, a higher velocity reduces f_{mob} , discouraging the selection of highly mobile nodes as CHs. This ensures that CHs remain stable and minimize the need for frequent re-clustering.

3.1.2. Calculation of Velocity

The velocity of a node can be estimated using various methods, such as:

- **GPS-based localization:** Nodes equipped with GPS can calculate their velocity based on position changes over time.
- **Neighbour-based estimation:** Nodes can estimate their velocity by measuring changes in the signal strength or distance to neighbouring nodes.

3.2. Modified CH_{prob} Formula

The CH selection probability CH_{prob} in M-HEED is modified to incorporate both residual energy and mobility. The formula is given by:

$$CH_{prob} = C_{prob} \times \left(\frac{E_{residual}}{E_{max}} \right) \times f_{mob}$$

Where:

- C_{prob} is the initial CH probability (a constant).
- $E_{residual}$ is the residual energy of the node.
- E_{max} is the maximum energy capacity of the node.
- f_{mob} is the mobility factor.

Here:

Energy Component: The term $\frac{E_{residual}}{E_{max}}$ ensures that nodes with higher residual energy are more likely to become CHs, promoting energy efficiency.

Mobility Component: The term f_{mob} ensures that nodes with lower mobility are prioritized, enhancing cluster stability.

4. M-HEED Algorithm

The M-HEED algorithm operates in rounds, with each round consisting of the following steps:

Pseudo code for M-HEED Algorithm

1. Initialize network parameters:
 - Set initial CH probability (C_prob).
 - Set maximum energy capacity (E_max).
 - Set node velocities and calculate mobility factor (f_mob).
2. For each node in the network:
 - a. Calculate CH_prob using the modified formula:
 $CH_prob = C_prob * (E_residual / E_max) * f_mob$
 - b. Broadcast CH_prob and f_mob to neighbors.
3. Cluster Head Selection:
 - a. For each node:
 - Generate a random number between 0 and 1.
 - If CH_prob > random number:
 - i. Declare itself as a tentative CH.
 - ii. Broadcast CH advertisement to neighbours.
 - Else:
 - i. Wait for CH advertisements from other nodes.
4. Cluster Formation:
 - a. For each non-CH node:
 - Receive CH advertisements from neighbouring CHs.
 - Select the CH with the highest RSS and lowest mobility.
 - Send a join request to the selected CH.
 - b. For each CH:
 - Receive join requests from non-CH nodes.
 - Create a TDMA schedule for cluster members.
5. Data Transmission:
 - a. For each cluster member:
 - Transmit data to the CH during the allocated TDMA slot.
 - b. For each CH:
 - Aggregate data from cluster members.
 - Forward aggregated data to the base station (BS).
6. Re-clustering:
 - a. At the end of each round:
 - Re-calculate CH_prob for all nodes.
 - Re-select CHs based on updated CH_prob values.
 - Reform clusters and update TDMA schedules.

4.1. Steps of M-HEED Protocol

4.1.1. Initialization Phase

The initialization phase sets up the network and prepares nodes for the clustering process. This phase is executed once at the beginning of the network operation.

Steps:

1. Network Setup:

- Deploy sensor nodes randomly or in a predefined pattern across the network area.

- Assign unique IDs to each node for identification.
- 2. **Parameter Initialization:**
 - Set the initial cluster head probability C_{prob} for all nodes.
 - Define the maximum energy capacity E_{max} of each node.
 - Initialize the residual energy $E_{residual}$ of each node to E_{max} .
- 3. **Mobility Factor Calculation:**
 - Each node calculates its mobility factor f_{mob} using the formula:
- 1.
$$f_{mob} = \frac{1}{1 + velocity}$$
 - Velocity is estimated using GPS or neighbour-based methods.
- 4. **Broadcast Initial Information:**
 - Nodes broadcast their initial H_{prob} , residual energy, and mobility factor to their neighbours.

4.1.2. CH Selection Phase

In this phase, nodes determine whether they will act as cluster heads (CHs) for the current round. The selection is based on the modified CH_{prob} formula.

Steps:

1. **Calculate CH_{prob} :**
 - Each node calculates its CH_{prob} using the formula:
$$CH_{prob} = C_{prob} \times \left(\frac{E_{residual}}{E_{max}} \right) \times f_{mob}$$
2. **Compare with Random Number:**
 - Each node generates a random number between 0 and 1.
 - If $CH_{prob} >$ random number, the node declares itself as a **tentative CH**.
3. **Broadcast CH Advertisement:**
 - Tentative CHs broadcast CH advertisements to their neighbours, containing their ID, residual energy, and mobility factor.
4. **Final CH Selection:**
 - If multiple tentative CHs are within communication range, the node with the highest residual energy and lowest mobility is selected as the final CH.

4.1.3. Cluster Formation Phase

In this phase, non-CH nodes join clusters based on the CH advertisements received during the Cluster Head Selection Phase.

Steps:

1. **Receive CH Advertisements:**
 - Non-CH nodes receive CH advertisements from neighbouring CHs.
2. **Select Nearest CH:**
 - Non-CH nodes select the nearest CH based on received signal strength (RSS) and mobility factor.
 - Nodes prefer CHs with lower mobility to ensure cluster stability.
3. **Send Join Request:**
 - Non-CH nodes send a join request to their selected CH.
4. **TDMA Schedule Creation:**
 - CHs create a Time Division Multiple Access (TDMA) schedule for their cluster members.
 - The schedule assigns specific time slots to each member for data transmission.

4.1.4. Data Transmission Phase

In this phase, cluster members transmit data to their CH, and CHs forward the aggregated data to the base station (BS).

Steps:

1. **Intra-Cluster Communication:**
 - Cluster members transmit data to their CH during their allocated TDMA slots.
 - Data transmission is collision-free due to the TDMA schedule.
2. **Data Aggregation:**
 - CHs aggregate the data received from cluster members to reduce redundancy and save energy.
3. **Inter-Cluster Communication:**

- CHs forward the aggregated data to the BS using single-hop or multi-hop communication.
- If multi-hop communication is used, CHs relay data through intermediate CHs to reach the BS.

4.1.5. Re-Clustering Phase

Re-clustering is performed at the end of each round to adapt to changes in node mobility and energy levels.

Steps:

1. **Re-calculate CH_{prob} :**

- Nodes update their residual energy and mobility factor.
- Re-calculate CH_{prob} using the modified formula:

$$CH_{prob} = C_{prob} \times \left(\frac{E_{residual}}{E_{max}} \right) \times f_{mob}$$

2. **Re-select CHs:**

- Nodes with higher CH_{prob} replace existing CHs.
- Nodes with depleted energy or increased mobility are replaced by new CHs.

3. **Reform Clusters:**

- Non-CH nodes join the new CHs based on updated RSS and mobility factors.
- CHs create new TDMA schedules for their cluster members.

4. **Repeat Process:**

- The network repeats the clustering and data transmission process for the next round.

4.1.6. Performance Analysis

The performance of M-HEED is evaluated based on the following metrics:

Energy Consumption: Total energy consumed during clustering and data transmission.

Network Lifetime: Time until the first node depletes its energy.

Cluster Stability: Frequency of cluster reformation due to CH mobility.

Packet Delivery Ratio: Ratio of successfully delivered packets to the BS.

Table 4 compares M-HEED with traditional HEED in terms of these metrics.

Metric	HEED	M-HEED
Energy Consumption	High	Low
Network Lifetime	Short	Long
Cluster Stability	Low	High
Packet Delivery Ratio	Moderate	High

4.2. Flowchart

Figure 1: Flowchart of M-Heed Protocol presents the flow of operations in the proposed M-HEED protocol, highlighting the algorithmic stages of cluster head selection and subsequent cluster formation.

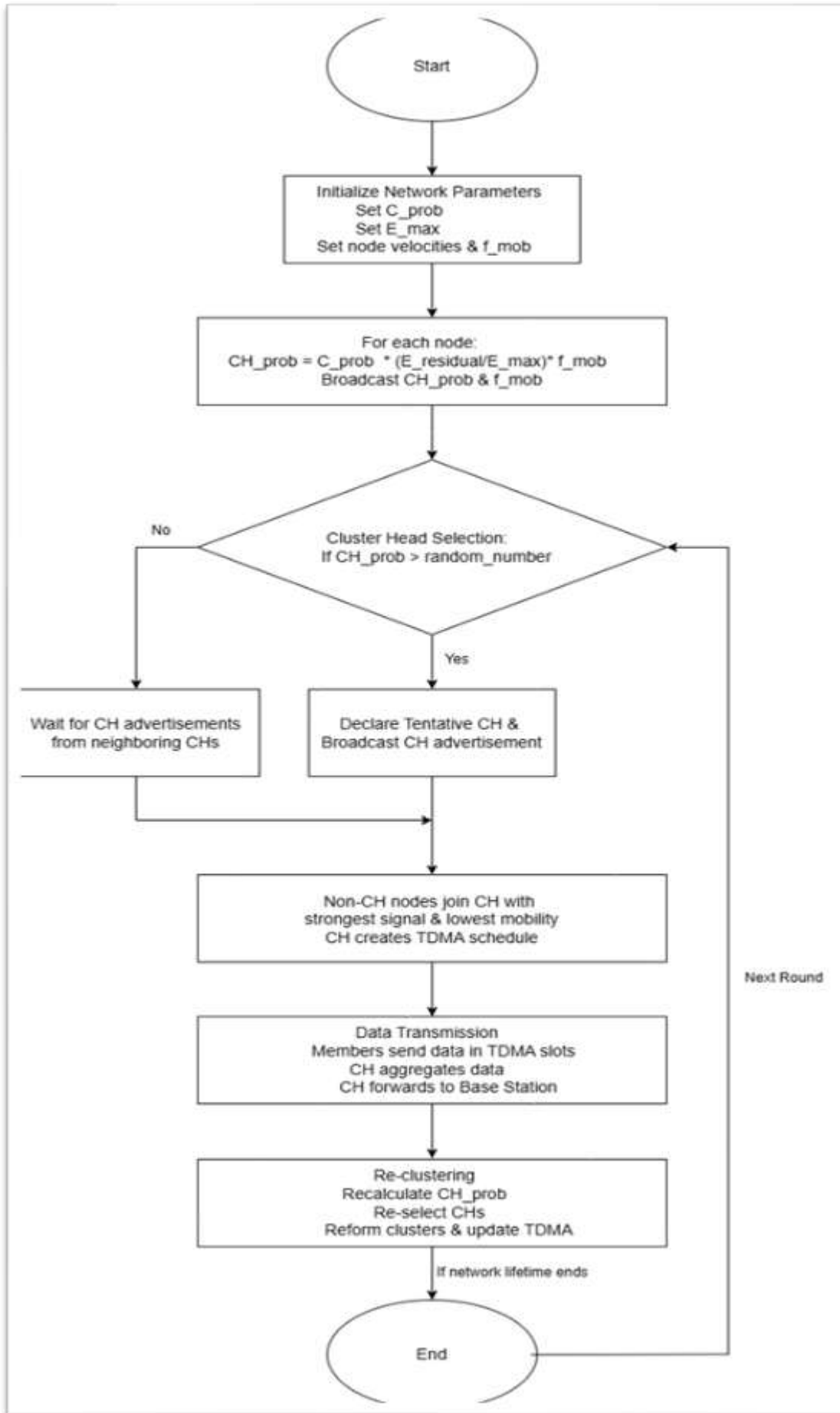


Figure 1: Flowchart of M-Heed Protocol

5. CONCLUSION

This study presents a Mobility-aware Hybrid Energy-Efficient Distributed (M-HEED) protocol for clustering in mobile Wireless Sensor Networks (WSNs). By integrating a mobility factor into the cluster head (CH) selection process alongside residual energy and communication cost, M-HEED addresses the limitations of conventional HEED in dynamic environments. Comparative analysis with existing protocols demonstrates that M-HEED enhances cluster stability, reduces energy consumption, and improves packet delivery performance under node mobility. The flowchart and algorithmic framework further clarify its operational workflow, emphasizing the efficiency of mobility-aware CH selection. Overall, M-HEED offers a robust and scalable solution for energy-efficient and reliable data transmission in mobile WSN scenarios, making it a promising approach for real-world applications where node movement is significant.

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