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RESEARCH ARTICLE

Energy-Efficient Hybrid Protocol for Wireless Sensor Networks

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Abstract – A wireless sensor network (WSN) is a giant web of tiny sensor nodes for specific monitoring and control purposes. It is becoming increasingly common to see WSN-enabled applications in our daily lives. Sensor nodes in most applications rely solely on battery power to function. To monitor fire and animal life, the nodes are placed in remote areas like forests, and the communication in WSN tends to be multi-hop. In such a scenario, if nodes fail due to battery power depletion, recharging or replacing the nodes' batteries becomes difficult or impossible, resulting in network failure. Efficient energy usage is critical for extending the life of the network and lowering the cost of replacement. This multi-hop communication requires an efficient routing mechanism to send the packets from source to destination. Several methods for efficient routing have been proposed in the literature. Among them, the clustering method is shown to be the most energy-efficient. The cluster head (CH) selection process is crucial in cluster-based approaches since the process of CH selection consumes more energy. Low Energy Adaptive Clustering Hierarchical (LEACH) and its most recent versions are widely used in practice. However, in LEACH, the CH nodes are chosen at random without considering the leftover energy. This may result in quick depletion of the energy in the randomly selected CH, resulting in network failure. Energy Efficient Hybrid Clustering (EEHC) is the latest derivative and an improved version of LEACH. EEHC selects the nodes closest to the sink as CH. Due to this type of CH selection, the chances of nodes near the sink failing increase. To solve these difficulties, this article presents an Energy-Efficient Hybrid Protocol (EEHP), a technique for WSN that consumes relatively less energy. This protocol employs a novel CH selection mechanism based on how much energy is left and how far the nodes are from the sink. In each round, the nodes with the highest probability of becoming CH are determined by the combination of distance and residual energy. The outcome of this study is compared with the LEACH and EEHC protocols. The simulation results indicate that the proposed EEHP protocol increases the lifetime of the network by at least 3.8 times when compared to the EEHC protocol and by 6.3 times when compared to the LEACH protocol. Thus, the proposed protocol outperforms LEACH and EEHC in terms of enhanced lifespan by reducing consumed energy and routing overheads.

Index Terms – Energy Consumption, Energy Efficiency, Multi-Hop Routing, Routing Overhead, Wireless Sensor Networks.

1. INTRODUCTION

People across the world now exchange information, monitor, and manage their systems remotely. IoT networks continue to expand in every part of our lives. In addition to healthcare, military, surveillance, home, and environmental monitoring and control systems, there has been an increase in their use [1]. IoT networks rely heavily on wireless sensor nodes, which are critical components of the IoT network. Due to technical breakthroughs in Micro-Electro-Mechanical Systems (MEMS), the size of the sensor has become very small. These miniature sensors, capable of sensing, processing, and wireless communication, have become more affordable and accessible [2]. WSNs are one of the most prevalent types of wireless networks. They are composed of several small sensor nodes that work in concert to perform sensing, computing, and communication. Sensor nodes are responsible for sensing the environment, collecting data on a specific physical event in the environment, processing the data, and transmitting it to the base station (BS) or sink for further processing. Sensor nodes within the range can communicate with one another and perform the system's specified function. In many applications, such as environmental monitoring, it is difficult or impossible for humans to replace or recharge sensor node batteries. A typical wireless sensor node has a battery of less than 0.5Ah of power and a voltage of 1.2V [2]. Battery power is critical to the sensor nodes' operations and lifespan. Sensor nodes in high-traffic regions consume more energy, resulting in a rapid depletion of their batteries and eventual network failure. When designing WSN, energy efficiency is an important performance goal because it extends the network lifespan [3].

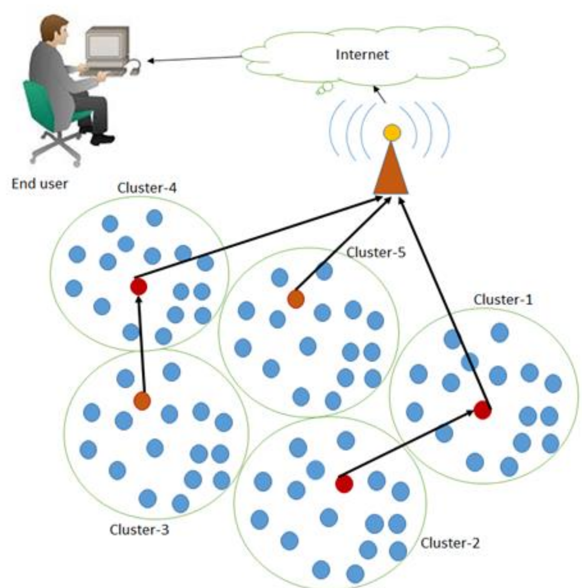

Figure 1 Clustering Structure of WS Nodes

In most real-time applications, a large number of sensors are randomly distributed in the field or the surrounding environment. These nodes are expected to operate for months, if not years, on a relatively tiny battery power supply [4]. When sensor nodes are deployed in the field to exchange data with the sink, both multi-hop (indirect) and direct communication are used. As a result, a robust and energy-efficient routing protocol that allows both direct and indirect communication while also extending the life of the WSN must be used. There is a wide range of routing methods in the literature to choose from in this area. In terms of achieving energy efficiency, clustering-based techniques were determined to be the most effective [5]. To reduce the amount of energy needed to communicate in a network, self-organized sensor nodes establish clusters and use data collection, data aggregation, and data fusion techniques in these clusters. This strategy is employed at the Network Layer (NL) since cluster-based routing approaches have been demonstrated to be more energy efficient.

Sensor nodes self-organize into groups in the clustering technique, depending on the clustering algorithm. Each group of nodes is referred to as a "cluster". A massive WSN will establish a large number of clusters, each with a CH and a few cluster members (CMs), as shown in Figure 1. CMs are sensor nodes associated with a particular cluster. The CMs detect changes in the environment and transmit the detected data to the CH. The CH will be one of the cluster nodes. The CH collects data from the CM, processes it, and forwards it directly or via multiple hops to the sink or BS for further processing. Figure 1 illustrates a cluster-based WSN structure.

The CH node consumes more energy in cluster-based routing because it performs data collection, aggregation, and processing operations. As a result, the CH's energy will be spent more rapidly than that of CMs. As a result, the CH's role must be rotated among the nodes. In this context, selecting a node as a CH is crucial for the network's longevity [2]. Numerous energy-efficiency-enhancing strategies have been developed in this category. The LEACH protocol and its derivatives are frequently used in energy-efficient WSN applications [6]. The goal of this paper is to propose a novel method for selecting CHs based on the most recent derivative of the LEACH-based clustering protocol. This novel CH selection technique for WSNs is called "Energy-Efficient Hybrid Protocol" (EEHP), and it significantly improves energy conservation and network longevity.

To address these shortcomings of the existing LEACH and its latest variant, EEHC, the EEHP proposes a computationally effective and energy-efficient CH selection mechanism. In the EEHP method, the probability of a node becoming a CH is based on a novel combination of the residual energy of the node and the distance of the node from the base station. Only nodes with remaining energy greater than the network's average remaining energy and the probabilistic distance according to equation (7) will be selected as the CH.

In EEHC, the probability of a node becoming CH (P_i) is calculated for all nodes in the network using equation (4). This involves additional computations during CH selection, which consume significant energy. To resolve this issue, only nodes with remaining energy greater than the network's average leftover energy are included in computing the distance probability (P_i) in the EEHP. Energy consumption has been reduced because of this method of CH selection in the proposed EEHP procedure [20].

2. RELATED WORK

In dynamic cluster-based routing protocols, LEACH is the first one that has been widely adopted and proven to be effective in practice. This protocol has inspired the development of a variety of cluster-based energy-efficient

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routing protocols. The protocols listed below are only a few examples of those that have been proposed in the literature: M.J. Handy et al. proposed Deterministic CH selection (DCHS) for energy efficiency [3]. They used a minimum number of CHs in this approach to increase longevity. Another version of the LEACH protocol, known as the A-LEACH protocol [4], was presented using alternative CH selection algorithms dependent on the nodes' remaining energy to reduce energy consumption. Similarly, K-LEACH [5] was developed with the optimum number of clusters and the nodes' current remaining energy to achieve energy efficiency. A. Azim et al. introduced the hybrid-LEACH methodology, which is based on modified energy factors [6]. Y. Lie et al. proposed N-LEACH as a modification to hybrid-LEACH to increase energy efficiency [7]. Similarly, R. Hou et al. introduced a novel CH selection for energy efficiency based on the probability of the node termed T-LEACH [8]. To reduce energy usage, Nguyen et al. presented DBEA-LEACH CH selection approaches based on distance and remaining energy [9]. Rubel et al. introduced EEHC [10], a combined approach to the protocols proposed by Nguyen et al. to improve network lifetime. In this vein, the EEHC protocol is the most recent development of a LEACH-based protocol for WSNs. This paper proposes and compares the proposed protocol to the LEACH and EEHC protocols based on an analysis of a range of protocols in this category. This section explains the CH selection procedures of the existing LEACH and EEHC protocols in detail.

2.1. LEACH

This is the most extensively used routing protocol for WSN applications and is based on dynamic clustering [11]. When compared to previous WSN protocols such as static clustering, this technique uses less energy to build and maintain clusters. The LEACH clustering approach spreads the energy burden evenly throughout the network's sensors via randomization.

The LEACH protocol performs operations in rounds. Each round of LEACH has a setup and a steady-state phase in which the clusters are built and data is transmitted. The steady-state period is longer than the initial setup phase to keep overhead expenses low. Figure 2 depicts the setup and steady-state of a LEACH protocol round. At a steady-state, the CHs collect data from their CMs, aggregate and fuse it, and then send the processed data down to the sink for further processing. Due to the amount of data that must be transferred from CH to a sink, the length of each steady-state phase may vary [12–14].

In the process of building clusters, each node decides whether or not it will be the current round's CH. The number of times a node has previously served as a CH, as well as the network's preferred percentage of CHs, are taken into account when determining which nodes should be CHs. Node N does this by selecting a random value between 0 and 1 and comparing it to the T (n) obtained using equation (1). If the value falls below a T(n) threshold, the node becomes the CH for the current round.

$$T(n) = \begin{cases} \frac{P}{1-P*\left(r \bmod \frac{1}{P}\right)}, & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

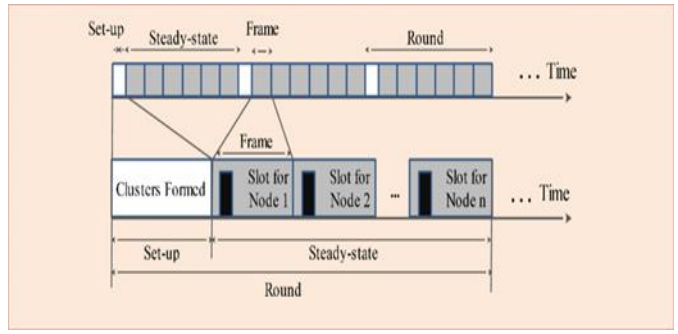

Figure 2 Set-up and Steady Phase of One Round

All nodes that have not been a CH in the last $\frac{1}{P}$ rounds are included in the collection of nodes G, where P specifies the required percentage of CHs. Using this threshold, each node (n) gets a chance to be a CH at some point during the $\frac{1}{P}$ rounds. Each node has a P percent chance of becoming a CH in round r = 0. Round 0 CHs are not allowed to be CHs in the succeeding rounds$\frac{1}{P}$. As a result, CHs will be more likely to form on the remaining nodes. For nodes that have not yet been CHs, T is equal to 1 after $\frac{1}{P} - 1$ round and after $\frac{1}{P}$ rounds for all nodes.

The elected CH nodes broadcast hello packets to their neighboring nodes. Nodes that receive hello packets from the CH send a join-request to the nearest CH and subsequently join the nearest CH using the CDMA technique [15]. The CH node will then provide a TDMA data transfer schedule to all of the CM nodes in the cluster, which will be subsequently used by the CM nodes to send data [16]. This transmission technique is quite energy-efficient. To save energy, each CM node's radio can be switched off until its allocated transmission time arrives. The CH nodes must keep their receivers on to receive all of the data from the CM nodes. After receiving all the data, the CH node processes it and then transfers it to the BS. This is a high-energy transmission due to the distance between the BS and the CHs. Following a predetermined period, the succeeding round begins with each node selecting whether it should be the round's CH and advertising this information, as described in Section 2.1.

Increased network longevity is the fundamental objective of this protocol. The LEACH protocol implementation, on the other hand, does not account for the node's leftover energy or

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the distances between nodes and the sink. If nodes with low residual energy are involved in the transmission, this leads such nodes to rapidly consume the energy. Furthermore, because energy consumption increases with distance, nodes at a greater distance involved in data transmission will quickly exhaust their node power.

2.1.1. LEACH Protocol's Drawbacks

The LEACH methodology described in this article has the following drawbacks:

a) The LEACH methodology suggested in the paper did not address the hierarchical clustering of multiple tiers. Modifying the LEACH to enable hierarchical clustering, in which CH nodes communicate with CHs farther up the tree until they reach the BS level, can significantly reduce energy consumption in large networks.

b) The CH selection threshold described in equation (1) ignores residual energy and distance between nodes and sinks throughout the CH selection process. As a result, nodes with little residual energy might also become CH in each round, rapidly depleting their energy.

c) Additionally, if nodes located at large distances from the sink are chosen as CHs, this results in the rapid depletion of the CH nodes' energy, as energy consumption increases with distance. Eventually, a criterion based on energy and distance can be introduced to select CH nodes to extend the network's lifetime [15].

Researchers proposed improvements to the LEACH methodology to solve these issues. Each methodology enhanced the WSNs' energy efficiency and lifetime through the use of novel CH selection techniques. The latest derivative of LEACH introduced in [14] is a hybrid clustering strategy called EEHC, in which the CH is chosen based on the sensor nodes' maximum remaining energy and their distance from the sink [9, 17, 18].

2.2. Energy-Efficient Hybrid Clustering (EEHC)

This strategy is carried out in three stages:

Stage-1: Selection of the CHs based on the distance of the node from the sink node.

Stage-2: Selection of the CHs based on the residual energy of the nodes.

Stage-3: Hybrid CHs selection by combining the distance and residual energy.

The following section discusses these three stages in detail.

Stage-1: Selection of the CHs based on the distance of the node from the sink node

When the transmission distance between nodes in a WSN increases, the energy consumption also increases proportionately. To minimize energy utilization, the nodes nearest to the sink shall be designated as CH. The likelihood of a node becoming CH [10] will be calculated according to the procedure described in (2).

$$P_i = 1 - \frac{d_i^2}{\sum_{j=1}^{n} d_j^2} \qquad (2)$$

The number of sensors is denoted by n, the distance from sensor node i to the sink is denoted by d_i, and the distance from each node j to the sink is denoted by d_j. P_i is a calculated probability that ranges between 0 and 1.

If the random probability of node i (S_i) is less than the calculated P_i from equation (2), then node i will be chosen as the CH. The random probability (S_i) ranges from 0 to 1. If we consistently choose those nodes as CH because they are closest to the sink, those nodes will eventually die. As a result, another technique has been developed in which the CHs are picked from the nodes with the highest residual energy. The following section discusses the CH selection process using residual energy.

Stage-2: Selection of the CHs based on residual energy of the nodes

Based on residual energy [10], the likelihood of each node becoming CH is indicated in (3).

$$P_i = \frac{E_i}{\sum_{j=1}^{n} E_j} \qquad (3)$$

Here, the remaining energy at node i is represented by E_i, and at node j is represented by E_j. The likelihood of a node i becoming CH is represented by P_i. Each round, based on probability, the nodes with the largest residual energy will be chosen as CHs. If the random probability of node i (S_i) is smaller than the P_i obtained from equation (3), node i will be selected as CH. The CH nodes are randomly selected based on the largest amount of remaining energy after each round.

Stage-3: Hybrid CHs selection by combining the distance and residual energy

Equation (4) calculates the likelihood of a node becoming CH [17] using (2) and (3). The factor α determines the best mix of energy and distance. A node with the highest residual energy near the sink node has a better chance of becoming a CH [10].

$$P_i = \alpha * \left(1 - \frac{d_i^2}{\sum_{j=1}^{n} d_j^2}\right) + (1-\alpha) * \left(\frac{E_i}{\sum_{j=1}^{n} E_j}\right) \qquad (4)$$

It was discovered that $\alpha=0.2$ produces the best results by combining 80 percent of the remaining energy and 20 percent of the distance. This technique, with $\alpha=0.2$, outperformed the LEACH protocol in terms of network lifespan.

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2.2.1. Drawbacks of EEHC Protocol

1. In equation (4), the CH selection probability (P_i) for all the nodes that are still alive is computed. Computational energy can be saved by excluding nodes with low residual energy and long distances between them.

2. EEHC frequently selects the nodes closest to the sink as CH. Because of this, the energy consumption of CH nodes increases. As a result, nodes closer to the sink rapidly deplete their remaining energy, resulting in network collapse.

The shortcomings of the LEACH methodology and the solutions provided in the proposed protocol

a) The LEACH did not address the hierarchical clustering of multiple tiers. Hence, in the proposed approach, hierarchical clustering is enabled by allowing the CH nodes to communicate with CHs farther up the tree until they reach the BS level, and hence energy consumption is significantly reduced.

b) The CH selection threshold described in LEACH equation (1) ignores residual energy and distance between nodes and sinks throughout the CH selection process. As a result, nodes with low residual energy may also become CH, further depleting the node's energy and resulting in rapid network collapse. Additionally, if nodes located at large distances from the sink are chosen as CHs, it results in the rapid depletion of the CH nodes' energy, as energy consumption increases with distance. To resolve these issues, the proposed EEHP protocol employs a CH selection strategy that takes into consideration nodes' residual energy and probabilistic distance in each round, thus extending the network's lifetime [15].

Problems with the EEHC technique and remedies offered in the proposed protocol

a) The EEHC approach frequently selects the nodes closest to the sink nodes as CHs, which increases the energy consumed by the CH nodes. As a result, nodes near the sink quickly deplete their residual energy, resulting in network failure. To address this shortcoming, the EEHP proposes a computationally effective and energy-efficient CH selection mechanism. In the EEHP, the probability of a node becoming a CH is based on a novel combination of the residual energy of the node and the distance of the node from the BS. Only nodes with remaining energy higher than the network's average remaining energy and a probabilistic distance of the node that is higher according to equation (7), will be selected as CH.

b) In EEHC, the probability of a node becoming CH (P_i) is calculated for all nodes in the network using (4). This involves additional computations during CH selection, which consume significant energy. To resolve this issue, only nodes with remaining energy greater than the network's average leftover energy are included in computing the distance probability (P_i) in the EEHP. Energy consumption has been reduced as a result of this method of CH selection in the EEHP procedure [20].

Based on these studies, this paper presents a unique CH selection process and compares it to the LEACH and EEHC protocols. The proposed approach alleviates the energy consumption difficulties of the LEACH and EEHC protocols and extends the network lifetime. The next section goes into detail about the proposed EEHP.

3. PROPOSED PROTOCOL

Transmission power attenuates dramatically with an increasing path length in wireless communication. When the transmission distance between nodes increases in a WSN, energy consumption increases as well [19]. In each round, the distance between the BS and the CHs and the distance between the CMs and the CH of the respective cluster affect the overall amount of energy consumed. Because of this, we must take into account how far the CH is from the BS and how far each CM is from the CH to minimize energy usage. In general, nodes that become CH consume more energy per round than non-CH nodes. To reduce energy consumption at the network layer, this article provides an energy-efficient hybrid protocol (EEHP) based on the widely used LEACH and its most recent variant, the EEHC protocols. This suggested EEHP protocol addresses the shortcomings of the LEACH and EEHC protocols and significantly improves the WSN's energy efficiency and longevity. This section goes into detail about the proposed protocol design.

The proposed routing algorithm is suited to the following specifications of a WSN: Nodes are fixed, i.e., they remain in the same location after being randomly dispersed. Each node is identified by a unique ID and is aware of its present location and remaining energy. Additionally, each node is equipped with sufficient power to interact directly with the sink. Each node starts with the same amount of energy and does not contain rechargeable batteries. Nodes cease to exist when their batteries run out.

The proposed protocol's operations are accomplished in the following steps:

1. CH Selection Phase

Step-1: Calculation of the average remaining energy of all the nodes in the cluster

Step-2: Determine the probabilistic distances between nodes whose remaining energy is greater than the cluster's average remaining energy

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Step-3: Choose a CH based on average residual energy and probabilistic distance

2. Cluster formation and schedule creation phase
3. Data transfer phase

3.1. CH Selection Phase

The EEHP performs operations in rounds. Just like in LEACH, two different phases are used in each round of this protocol. Each round has a setup phase and a steady-state phase, in which the clusters are built and data is transmitted, respectively. To keep overhead costs low, the steady-state phase lasts longer than the initial setup phase. At a steady-state, CHs acquire data from their CMs, aggregate and fuse it, and then transfer the processed data to the sink for further processing. The length of each steady-state phase can vary depending on the amount of data that must be transferred from CH to a sink [12–14].

Step-1: Calculation of the average remaining energy of all the nodes in the cluster

During the cluster construction process, each node selects whether or not it will be the current round's CH. To become CH, nodes must have higher residual energy than the average residual energy of the nodes in that round. The average remaining energy in the network is calculated using equation (5).

$$avgEnergy = \frac{sumEnergy}{Total\ number\ of\ nodes} \quad (5)$$

In this equation, sumEnergy is the sum of the residual energy of the nodes in that round. The average residual energy of the nodes in that round is denoted by avgEnergy. For each round, only nodes with residual energy greater than the avgEnergy are eligible to become CH.

Step-2: Determine the probabilistic distances between nodes whose remaining energy is greater than the cluster's average remaining energy

The probabilistic distance is determined only for the nodes whose residual energy is greater than the avgEnergy. The probability of a node becoming CH in the current round is determined first by calculating the distance between the eligible node and the sink. A sink node and a few sensor nodes spread around it in the WSN, as shown in Figure 3, are used to illustrate this point. Red dots indicate nodes whose remaining energy is less than the avgEnergy.

The nodes denoted by blue circles with numbers within have residual energy greater than the avgEnergy. The red nodes are not eligible to participate in that round's CH selection process. The remaining nodes (i.e., nodes 1 to 5) are eligible to become CH in the current round. The distances between nodes 1, 2, 3, 4, and 5 and the sink are determined using the Euclidean distance formula specified in equation (6). Table 1 summarizes the calculated distances.

From equation (6), we can deduce that the distance between node 1 and sink is 4 (d_1), that between node 2 and sink is 2.24 (d_2), that between node 3 and sink is 2.44 (d_3), that between node 4 and sink is 2.06 (d4), and finally, the distance between node 5 and sink is 3.513 (d_5). As can be seen from Table 1, the distance between node 1 and sink (d_1 = 4) is greater than other distances.

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (6)$$

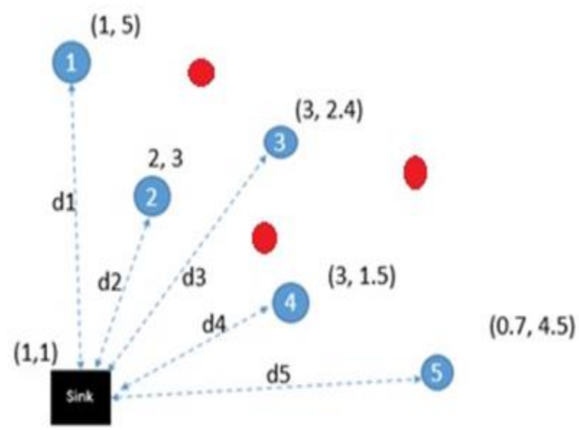

Figure 3 A WSN with Member Nodes Located at Varying Distances from one Another and a Sink Node

Step-3: Choose a CH based on average residual energy and probabilistic distance

After finding the node with the greatest distance “max(d)” from the sink, the probability of each node becoming CH is determined by dividing the distance of each node by the maximum distance “max(d)” and subtracting it from 1. The CH selection process is depicted in Algorithm 1.

This proposed probability scheme uses distance to ensure that nodes further away from the sink have a lower probability than nodes closer to the sink in each round. Table 2 contains the computed probability (P_i) for these five nodes using equation (7).

The probability (P_i) that a node will become CH based on these distances is:

$$P_i = 1 - \frac{d_i}{\max(d_i)} \quad (7)$$

In this case, node 4 has a greater possibility of becoming CH than the other nodes, based on the estimated P_i values. As a result, it qualifies to become CH in the current round.

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Distances from nodes 1, 2, 3, 4, and 5 to the sink - calculated using Euclidean distance formula			
Node id	Distance from node to sink	Distance from node to sink $d_i = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$	Order based on max (d_i)
Node 1	d_1	4	1 (higher)
Node 2	d_2	2.24	4
Node 3	d_3	2.44	3
Node 4	d_4	2.06	5
Node 5	d_5	3.513	2

Table 1 Calculated Distances between Nodes and Sinks using the Euclidean Distance Formula

Node Id	Probability of a node becoming a CH (P_i)
Node 1	0
Node 2	0.44
Node 3	0.39
Node 4	0.485 (higher)
Node 5	0.121

Table 2 Probability of Nodes Becoming a CH

After calculating the likelihood (P_i) of nodes becoming CH using equation (7), as the final step in the CH selection procedure, a random number is generated and compared to P_i. If P_i is greater than the random number for that round, that node becomes a CH. This randomization eliminates the possibility of consecutive rounds selecting the same node as CH. According to [21], the optimal number of clusters (c_{opt}) required for each round is calculated using equation (8).

$$c_{opt} = \sqrt{\frac{m}{2\pi}} * \frac{a}{y_{CHtoSink}} = \sqrt{\frac{m}{2\pi}} * \frac{2}{0.765} \quad (8)$$

In a network, the c_{opt} value is based on the node count, m, but it is independent of the deployment area, a. $y_{CHtoSink}$ denotes the average distance between CHs and the sink.

In the proposed EEHP, the CH selection is performed according to the process given in Algorithm 1. The time taken to select the CH can be calculated from equation (9)

$$T_{\text{CH-selection}} = T_{\text{compute avgEnegy of all nodes}} + T_{\text{compute probabilistic distance}} + T_{\text{compare random probability}} \quad (9)$$

Even if the remaining energy of the nodes near the sink is less than the avgEnergy, the nodes near the sink are still available to perform data forwarding when the nodes away from the sink carry out the CH role. Thus, the network's energy usage is balanced. This extends the stable network lifetime.

3.2. Cluster Formation and Schedule Creation Phase

Using the CSMA approach, all nodes that have elected themselves as the CH for the current round broadcast a hello packet to the rest of the network. This step of configuration requires CM nodes to turn on their receivers to receive hello packets from all CHs. During this phase, nodes that are not CHs have the option of joining any cluster [15]. This decision is made based on the strength of the received hello signal. The received signal strength (RSSI) value is calculated using a two-ray ground reflection model developed by T. S. Rappaport et al. [22], which calculates the received power of a transceiver held at a distance y using equation (10).

$$P_{re}(y) = \frac{P_{tr} * G_{tr} * G_{re} * h_{tr}^2 * h_{re}^2}{y^4} \quad (10)$$

Here, h_{tr} stands for the transmitter antenna height, h_{re} stands for receiver antenna height, and P_{re} stands for the received power. The transmit power is denoted by P_{tr}. G_{tr} denotes the gain of the transmitter antenna. G_{re} specifies the gain of the receiver antenna.

When a node decides which cluster to join, the CH node must be informed. This is accomplished by sending a "join-request" to the closest CH. Each node sends a "join-request" to the CH using the CSMA protocol. Throughout this phase, CH nodes must keep their receivers turned on at all times. After receiving "join-request" messages from non-CH nodes, the CH establishes the cluster and transmits a unique TDMA schedule to each node in the cluster. The CMs may send data to their CH during the reserved slots. The schedule is determined by the node count of the cluster [16]. Thus, the CH serves as the cluster's coordinator for the current round. As a result of these factors, CH nodes consume more energy than non-CH nodes.

3.3. Data transfer phase

Once clusters have been created and the TDMA schedule has been set, data transmission can begin. To conserve energy, each CM node's radio can be turned off until its allotted transmission period is up. During the given transmission

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time, the CM nodes send the data they have to CH. The algorithm for CH broadcasts TDMA schedules to CMs is depicted in Algorithm 1. Adopting this method of transmission saves a lot of energy. To receive all of the data from the CM nodes, the CH nodes must keep their receivers on at all times. After receiving all the data, the CH node processes it and then transfers it to the BS. Due to the wide distance between the BS and the CHs, this is a high-energy transmission.

```
Algorithm: CH election and data transfer operations

/* CH election based on average energy and maximum distance*/

For_Each(N)
    If (N residual energy > avgEnergy)
        Calculate the distance (d_i) between sink
        and N
        Calculate P_i = 1 – d_i/max(d_i)
        Using the range 0 to 1, generate a random
        number R_i
        If (R_i < P_i)
            Select N as CH
        End if
    End if
End for

/* CH broadcast TDMA schedule to CMs*/

For_Each (CH)
    CH advertises the TDMA schedule to all cluster nodes
    CM nodes receive the TDMA schedule
    CMs use the TDMA slot for data transfer to CH
End for

/* Data transmission phase */

For_Each (N)
    The detected data is sent to the CH in its TDMA slot
  For_Each (CH)
    CH gets data from the CM nodes
    Aggregates the data
    Data is transferred to the sink
  End_for
End_for
```

Notation: Number of nodes - N; cluster head – CH

Algorithm 1 CH Election and Data Transfer Operations

At the end of each round, the nodes are reset, and the entire network formation mechanism is resumed after a predefined period. Each round, the process is repeated with new clusters and CHs. The remaining energy and the probable distance between the nodes determine which nodes are picked as CHs in each round. This technique maintains a balance between the energy consumption of all network nodes [23]. The algorithm for data delivery is depicted in Algorithm 1.

4. RESULTS AND DISCUSSIONS

MATLAB simulation software has been used for the simulation and analysis of the protocols since it provides a multi-paradigm computing background. The network scenario used for the simulations consists of 100 nodes randomly deployed in a fixed position. After the deployment, the nodes are stationary. Their unique ID and their position can identify sensor nodes in the network. Each node is designed with a tiny battery. The network is deployed over 100 x 100 square meters. The sink node is located at 1 m x 1 m. The initial energy ($E_{initial}$) is 0.15Joules. Table 3 contains a list of all the simulation parameters utilized in this article.

Parameters	Values
Network Area	100 m * 100 m
Node count (N)	100
Sink Location (X, Y)	1 m * 1 m
Nodes' initial energy ($E_{initial}$)	0.15 J
Transmission energy(E_{Tx})	50 nJ/bit
Receiving energy (E_{Rx})	50 nJ/bit
Data aggregation energy (E_{DA})	5 nJ
Maximum number of rounds (r)	10000
Size of the data packet ($D_{packetLen}$)	400 Bytes
Hello packet length ($H_{packetLen}$)	100 Bytes
Number of packets sent in steady-state (P_{ss})	10
Free space propagation fading energy (ϵ_{fx})	10 pJ/bit/m^2
Multipath propagation fading energy (ϵ_{mp})	0.0013 pJ/bit/m^4
Transmission speed (TX_{speed})	10 kbits
Learning parameter (α)	0.2
Percentage of CHs	0.1
Radio range (RR)	70.7 meters

Table 3 Parameters Utilized in the Simulation

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Sensor nodes' distance from the sink as well as their average remaining energy is used as essential parameters in the selection of CHs in the EEHP approach [24].

4.1. Lifetime Comparison of the Protocols

The following three parameters are used to compare the network lifetimes of the LEACH, EEHC, and EEHP protocols:

- Stable network lifetime (SNL)
- Reliable network lifetime (RNL)
- Total network lifetime (TNL)

4.1.1. Stable Network Lifetime (SNL) Comparison

The number of rounds in which all nodes are alive before the first node dies defines the stable network lifetime (SNL) of a WSN. As long as all sensors are operational, the network remains stable. The network's lifespan is largely determined by the time it takes for the first node to die. As a result, it is critical to determine the round in which the first node died for any protocol-based network. Once the first node dies, the remaining nodes begin to perish one by one. Nodes die gradually until they reach 20%, at which point they die rapidly. The number of rounds in which 80% of the nodes in a WSN remain alive defines the reliable network lifetime (RNL). When 20% of nodes in a network die, the network begins to experience instability, and nodes die rapidly. The round in which the last node in a WSN dies defines the total network lifetime (TNL).

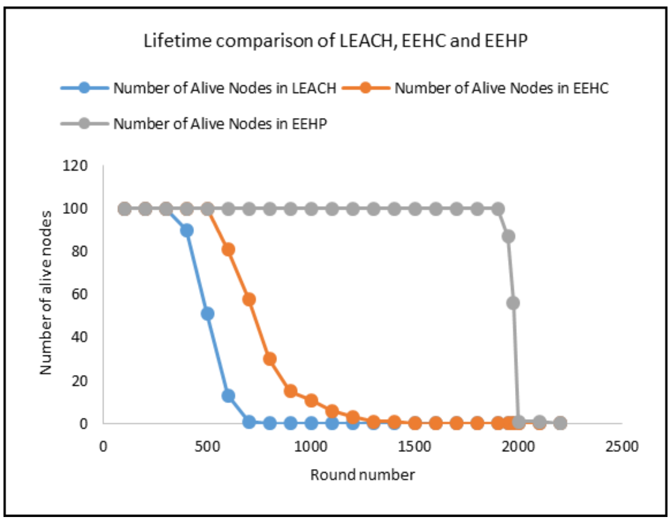

Figure 4 Lifetime Comparison of LEACH, EEHC, and EEHP

Figure 4 illustrates the number of rounds (X-axis) versus the number of alive nodes (Y-axis) for the LEACH, EEHC, and EEHP protocols. As seen in Figure 4, all 100 nodes remain alive for up to 300 rounds of LEACH, 500 rounds of EEHC, and 1900 rounds of EEHP. Thus, when compared to the EEHC protocol, the EEHP protocol increases the SNL by 3.8 times (1900/500) and by 6.3 times (1900/300) when compared to the LEACH protocol [25]. Table 4 indicates the number of rounds for LEACH, EEHC, and EEHP when all nodes are alive as well as when 20% of the nodes are dead and all nodes are dead.

Lifetime in Number of rounds	**Protocols**		
	LEACH	**EEHC**	**EEHP**
SNL – number of rounds when all nodes are alive.	300	500	1900
RNL – number of rounds when 20% of the nodes are dead	420	602	1981
TNL – number of rounds in which all the nodes are dead.	793	1242	2278

Table 4 Lifetime Comparison of LEACH, EEHC, and EEHP in Rounds

4.1.2. Reliable Network Lifetime (RNL) Comparison

As long as 80% of nodes are alive in a WSN, the network remains viable for reliable data transmission [26]. Figure 5 illustrates the network lifetime for LEACH, EEHC, and EEHP when all nodes are alive, 20% of nodes are dead, and all nodes are dead. As seen in the graph, 20% of nodes died in 420 rounds for LEACH, 602 rounds for EEHC, and 1981 rounds for the EEHP protocol. For LEACH, EEHC, and the EEHP protocols, the reliability ratio in terms of network lifespan based on 20% dead nodes is 1: 1.43: 4.7 (420: 602: 1981). When compared to the LEACH and EEHC protocols, the EEHP protocol enhances network reliability.

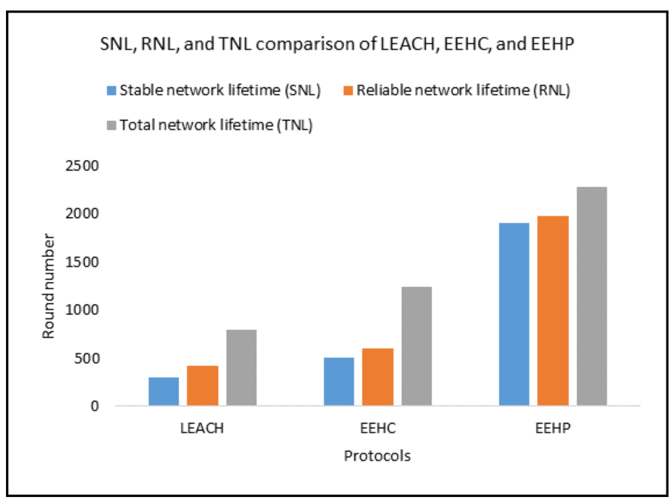

Figure 5 SNL, RNL, and TNL Comparison of LEACH, EEHC, and EEHP

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4.1.3. Total Network Lifetime (TNL) Comparison

The round in which the last node in a WSN dies defines the total network lifetime (TNL). As seen in Figure 5, 100% of nodes died in 793 rounds for LEACH, 1242 rounds for EEHC, and 2278 rounds for the EEHP protocol. For LEACH, EEHC, and the EEHP protocols, the TNL ratio is 1: 1.57: 2.87 (793: 1242: 2278). When compared to the LEACH and EEHC protocols, the EEHP protocol enhances TNL.

4.2. Consumed Energy (CE) Comparison of the Protocols

Protocol	LEACH	EEHC	EEHP
Energy consumption in millijoules	141.45	107.51	45.243
Energy consumption ratio	3.126	2.376	1

Table 5 Energy Consumption of the Network at 500th Round

WSNs must be designed to consume as little energy as possible to maximize the network's longevity. Figure 6 illustrates the energy consumed at the end of each round for the LEACH, EEHC, and EEHP protocols.

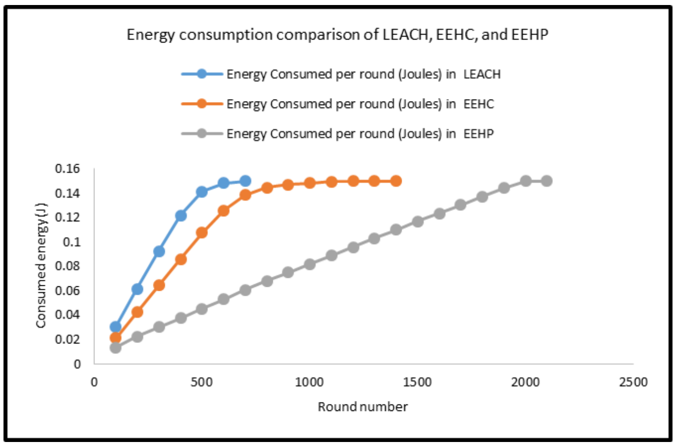

Figure 6 Energy Consumption Comparison of LEACH, EEHC, and EEHP

The X-axis counts the number of rounds, while the Y-axis shows how much energy is expended per round in joules. Initially, each node receives 0.15 joules of starting energy. As seen in the graph, for LEACH, all 100 nodes lost their energy and died after 700 rounds. All nodes died at 1400 rounds in the EEHC protocol and 2100 rounds in the EEHP protocol. The energy consumption of the protocols at the 500th round is depicted in Figure 7.

The energy spent by the network at the end of the 500th round is shown in Table 5. The energy consumption ratios for the LEACH, EEHC, and EEHP protocols are 3.126: 2.376: 1.

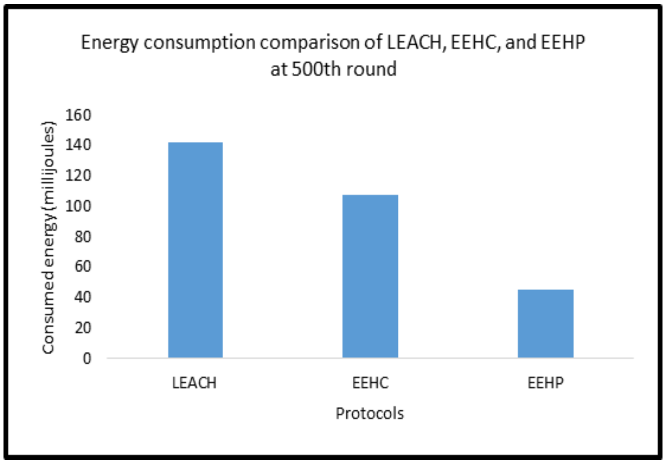

Figure 7 Consumed Energy Comparison of LEACH, EEHC, and EEHP at 500th Round

4.3. Residual Energy Comparison of the Protocols

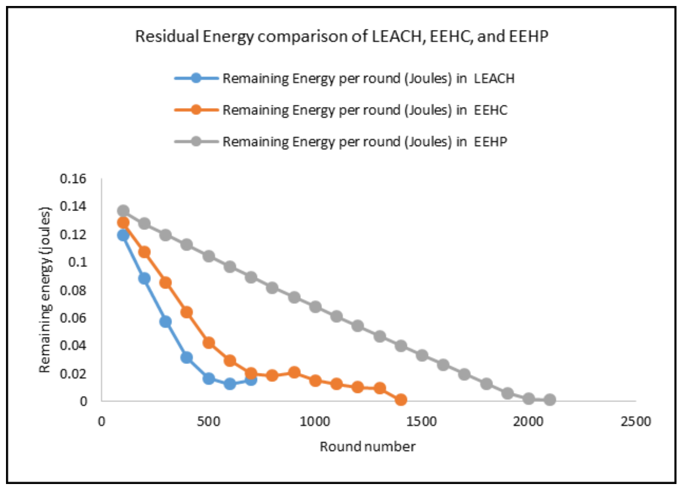

Figure 8 Residual Energy Comparison of LEACH, EEHC, and EEHP

Protocol	LEACH	EEHC	EEHP
Residual energy of the network in millijoules	16.772	42.487	104.76
Residual energy ratio	1	2.533	6.246

Table 6 Residual Energy Comparison of LEACH, EEHC, and EEHP at 500th Round

Figure 8 illustrates the remaining energy at the end of each round for the LEACH, EEHC, and EEHP protocols, with each node having starting energy of 0.15 joules. As seen in the graph, for LEACH, all 100 nodes lost their energy and died after 700 rounds. All nodes perished at 1400 rounds for the EEHC protocol and 2100 rounds for the EEHP protocol. For the LEACH, EEHC, and EEHP protocols, the network

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lifespan in terms of residual energy is 1: 2.533: 6.246. The residual energy at the 500th round is shown in Table 6. Figure 9 compares the protocols' residual energy consumption after the 500th round.

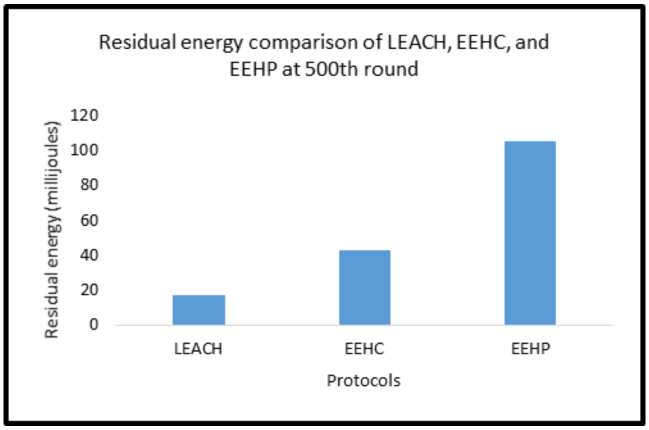

Figure 9 Residual Energy Comparison of LEACH, EEHC, and EEHP at 500th Round

4.4. Routing Overhead Comparison of the Protocols

Figure 10 shows the routing overhead at the end of each round for LEACH, EEHC, and the EEHP protocol.

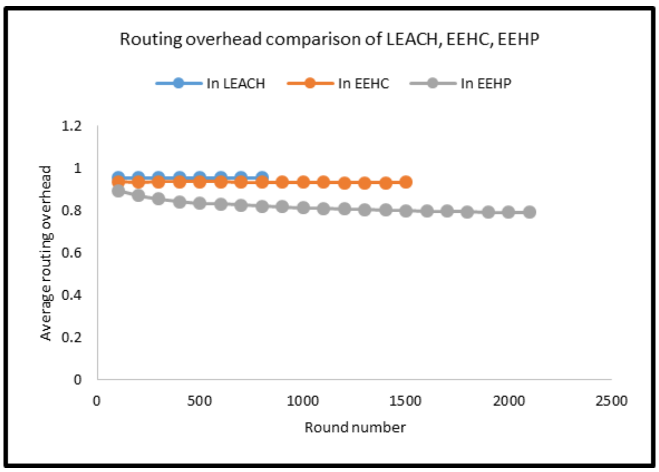

Figure 10 Routing Overhead Comparison of LEACH, EEHC, and EEHP

Routing overhead [27, 28] refers to the volume of routing packets (such as route request, route reply, route error, and hello) transmitted during network operation. Routing overhead packets are control packets that are utilized throughout the network to maintain current routing information about wireless connections between nodes. These are short packets that include solely control information and do not contain any application data. If a routing protocol employed in a network provides additional routing overhead, the network's energy consumption and latency will increase. A good protocol should have fewer network routing overheads. Using the ratio of routing packets to data packets in each round, the routing overhead is determined, as seen in equation (11). Table 7 summarizes the average routing overhead observed in simulations for the three protocols. As illustrated in Figure 11, the EEHP protocol has a lower routing overhead than the LEACH and EEHC protocols.

$$Routing\ overhead = \frac{Routing\ packet\ count}{Data\ packet\ count} \qquad (11)$$

Protocol	LEACH	EEHC	EEHP
Average routing overhead	0.95464	0.93565	0.83508

Table 7 Average Routing Overhead Comparison of LEACH, EEHC, and EEHP

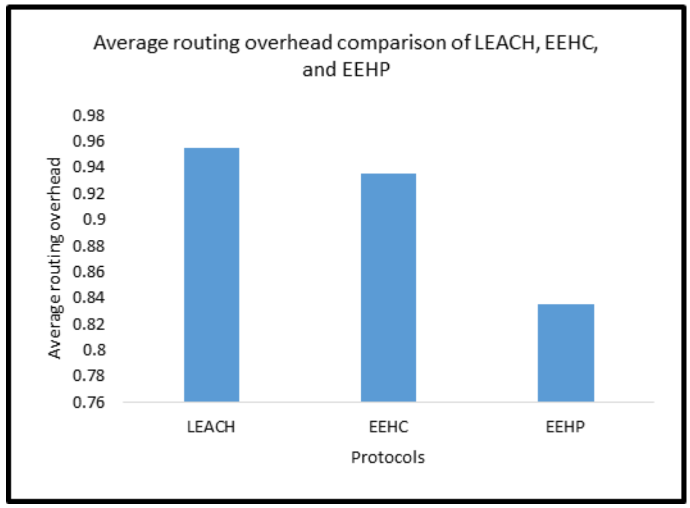

Figure 11 Average Routing Overhead Comparison of LEACH, EEHC, and EEHP

4.5. Packet Delivery Ratio (PDR) Comparison of the Protocols

It is the ratio of the number of data packets received at the destination to the total number of packets transmitted from the source [15] [16]. The PDR is determined using the following equation (12).

$$PDR = \frac{Number\ of\ data\ packets\ arrived\ at\ Sink}{Number\ of\ data\ packets\ sent\ from\ source\ nodes} \qquad (12)$$

The total number of data packets sent and received for these protocols is presented in Table 8 based on the simulation results obtained for LEACH, EEHC, and EEHP in each round. Figure 12 shows the comparison of sent and received data packets in LEACH, EEHC, and EEHP. The comparison of the PDR [15], [16] of the present LEACH and EEHC protocols with the proposed EEHP is illustrated in Figure 13. The number of packets sent and received in the proposed EEHP protocol is at least three times that of the EEHC

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protocol and four times that of the LEACH protocol, owing to the EEHP's reduced control overhead packets. The proposed EEHP has a PDR of 99.93 percent, which is higher than the existing EEHC's (99.79 percent) and LEACH (95.83 percent). According to the PDR comparison given in Figure 13, the proposed EEHP has a PDR of 0.1433 percent greater than the existing EEHC procedure and 4.1 percent greater than LEACH.

PDR Comparison			
Protocol	Sent Data Packets (SDP)	Received Data Packets (RDP)	Packet Delivery Ratio (%)
LEACH	50385	48284	95.83011
EEHC	69456	69308	99.78692
EEHP	212187	212039	99.93025

Table 8 Sent, Received, and PDR Comparison of LEACH, EEHC, and EEHP

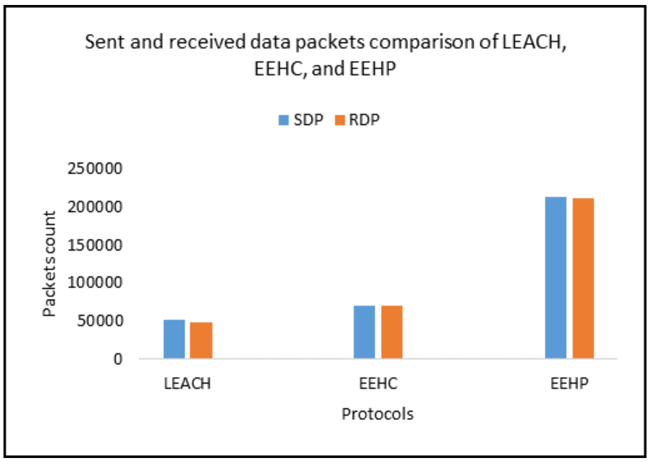

Figure 12 Sent and Received Data Packets Comparison of LEACH, EEHC, and EEHP

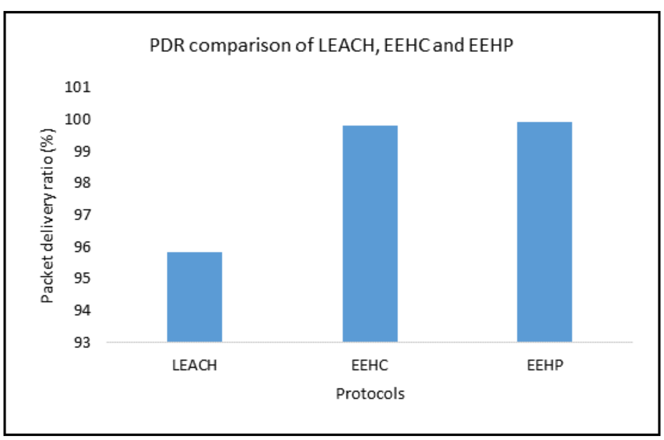

Figure 13 PDR Comparison of LEACH, EEHC, and EEHP

4.6. Overall Comparison of the Protocols

Table 9 compares the overall performance of the LEACH, EEHC, and EEHP protocols. The summary table compares the three protocols' lifetimes, energy consumed, residual energy, and routing overhead.

Sl. No.	**Parameter of comparison**	**Protocols**		
		LEACH	**EEHC**	**EEHP**
1.	SNL in rounds	300	500	1900
2.	RNL in rounds	420	602	1981
3	TNL in rounds	793	1242	2278
3.	CE at 500^{th} round in millijoules	141.45	107.51	45.243
4.	RE at 500^{th} round in millijoules	16.772	42.487	104.76
5.	Average routing overhead (ARO)	0.955067	0.934124	0.818818
6	PDR (%)	95.83011	99.78692	99.93025

Table 9 Performance Comparison of LEACH, EEHC, and EEHP Protocol

In the proposed EEHP approach, hierarchical clustering is enabled by allowing the CH nodes to communicate with CHs farther up the tree until they reach the BS level, and hence energy consumption is significantly reduced. The EEHP proposes a computationally effective and energy-efficient CH selection mechanism. In the EEHP, the probability of a node becoming a CH is based on the novel combination of residual energy of the node and the distance of the node from the BS. Only nodes with remaining energy higher than the network's average remaining energy and the probabilistic distance of the node is higher according to the equation (7), then the node will be selected as CH. Energy consumption has been reduced as a result of this method of CH selection in the EEHP procedure [20]. The performance comparison in Table 9 demonstrates the enhanced lifetime, energy efficiency, and packet delivery because of the proposed EEHP's efficient CH selection approach.

5. CONCLUSION

The EEHP effort is intended to increase the performance of the WSN to extend its lifetime. By utilizing the maximum distance and residual energy of the network's nodes, we devised a CH selection process. When all nodes are alive, this strategy increases the network's lifetime by 3.8 times (1900/500) when compared to the EEHC protocol and by 6.3

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times (1900/300) when compared to the LEACH protocol. Energy consumption reduction is critical in WSN-based applications [29]. The lesser the energy consumed, the more the energy remains. The remaining energy of the EEHP algorithm is 6.246 times greater than that of the LEACH algorithm and 2.533 times greater than that of the EEHC protocol. Additionally, the EEHP algorithm has a lower routing overhead than both the LEACH and EEHC protocols, increasing the network's lifetime. This algorithm makes efficient use of the battery power to prolong the network's lifespan. This minimizes the cost of WSN deployment and redeployment frequently. This is an appropriate solution for cost-effective and energy-efficient WSN applications. The EEHP method is well-suited for networks deployed for remote monitoring applications that include battery-powered wireless sensor nodes [30]. The extended lifetime is critical in applications where battery replacement or recharging is extremely difficult or impossible.

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