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RESEARCH ARTICLE

Improved Energy-Efficient Hybrid Protocol (I-EEHP) to Maximize Energy Conservation in Wireless Sensor Networks

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Abstract – Nodes running on small batteries in a wireless sensor network (WSN) act as sensors, monitors, and controllers for the entire system. In IoT contexts, these sensor nodes are increasingly common for monitoring, measurement, and control. Minimizing the sensor nodes' energy consumption is essential for maximizing energy conservation and extending the nodes' lifespan. Prolonging the lifetime of a WSN helps cut down on the cost needed to replace or redeploy it. According to reviews of the literature, most of the energy is used for routing and data transfer. This article suggests an "Improved Energy-Efficient Hybrid Protocol (I-EEHP) to Maximize Energy Conservation in Wireless Sensor Networks" that combines these two elements to maximize energy efficiency in order to reduce the energy consumption resulting from routing and data transfer. The data transfer method of an "Energy Efficient Hybrid Protocol (EEHP)" is modified to design the I-EEHP. The I-EEHP uses a multihop hierarchical communication method to reduce energy usage. This makes the routing more energy efficient. In addition, this protocol uses a technique based on IEEE 802.15.4 CSMA/CA to exchange data between cluster members, cluster heads, and sink nodes. This aids in node energy conservation, which ultimately increases the lifespan of the network. The efficiency of the proposed I-EEHP was compared with the already existing LEACH, EEHC, and EEHP using the simulation results. The I-EEHP exhibits noteworthy enhancements in network performance with regards to lifetime, energy, overhead, and packet delivery. The I-EEHP is a feasible option for low-cost and low-power WSN applications.

Index Terms – Wireless Sensor Network, Energy Efficiency, Multihop Communication, Energy Consumption, Residual Energy, Routing Overhead, Packet Delivery Ratio.

1. INTRODUCTION

IoT has made it possible for people all over the world to exchange data, monitor their systems, and exercise remote control over them. IoT networks rely heavily on wireless sensors for sensing, processing, and transmission since they are essential to the network [1]. The technological advancements of Micro-Electro-Mechanical Systems (MEMS) have led to the increased availability and affordability of small wireless sensors for various applications [2]. WSN consists of a collection of tiny sensors that collaborate to perform the designated task. Sensor nodes collect information about the surrounding location, process it, and then transfer it to the sink. The nodes must have adequate power to carry out these operations, and at the same time, their lifetimes must be prolonged. The batteries in most sensor nodes have a capacity of less than 0.5 Ah and a voltage of approximately 1.2 volts [2]. Moreover, in many scenarios, it may be hard or impractical to replace or charge the batteries in the nodes. Hence, energy efficiency (EE) is vital in the design of WSNs [3].

Networks of distributed sensors are frequently utilized in real-time monitoring applications [4]. In such circumstances, indirect and direct communications are used to share data between the nodes and the sink. To make the WSN last longer, it needs a routing scheme that uses less energy and allows for both direct and indirect communications. For these purposes, clustering techniques are found to be the most suitable. In cluster-based networks, self-organizing sensors build clusters and use data aggregation and data fusion

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techniques to perform energy-efficient data transfer (DT). Among the many cluster-based protocols existing for WSN applications, the "Low Energy Adaptive Clustering Hierarchy (LEACH)" and its deviations are the most popular. This work proposes a LEACH-based strategy for routing [5]. In contrast to alternative protocols for WNSs, this particular approach exhibits significantly lower energy consumption for the purposes of constructing and maintaining clusters. Figure 1 shows a cluster-based WSN. Each group represented in the dashed circle is a cluster. A cluster will have a cluster head (CH) and a limited percentage of cluster members (CMs). The CMs collect the data from the environment and send it to the CH. The CH processes the collected data and transmits it either directly or via one or more CHs to the sink [6][7]. Protocols based on LEACH use iterative cycles known as "rounds" to accomplish the tasks. Figure 2 depicts the two phases of a cycle: the "cluster setup phase," in which new clusters are established, and the "steady-state phase," in which data is actually exchanged [8][9].

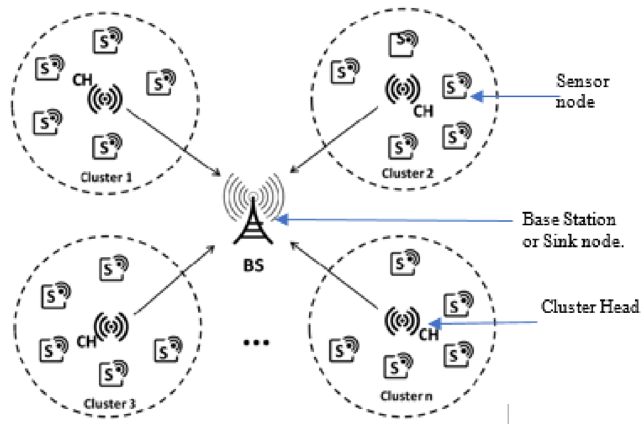

Figure 1 Cluster Structure of a WSN [6]

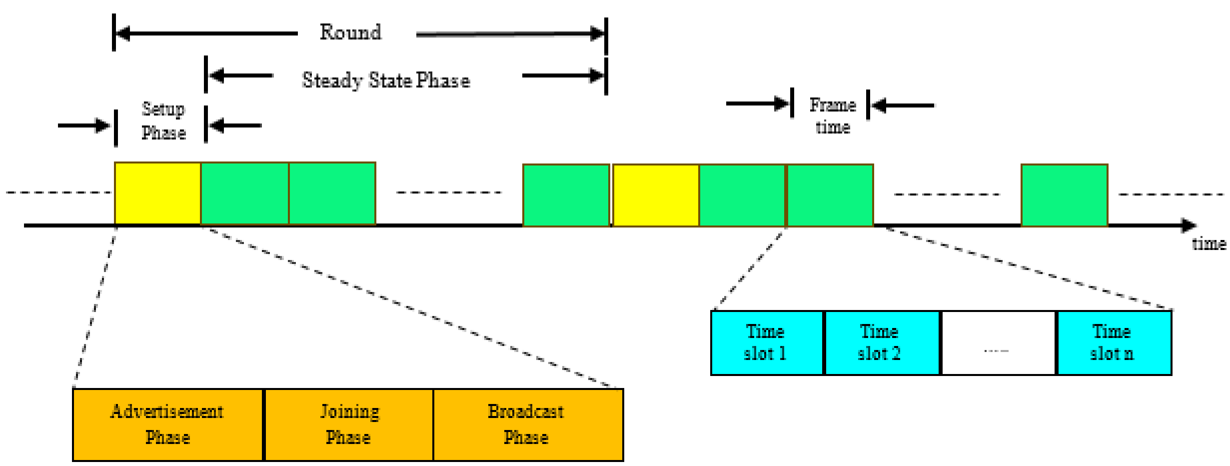

Figure 2 Setup and Steady Phases in a LEACH-based Protocol [10]

The LEACH protocol was designed to make the network last longer. However, while choosing the CH, this protocol ignores the node's residual energy (RE) and how far it is from the sink. With this method, nodes with low RE can also be chosen as CH. If low-RE nodes become CHs, they run out of RE quickly and fail. In addition, as energy consumption (EC) increases with distance, nodes that are far from the sink that sends data will run out of energy quickly. These are the issues that need to be fixed in the LEACH protocol [10].

The EC of the DT operations in LEACH is significantly higher. Therefore, it is essential to use a DT scheme that consumes little energy without limiting the information to be transmitted. EC can be minimized by reducing the node's wake-up time, reducing packet collisions and retransmissions, and controlling overhead. So, it's important to use a method of DT that keeps these things to a minimum [11][12].

1.1. Contribution and Objectives of this Article

The LEACH protocol and its variants described in the literature use the Time Division Multiple Access (TDMA) method to perform DT operations. The use of TDMA for DT in LEACH-based WSNs causes high overhead for synchronization and increased delay in multi-hop communications.

Therefore, this article implements an IEEE 802.15.4-based DT scheme instead of the TDMA approach in the existing EEHP. The EEHP is a recent derivative of the LEACH protocol. The proposed protocol introduces a new approach to the DT method utilized in the existing EEHP, with the aim of optimizing energy conservation. As a result, it has been designated as the "Novel EEHP (I-EEHP) to maximize energy conservation in wireless sensor networks".

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The objective of this article is to improve the EE of the proposed protocol. The proposed protocol enhances the WSN's lifetime, EE, and packet delivery ratio by significantly minimizing collisions and regulating packets without unnecessary overhead [13].

1.2. Problem Statement

To design and implement the LEACH-based protocol for improved EE, this work carried out the following steps:

- Selection of the most appropriate DT method that is suitable for the EEHP, which is the latest variant of the LEACH protocol for the WSN,
- Selection of appropriate parameters for the proposed DT method and
- Implementation of the proposed DT method

The existing protocols in this category are reviewed in Section 2, and the proposed protocol is given in Section 3.

2. RELATED WORKS

This section describes a few popular, currently used LEACH-based protocols. Even though many protocols exist in this category, the ones covered here are just a small sample. In the domain of WSNs, LEACH is the cluster-based routing method that has seen the most widespread adoption. The reason is that this approach consumes relatively less energy to construct and maintain clusters compared to other WSN protocols. This protocol's primary purpose is to prolong the lifespan of the WSN. In contrast, the LEACH implementation ignores the nodes' RE and their distances from the sink during the CH selection. This increases the EC and reduces the lifetime of the network. These concerns about the LEACH protocol must be addressed [6][14]. Following is a review of the literature pertaining to LEACH-based protocols that address EC issues through various methods.

M. J. Handy et al. [15] designed "Deterministic CH selection (DCHS)" for EE. This protocol utilizes a smaller pool of CHs in each round, which helps the network last longer. The primary objective of this article is to mitigate the power consumption of WSNs based on the LEACH protocol. The CH selection was modified for the aforementioned purpose by incorporating a deterministic component. The proposed methodology exhibits a 30% increase in lifespan in comparison to LEACH. The deterministic selection of CHs solely requires local information and does not necessitate global information. The selection of CHs is contingent on the nodes themselves. It is not essential to establish a communication link with either the sink or an arbitrator node.

A-LEACH [16] presented a novel CH selection algorithm that takes into account the node's RE in an effort to lower EC. Due to the power constraints of the nodes, it is imperative that the routing protocol developed for WSNs be both energy efficient and capable of providing low latency. In light of this circumstance, the authors present advanced LEACH (A-LEACH), which is a protocol architecture based on clustering. In this architecture, nodes are capable of making independent decisions without the need for any central intervention. The proposed A-LEACH aims to enhance the CH selection process by identifying the most appropriate node for this role. Additionally, this algorithm facilitates the creation of adaptive clusters and the rotation of CH positions, which serve to equitably distribute the energy load across all nodes. The outcome of the simulation demonstrates that the A-LEACH can enhance the longevity and EE of the WSN.

K-LEACH [17] was designed with the optimal amount of clusters to maximize EE. The utilization of clustering as a fundamental routing strategy is imperative for the reduction of EC. The act of grouping sensors into clusters, whereby sensors solely transfer data to CHs, and subsequently, the CHs relay the consolidated data to the BS, results in energy conservation and, consequently, an extension of the network's operational lifespan. The present study introduces an algorithm for selecting CHs that can adapt to clusters and rotate CH positions. The proposed algorithm aims to achieve an even distribution of energy loads among all nodes. This study introduces an extension to the stochastic CH selection algorithm of LEACH through the modification of the probability distribution governing the selection of CHs. This modification is based on the RE levels of sensor nodes designated for transmission. The results indicate that this approach is capable of effectively implementing load balancing and extending the longevity of the network.

By tweaking the energy parameters, Azim et al. [18] created the hybrid-LEACH approach. The LEACH protocol is limited in its ability to address the challenge of prolonging the lifespan of networks, as a significant amount of energy is lost from sensor nodes that are designated as CHs for communication purposes. In order to conserve the energy of CHs, relay node-based schemes employ autonomous relay nodes to serve as CHs. Notwithstanding, these schemes continue to encounter issues related to the placement of relay nodes, areas with no coverage, and premature failure of CHs. This article implements a novel method to address the aforementioned issues by introducing a robust hybrid LEACH protocol that utilizes relay nodes. The proposed method incorporates a novel approach by regulating the cluster size in a distributed manner, thereby preserving EE. The simulation outcomes demonstrate that the proposed method outperforms the relay node-based method, resulting in an additional 3–30% increase in network lifetime and a notable decrease in packet loss during communication.

Y. Lie et al. [19] proposed N-LEACH, a hybrid form of LEACH, to increase EE. The present study introduces a novel

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approach, denoted N-LEACH, that enhances the performance of LEACH. The selection of nodes as the CH is contingent upon the RE of the nodes within the cluster. This approach can ensure the rationality of the selection of CHs. Furthermore, the resilience of the WSN can be augmented, and the longevity of its lifetime can be extended. The findings of the simulation indicate that the algorithm presented in this study exhibits superior performance compared to LEACH in three key areas: the quantity of viable nodes, energy expenditure, and DT.

R. Hou et al. [20] proposed T-LEACH, which presented an alternative method of choosing the CH for EE by taking into account the node's probability. This study focuses on monitoring applications in specific regions, taking into account the RE and distance constraint conditions between CHs. This study introduces a novel clustering algorithm for WSNs, namely Energy and Distance LEACH (EDL), which aims to address the challenges associated with limited energy and energy equilibrium in WSNs. The results show that the algorithm managed to minimize energy loss that might result from wireless interference due to distance while achieving a uniform distribution of CH within the physical boundaries.

Nguyen et al. [21] introduced DBEA-LEACH, which takes RE and distance into account when choosing CH, to reduce EC. In WSNs, the CH nodes consume more energy than the nodes that do not become CH. Md. Saiful Islam Rubel developed “Energy Efficient Hybrid Clustering (EEHC)” to increase network lifetime (NLT) [22]. This technique proposes a CH selection strategy based on a combination of RE and distance [23][24]. The central concern in designing communication protocols for WSNs is the attainment of EE. The utilization of clustering methodologies has proven to be highly effective in achieving scalability and energy conservation in WSNs. The implementation of hierarchical structures on nodes facilitates the optimization of scarce resources. The present study introduces a hybrid clustering approach that effectively addresses the energy limitations of WSNs. This technology facilitates the DT from sensor nodes to the sink while minimizing EC. Compared to earlier strategies, the EEHC decreased EC. However, in the EEHC protocol, nodes adjacent to the sink node are frequently selected as CHs, which depletes the RE of nodes around the sink. As a result, nodes in close proximity to the sink fail, isolating the sink. Eventually, the network will no longer function. In addition, the EEHC method requires complex computations to determine the CH, which causes significant EC.

Arockiaraj et al. [25] proposed the "Energy Efficient Hybrid Protocol (EEHP)," which uses a CH selection method that includes nodes that have RE greater than the networks' average residual energy (ARE). After calculating the likelihood, each node generates a uniform random number (RN) in the range 0 and 1 and compares it with the calculated probability of the node. A node becomes CH if its RN is less than the computed probability value [26]. The EEHP reduces EC and routing overhead (RO), consequently increasing NLT and packet delivery ratio (PDR) [27][28].

All the above-mentioned techniques reduce EC by employing distinct CH selection strategies. Nevertheless, all protocols adhered to the same TDMA method, in which each CM transmits data to its CH in its TDMA slot. Later, the CH sends the processed information to the sink. Each round ends with all nodes being reset. Each round of cluster formation involves the selection of new CHs.

In the proposed method, a novel DT mechanism is implemented to improve network performance. Using the proposed DT technique, CMs communicate with their respective CHs. The proposed protocol enhances EE by significantly minimizing collisions and reducing excessive overhead packets [13]. The following section describes the proposed protocol.

3. PROPOSED PROTOCOL: IMPROVED ENERGY-EFFICIENT HYBRID PROTOCOL (I-EEHP)

Methods used in the development of the proposed I-EEHP include:

- Selection of the most appropriate DT method
- Parameter selection for the proposed DT method
- Implementation of the proposed DT method

The following section details how to choose the best DT method for the proposed I-EEHP.

3.1. Selection of the Most Appropriate DT Method

Identifying a protocol that reduces EC for communication is crucial since communication processes consume more energy than any other type of operation. The DT capacities of IEEE 802.15.4 were compared to those of low-power application MAC protocols such as S-MAC, B-MAC, X-MAC, and L-MAC [29][30][31]. It is shown in [29] that IEEE 802.15.4 has better EE, latency, and PDR than competing protocols.

In addition, [32] compares three different MAC protocols—the Tunable MAC (TMAC), IEEE 802.15.6, and IEEE 802.15.4—to see which would be the most efficient for use with WSNs. The results show that the IEEE 802.15.4 protocol is superior to the TMAC and the IEEE 802.15.6 protocol in terms of PDR. When compared to IEEE 802.15.6 and IEEE 802.15.4 MAC, TMAC has a better EC. The paper [32] contends that there are substantial tradeoffs to be made when settling on a protocol for WSN. Therefore, this paper proposes a new method of DT by modifying IEEE 802.15.4

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CSMA/CA and incorporating it into the I-EEHP. Parameter selection for I-EEHP is discussed in Section 3.2.

3.2. Parameter Selection for the Proposed DT Method

The IEEE 802.15.4 CSMA/CA uses a duty cycle that is not flexible enough to change as the data to be sent from the node changes. Therefore, this article suggests a novel technique that would allow flexible DT depending on how much data is available at the node. The proposed DT scheme first chooses a DT threshold (dt_{thres}) and the optimal retry (opt_{retry}) parameters. To do so, this work runs simulations and selects the one that maximizes stable network lifetime (SNL), RE, and PDR. Figure 3 shows how the chosen values for dt_{thres} and opt_{retry} are implemented [33].

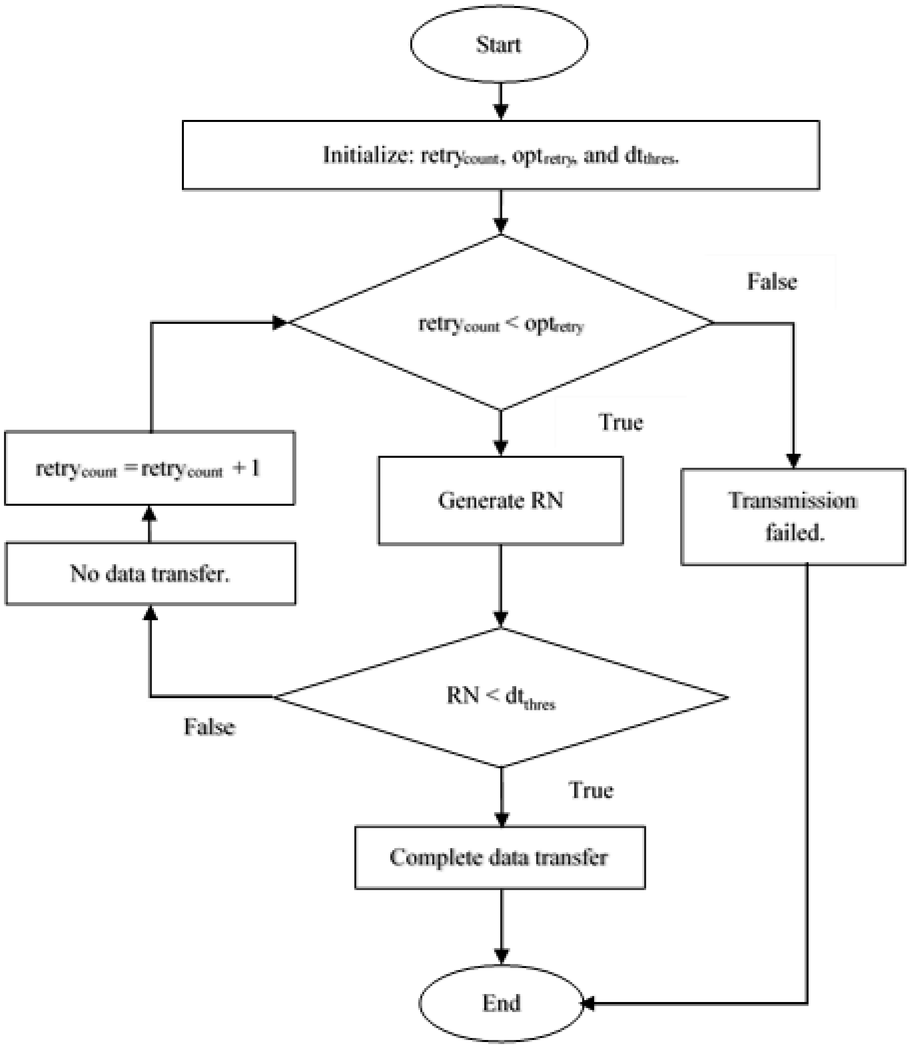

Figure 3 Proposed DT Method for the I-EEHP Protocol

Setting up the appropriate values for the $retry_{count}$, opt_{retry}, and dt_{thres} parameters is the next step in implementing the modified DT method. As long as the $retry_{count}$ is less than the opt_{retry}, before sending data, nodes compare the generated RN with the dt_{thres}. If the RN is less than dt_{thres}, the data will be transferred. If this fails, the nodes will try again each time with the newly generated RN until the node's opt_{retry} value is reached. If RN is higher in all attempts, data transmission fails. This method of comparing RN with dt_{thres} makes it possible to transfer data based on the availability at the node. This reduces the data collision and improves the data delivery ratio [10][34][35].

The selection of a DT threshold (dt_{thres}) value is carried out in this section. The simulation network scenario consists of 100 nodes deployed in a 100m x 100m area in a random manner. The sink is located at 1m x 1m. After the deployment, the nodes are stationary. Sensor nodes in the network can be identified by their unique ID and their position. Each node is embedded with a tiny battery. All the nodes in the network have been set with an initial energy ($E_{initial}$) of 0.5 joules. The

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simulation parameters are listed in Table 1. Simulations were done with the MATLAB tool. MATLAB's ZigBee® protocol, available in the Communications ToolboxTM library, was used to run a simulation of IEEE 802.15.4 CSMA/CA [36]. Packetized wireless modems act as the sensor nodes. Each node is responsible for performing physical layer activities such as packet modulation and demodulation and packet transmission and reception via a common channel [37].

TABLE 1 Simulation Parameters [38]

Sl. No.	Parameters and values used in the simulations	
	Parameter	Values
1	Simulation area (x, y)	100 meters x 100 meters
2	No. of nodes	100, 200, 300, 400, 500
3	Sink location (x, y)	bottom left corner (0, 0)
4	Sensor deployment	Random
5	Mobility	Nodes are not mobile after the deployment
6	Optimal number of CH	10%
7	DT threshold (dt_{thres}) value	0.0 to 1.0
8	Initial energy of nodes	0.5 Joules
9	Transmit energy (E_{TX})	$50 * 10^{-9}$ J
10	Receive energy (E_{RX})	$50 * 10^{-9}$ J
11	Energy utilized in free space propagation by the transmit amplifier	$E_{fs} = 10*10^{-12}$ J
12	Energy utilized in multipath propagation by the transmit amplifier	$E_{mp} = 0.0013*10^{-12}$ J
13	Energy spent for data aggregation	$E_{DA} = 5*10^{-9}$ J
14	Calculate d_o	$d_o = \sqrt{(E_{fs}/E_{mp})}$
15	Radio range	$RR = 0.5*Area.x*\sqrt{2}$ meters

Figure 4 shows the relationship between RE and dt_{thres} graphically. A decrease in RE was seen as dt_{thres} increased from 0 to 1, with a statistically significant drop occurring at dt_{thres} of 0.8 and above. As dt_{thres} rises above 0.8, RE drops off dramatically, so 0.8 has been selected as the dt_{thres}. Setting the dt_{thres} value in the proposed method to 0.80 produces a more consistent RE. The following section discusses the selection of optimal values for the retry.

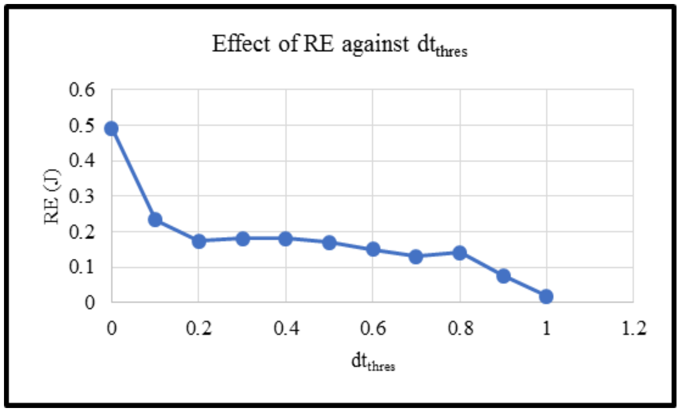

Figure 4 Effect of RE against dt_{thres}

Simulations were run to determine the optimum retry value (opt_{retry}). The average of the results was taken for study after simulating from 100 to 500 nodes for retry values of 2 to 10. The proposed DT mechanism then incorporates the selected retry value. Parameters such as stable network lifetime (SNL), RE, received data packets (RDP), and RO packets are used to determine the optimum value for opt_{retry}. The simulation results for optimum retry (opt_{retry}) selection are given here. The SNL and RDP for retry values from two to ten are shown in Figures 5 and 6. It was found that retry 3, with its long SNL and high RDP, is the optimum value for the proposed method of DT.

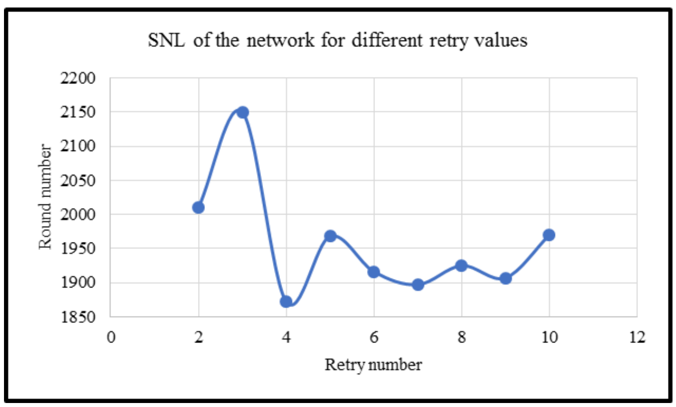

Figure 5 SNL for Different Retry Values

Each node decides for itself whether or not to take part in the current round of DT, as depicted in Figure 3. For that purpose, the DT threshold (dt_{thres} = 0.8) is checked against the generated RN. If the RN is less than the dt_{thres}; the node proceeds with the DT; otherwise, retry until the opt_{retry} reaches 3. DT will fail if RN exceeds the dt_{thres}. By varying the time each node spends in an active state depending on the amount

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of data at the node, this approach paves the way for collision-free dynamic DT. The proposed method improves performance when compared to the candidate protocols [35]. Section 3.3 describes the implementation of the proposed I-EEHP method.

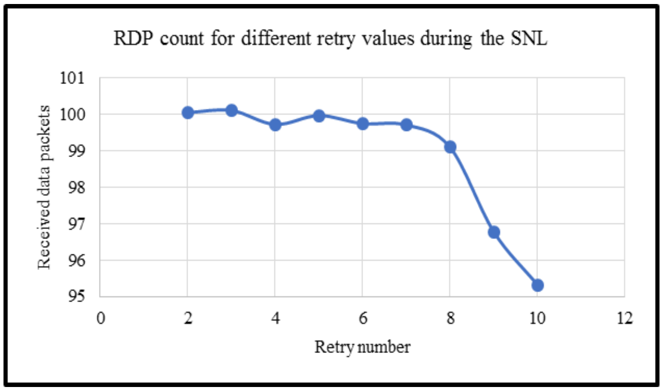

Figure 6 RDP Count for Different Retry Values

3.3. Implementation of the Proposed I-EEHP Protocol

This article proposes a new protocol called the "Improved Energy-Efficient Hybrid Protocol (I-EEHP) to maximize energy conservation in Wireless Sensor Networks" that improves the efficiency of the current EEHP in terms of NLT, EE, and PDR. The proposed novel DT mechanism is implemented in I-EEHP, as depicted in Figure 3. In the steady state, the CMs follow the proposed DT technique to send data to the CH.

The election of CH, construction of clusters, and transfer of data are carried out at the beginning of each round as follows:

A WSN with N sensors in a square area A of dimension $a * a$ with the sink node deployed in the middle. A node's distance from its CH or sink should be less than or equal to y_0. In this scenario, the EC can be calculated per round by the CH using the following equation (1).

$$E_{CH} = \left(\frac{N}{c} - 1\right) * n * E_{elec} + \frac{N}{c} * n * E_{DA} + n * E_{elec} + n * \epsilon_{fs} * y_{CHtoSink}^2 \ (Joules/sec.) \quad (1)$$

The variable c represents the number of clusters, while E_{DA} denotes the per-bit EC by the CH to perform data aggregation, and the variable $y_{CHtoSink}$ represents the probabilistic distance that exists between the CH and the sink. The EC per round by the cluster member node is given in equation (2)

$$E_{CM} = n * E_{elec} + n * \epsilon_{fs} * y_{CMtoCH}^2 \ (Joules/sec.) \quad (2)$$

Here, y_{CMtoCH} is the distance between a CM and its CH. The EC per round in a cluster is calculated using equation (3).

$$E_{cluster} = E_{CH} + \frac{m}{c} E_{CM} \ (Joules/sec.) \quad (3)$$

Here, E_{CH} is the EC per round by CH, and E_{CM} is the EC per round by CM. Using Equations (1), (2), and (3), the total EC in a cluster per round is calculated as given in equation (4).

$$E_{Tot-con} = n * \left(2 * m * E_{elec} + m * E_{DA} + \epsilon_{fs} \left(c * y_{CHtoSink}^2 + m * y_{CMtoCH}^2\right)\right) (Joules/sec.) \quad (4)$$

Each node in the WSN is initialized with energy value E_{init} which is the residual energy E_{res} in the beginning of the network operation. The total EC in the beginning $E_{Tot-con}$ is zero. This is given in equation (5).

$$E_{res} = E_{init} - E_{Tot-con} \ (Joules/\ sec.) \quad (5)$$

At the onset of each round, all the alive nodes transfer the E_{res} to the sink. Using equation (6), the sink calculates the average residual energy E_{AvgRes} and sends it to all the nodes.

$$E_{AvgRes} = \frac{\sum_{i=1}^{N} E_{res(i)}}{N} \ (Joules/sec.) \quad (6)$$

Each node compares its E_{res} with the received E_{AvgRes}. Only the nodes whose E_{res} is higher than the E_{AvgRes} are eligible to become CH in the current round. In the proposed model, instead of geometric distance, the probabilistic distance approach is used to calculate the distance between CMs and CH, and between CH and sink. Each eligible node calculates P_i using equation (7).

$$P_i = 1 - \frac{d_i}{d_j} \ for\ all\ nodes\ i = 1\ to\ N \quad (7)$$

Then these nodes generate a uniform RN between 0 and 1 and check it against the P_i value. From the nodes with P_i greater than the RN, the optimal number of CHs are elected for that round. The optimum clusters for the current round are calculated using equation (8).

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

It is clear from the above equation that the c_{opt} depends on the number of nodes 'N' but not on the area 'A' in which the nodes are deployed. Using equation (9), the optimal number of nodes to become a CH in the current round CH_p can be calculated:

$$CH_p = \frac{c_{opt}}{N} \quad (9)$$

The determination of the optimal clusters, which is analogous to identifying the optimal probability for a node to assume the role of a CH, holds significant importance. The authors demonstrated in [3] that a nonoptimal number of clusters results in an exponential increase in the total EC of the network per round.

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The elected CHs will transmit "hello" packets to the neighboring nodes. The nodes in the surrounding area that have received the "hello" packets will then communicate with the nearest CH to join the cluster. The nearest CH is identified by the "received signal strength indicator (RSSI)" value contained in the hello packet that can be calculated using equation (10). This concludes cluster creation. The CH election and cluster creation processes are illustrated in Figure 7.

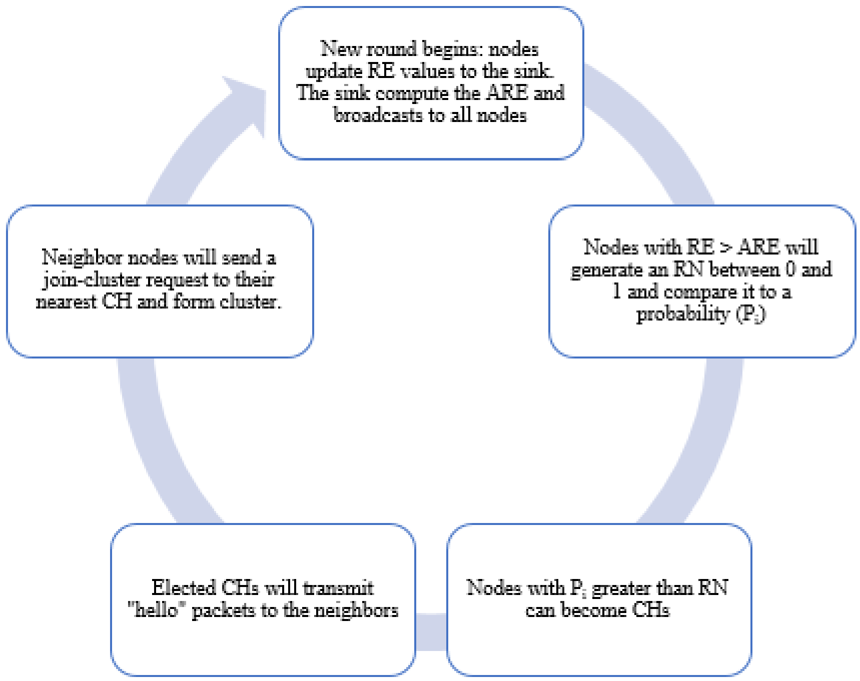

Figure 7 CH Election and Cluster Creation Process

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

Here, P_{re} and P_{tr} represent the power of the receiver and transmitter antennas, respectively. G_{tr} and G_{re} represent the gain of the transmitting and receiving antennas, and h_{tr} and h_{re} represent the height of the transmitting and receiving antennas.

3.4. DT in the Proposed I-EEHP

When non-CH nodes join the CH, they become members of the cluster for that round. The members of the cluster send data to the CH using the proposed DT method. In the proposed technique, whenever a node is ready to send, it can do so by checking its dt_{thres} value against a generated RN to find out how likely it is to reach the channel and send the data successfully. If the RN is less than the dt_{thres}, the DT works. If not, the nodes try again with a different RN, as given in equations (11)–(13).

$$RN \leftarrow uniform[0,1] \tag{11}$$

$$if\,(RN_{(i)} < dt_{thres(i)}), \forall\,(node_{(i)}\ where\ (1\ to\ N) \tag{12}$$

$$then\ CH_{(i)} \leftarrow node(i);\ \ else\ retry\ (1,2,3) \tag{13}$$

If the RN is greater than the dt_{thres}, the data transmission will fail every time. Until a maximum retry value has been reached, this process will be repeated. As a result of the implementation of RN and dt_{thres}, collision-free dynamic DT that is based on the quantity of data present in the node is performed. After getting data from CMs, CH performs aggregation and fusion on the received data to condense the data. After the data has been processed, each CH sends it to the sink so the end user can use it for further decisions. As shown in Equation (7), nodes with a higher RE than ARE have a greater chance of electing themselves as CHs in each round, making the I-EEHP design optimal. This method avoids picking CHs from nodes with REs lower than the ARE value. In addition, the proposed data transmission dynamically modifies the active-sleep period of CM nodes based on the data they have. Therefore, the EC of network nodes is reduced, resulting in a longer lifespan for the network. Consequently, the performance has been enhanced relative to existing methods [10][25][34][35].

4. RESULTS AND DISCUSSION

The results of these simulations were used to draw conclusions about how well the proposed I-EEHP performs in comparison to the existing LEACH, EEHC, and EEHP

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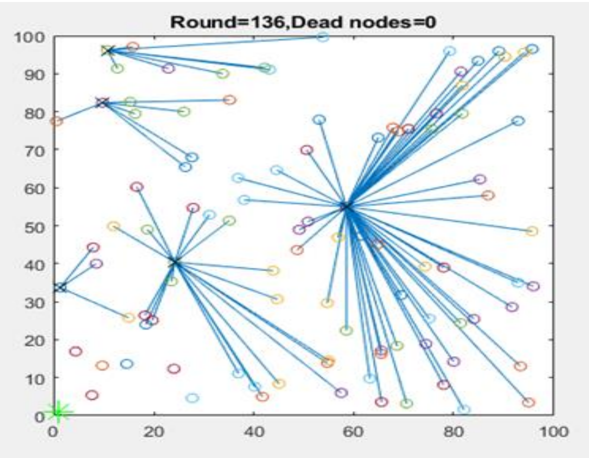
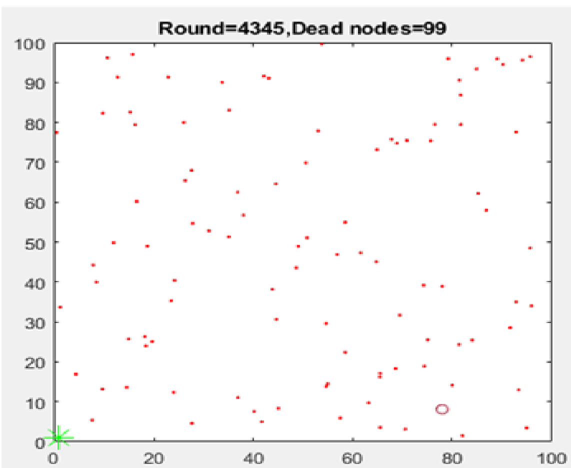
protocols. The placement of the sensor nodes within the simulation environment was randomized, with a sink located at the lower left corner. Once deployed, the nodes remain in place permanently. Averages were taken from simulations conducted with 100, 200, 300, 400, and 500 sensor nodes. The simulation screenshots taken from the 100-node simulation are shown in Figure 8. Figure 8 (a) shows the simulation screenshot at round 136, in which all nodes are alive, and Figure 8 (b) shows the simulation screenshot at round 4345, in which 99 nodes are dead.



(a)



(b)

Figure 8 Sample Simulation Screenshot and Results Extraction

4.1. Lifetime Comparison

The lifespan of a network can be estimated from the number of active nodes in the current round. LEACH, EEHC, EEHP, and I-EEHP are compared in terms of their "stable network lifetime (SNL), reliable network lifetime (RNL), and total network lifetime (TNL)" metrics.

The round at which the first node dies is defined as the SNL of the network. The network is stable as long as all nodes are alive. It is important for any LEACH-based network to know in which round the first node dies. After the first node died, the others followed suit. The round number at which 80% of the nodes are still alive defines the RNL. When 20% of the nodes die, the network becomes unstable, and the remaining nodes die soon after. When the percentage of nodes drops below 20%, the nodes begin to die rapidly. TNL indicates how many rounds it takes for all nodes in a network to die. SNL, RNL, and TNL for all four protocols are shown in Figure 9.

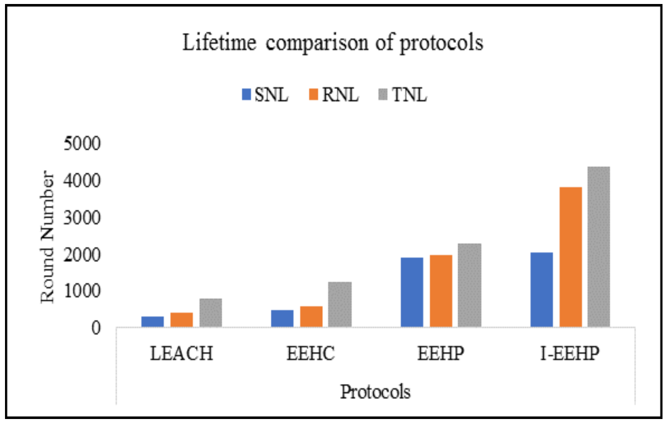


Figure 9 SNL, RNL, and TNL Comparison of the Four Protocols

4.1.1. Stable Network Lifetime (SNL)

Figure 9 shows that all nodes survive up to 300 rounds for LEACH, 500 rounds for EEHC, 1900 rounds for EEHP, and 2038 rounds for I-EEHP. The study reveals that the I-EEHP exhibits a higher SNL in comparison to the EEHP, EEHC, and LEACH techniques. Specifically, the SNL of the I-EEHP is 1.07 times (2038/1900) greater than that of the EEHP, 4.076 times (2038/500) greater than that of the EEHC, and 6.79 times (2038/300) greater than that of the LEACH technique [39].

4.1.2. Reliable Network Lifetime (RNL)

To transmit data reliably, a network needs at least 80% of its nodes to be alive [26]. Figure 9 shows that 80% of nodes survive up to 420 rounds in LEACH, 602 rounds in EEHC, 1981 rounds in EEHP, and 3809 rounds in I-EEHP. The reliability ratio is 1: 1.43: 4.7: 9.07 (420: 602: 1981: 3809) for LEACH, EEHC, EEHP, and I-EEHP. According to a study [39], the RNL of the I-EEHP exhibits a significant increase of 1.92 times (3809/1981), 6.33 times (3809/602), and 9.07 times (3809/420) over the EEHP, EEHC, and LEACH methodologies, respectively. In comparison to LEACH, EEHC, and EEHP, the implementation of I-EEHP enhances the reliability of the network.

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Total Network Lifetime (TNL): The round number at which the last node dies is defined as the TNL. As can be seen in Figure 9, at 793 rounds in LEACH, 1242 rounds in EEHC, 2278 rounds in EEHP, and 4356 rounds in I-EEHP, all nodes had died. The ratio of the TNL for LEACH, EECH, EEHP, and I-EEHP is 1: 1.57: 2.87: 5.49 (793: 1242: 2278: 4356). The I-EEHP increases the TNL by 1.91 times (4356/2278), 3.51 times (4356/1242), and 5.49 times (4356/793) compared to the EEHP, the EEHC, and the LEACH protocols, respectively [34]. Lifetime analysis implies that because of the better SNL, RNL, and TNL, the I-EEHP is preferable to the LEACH, EEHC, and EEHP [39].

4.2. Energy Consumption (EC) Analysis

WSNs should minimize EC to prolong the network's lifetime. Figure 10 shows the amount of energy these four protocols consumed at the end of 500 rounds. The EC ratio for the LEACH, EEHC, EEHP, and I-EEHP is 7.14: 5.43: 2.29: 1. The proposed protocol significantly minimizes EC when compared to existing protocols.

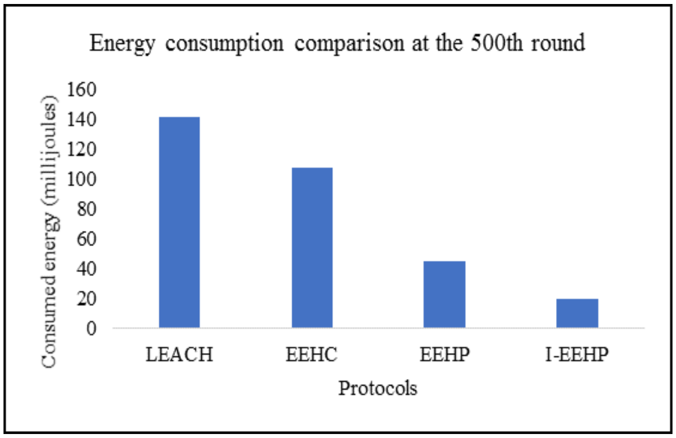

Figure 10 Energy Consumption at the End of the 500th Round for the Four Protocols

4.3. Routing Overhead (RO) Comparison

Control packets are used to manage the current topology of the entire network [40][41]. As the control packets share the medium with data packets, they are called routing overhead packets (RO). These packets are very small and solely contain control information; no actual application data is included. The EC and latency of a network will increase if the routing protocol has more RO packets. For EE, a protocol should use fewer RO packets. RO can be calculated from Equation (14).

$$Routing\ overhead = \frac{No.\ of\ routing\ packets}{No.\ of\ data\ packets} \tag{14}$$

Figure 11 shows the RO that was computed for LEACH, EEHC, EEHP, and I-EEHP. The proposed I-EEHP has a RO that is at least 1.856% lower than the RO of the baseline protocol used in the comparison. Therefore, compared to LEACH, EEHC, and EEHP, I-EEHP has fewer RO packets.

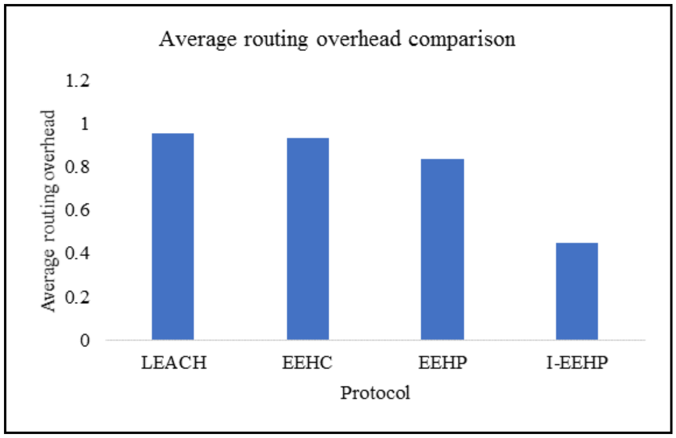

Figure 11 Average Routing Overhead

4.4. Packet Delivery Ratio (PDR) Comparison

The computation of the PDR involves determining the proportion of packets received at the intended destination relative to the aggregate number of packets transmitted by all source nodes [41][42]. Equation (15) serves as the basis for calculating the PDR.

$$\text{PDR} = \frac{\text{Number of RDP at Sink}}{\text{Number of SDP from source nodes}} \tag{15}$$

In Figure 12, the proposed I-EEHP's PDR is shown against those of the currently used protocols. The PDR for the I-EEHP is 99.97%, which is higher than the PDRs for the current EEHP (99.93%), EEHC (99.79%), and LEACH (95.83 percent) protocols. The proposed I-EEHP has a PDR at least 0.04% higher than the candidate protocols.

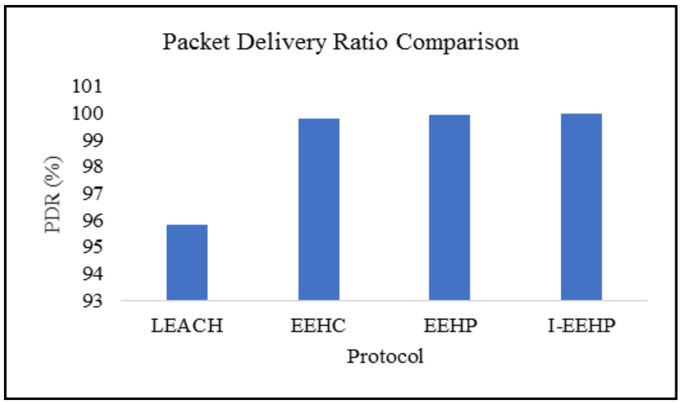

Figure 12 PDR Comparison of the Proposed and Current Protocols

4.5. Packet Drop Ratio Comparison

The packet drop ratio involves calculating the percentage of packets that failed to reach their intended destination in

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comparison to the total number of packets that all source nodes transmitted [41][42]. Equation (16) serves as the basis for calculating the packet drop ratio.

$$\text{Packet Drop Ratio} = 100 - \frac{\text{Number of RDP at Sink}}{\text{Number of SDP from source nodes}} \quad (16)$$

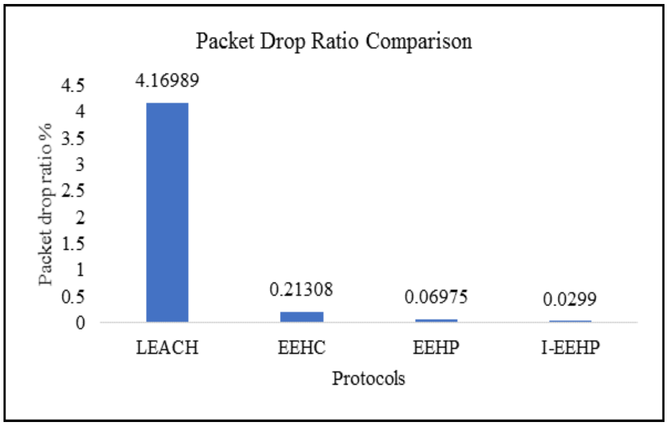

Figure 13 Packet Drop Ratio Comparison of the Proposed and Current Protocols

In Figure 13, the proposed I-EEHP's packet drop ratio is shown against that of the currently used protocols. The packet drop ratio for the I-EEHP is 0.0299%, which is lower than the packet drop ratios of the current EEHP (0.06975%), EEHC (0.21308%), and LEACH (4.16989%) protocols. The proposed I-EEHP has a packet drop ratio at least 0.04% lower than the candidate protocols.

4.6. Overall Performance Comparison

Table 2 shows the NLT, EC, RO, PDR, and Packet Drop Ratio results for the LEACH, EEHC, EEHP, and I-EEHP.

In Table 2, the simulation results are summed up, and from the parameter comparison, the I-EEHP performs better than the candidate protocols. The proposed I-EEHP improves the SNL by at least a factor of 1.07. I-EEHP has a minimum EC that is 2.29 times lower than competing protocols. The I-EEHP also has a RO that is at least 1.86 times lower than that of competing protocols. I-EEHP's PDR is at least 0.04% higher than competing protocols. I-EEHP's packet drop ratio is at least 0.04% lower than competing protocols. This implies that sensor nodes that run on batteries in a WSN, such as those used for remote monitoring, can benefit from the proposed I-EEHP [43]. The proposed DT scheme entails the adaptation of the protocol's duty cycle in response to the quantity of data present at the node. The nodes employ a dt_{thres} and an RN comparison for this purpose. This makes the proposed model perform better than the protocols used in the comparative analysis.

Table 2 Simulation Results Comparison

Performance comparison of the LEACH, EEHC, EEHP, and I-EEHP				
Parameter	Protocols			
	LEACH	EEHC	EEHP	I-EEHP
SNL (rounds)	300	500	1900	2038 (At least 1.07 times more)
RNL (rounds)	420	602	1981	3809 (At least 1.92 times more)
TNL (rounds)	793	1242	2278	4356 (At least 1.91 times more)
EC at 500^{th} round (mJ)	141.45	107.51	45.24	19.8 (At least 2.29 times less)
Average RO (packet)	0.9546	0.9357	0.8351	0.4499 (At least 1.86 times less)
Packet Delivery Ratio (%)	95.83	99.79	99.93	99.97 (At least 0.04% more)
Packet Drop Ratio (%)	4.16989	0.21308	0.06975	0.0299 (At least 0.04% less)

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5. CONCLUSION

The utilization of tiny, battery-powered sensor nodes for a WSN is crucial for the purpose of instantaneous monitoring. However, it is imperative that these nodes minimize their EC in order to extend the network's longevity. The EC of the battery in WSNs is primarily attributed to the routing and DT procedures. This article modified the DT method of the EEHP in order to optimize EC. The current implementation of EEHP involves a TDMA technique for DT. This work proposes an alternative approach to TDMA that involves a modified version of the IEEE 802.15.4 dynamic DT method. The aim of this modification is to decrease the EC and improve the overall performance of the network. The proposed scheme entails the adaptation of the protocol's duty cycle in response to the quantity of data present at the node. The nodes employ a dt_{thres} and an RN comparison for this purpose. The performance of I-EEHP has been observed to be better than that of the EEHP protocol. The I-EEHP results in an increase in the NLT due to the reduction of the EC of the nodes in the network. The results of the PDR and RO have been improved. The I-EEHP protocol, as proposed, exhibits a significant enhancement in terms of SNL, with a minimum improvement factor of 1.07. Additionally, it demonstrates a reduction in EC by at least 2.29 times, RO by at least 1.86 times, an increase in PDR by at least 0.04%, and a decrease in packet drop ratio by at least 0.04% when compared to the EEHP, EEHC, and LEACH protocols. The I-EEHP has been proposed as a viable solution for remote monitoring networks that rely on battery-powered sensor nodes. The extended lifespan that this approach offers becomes especially crucial in situations where battery replacement or recharging are not practical. The I-EEHP has been deemed a viable alternative for implementing low-cost and low-power WSN applications.

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