

Article

Design and Implementation of EOICHD Based Clustered Routing Protocol Variants for Wireless Sensor Networks

Anupkumar Bongale ^{1,*}, Arunkumar Bongale ^{1,†}, Satish Kumar ^{1,†}, Rahul Joshi ^{1,†} and Kishore Bhamidipati ^{2,†}

¹ Symbiosis Institute of Technology, Symbiosis International (Deemed University), Lavale, Pune 412115, Maharashtra, India; arunbongale1980@gmail.com (A.B.); satishkumar.vc@gmail.com (S.K.); rahulj@sitpune.edu.in (R.J.)

² School of Electrical Engineering and Computer Science, Oregon State University, Corvallis, OR 97331, USA; bhamidik@oregonstate.edu

* Correspondence: ambongale@gmail.com

† These authors contributed equally to this work.

Abstract: Efficient energy utilization and network life prolongation are primary objectives to be considered when designing a Wireless Sensor Network. Cluster-based routing protocols are most suitable for achieving such goals. Energy and Optimal Inter Cluster Head Distance (EOICHD) is a cluster-based hierarchical routing protocol inspired by the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol. EOICHD resolves the problems associated with LEACH protocol, such as selecting cluster head nodes in close proximity. By carefully selecting the cluster head nodes based on residual energy and optimal inter-cluster head distance, EOICHD ensures that selected cluster head nodes are separated by a certain optimal distance. This approach ensures uniform distribution of cluster head nodes across the entire network. The study of the EOICHD protocol presented so far is not sufficient. Hence, in this paper, we propose three variants of EOICHD protocol to understand its behavior in a better manner. A comparative analysis of all three EOICHD variants, LEACH and LEACH-central constrained (LEACH-C) protocol, is performed by considering comparative parameters such as alive nodes, cumulative network energy, data packets arrived at the base station, and stability of the network.

Keywords: cluster head node; EOICHD; energy efficiency; cluster distance



Citation: Bongale, A.; Bongale, A.; Kumar, S.; Joshi, R.; Bhamidipati, K. Design and Implementation of EOICHD Based Clustered Routing Protocol Variants for Wireless Sensor Networks. *Appl. Syst. Innov.* **2021**, *4*, 25. <https://doi.org/10.3390/asi4020025>

Academic Editor: Claudio Zunino

Received: 28 December 2021

Accepted: 29 March 2021

Published: 7 April 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

A Wireless Sensor Network (WSN) constitutes several sensor nodes (or simply nodes) forming a network amongst themselves and sensing information from their surrounding environment. The sensed information will be transmitted to a data collection point known as sink node or Base Station (BS) [1]. The sensed information is typically environmental parameters such as temperature, pH values of soil, etc., depending upon the type of the applications [2,3]. The data collected at the BS are interpreted for any abnormal activities, and accordingly, suitable measures will be taken. WSN has various applications such as habitat monitoring, volcanic eruption monitoring, landslide detections, and many more. To quote an example of a specific application, Sunny et al. in [4] have developed a wireless sensor system for monitoring harsh environments such as nuclear storage facilities. Research in WSNs is not just limited to routing protocol design, but other sub-areas such as battery-free communication and underwater sensor communication are also extensively explored [5].

In WSN, every node is equipped with a battery and a husky computational processor. The activities performed by nodes such as data sensing, reception, and transmission consume some energy. The battery power keeps on depleting due to such activities, and ultimately, the battery is exhausted. As WSNs are deployed in mission-critical applications, it is practically impossible to replace the battery of the nodes after the battery power is

completely drained [6]. Hence, the majority of the research work on WSN focuses on efficient utilization. The network's energy consumption could be effectively prolonged through better deployment strategies, data aggregation schemes, designing efficient routing protocols, and many more [7]. Routing protocol design has attracted many researchers of the WSN community, and it has been found that cluster-based routing protocols have proven to provide promising expected results. Cluster-based routing strategies are further mentioned in [1,7,8].

Network lifetime improvement is the primary design goal of WSNs. Clustering and routing have been the two most preferred network lifetime enhancement methods for WSNs [9–12]. Clustering is a process where the most eligible sensor node is designated as cluster head, which will ensure energy-efficient data aggregation and transmission among the member nodes. The challenges lie in selecting such a suitable node as a cluster head, resulting in network life prolongation. The idea behind selecting a cluster head node is to reduce the data transmission distance, as it is directly proportional to the energy consumption pattern of the nodes. Some routing and clustering methods showcase single-hop and multi-hop communication architectures for achieving the energy efficiency of the network. In single-hop communication, cluster heads are expected to send the data directly to the sink node. In contrast, in multi-hop communication, cluster heads can transmit data via other cluster head nodes to the sink node. The choice of communication, i.e., either single-hop or multi-hop, largely depends upon the number of nodes. Ideally, if the number of nodes in the network is large, then multi-hop communication is suitable.

Though the clustering approach has its benefits, ensuring cluster quality is a challenge [13]. Cluster quality can be measured with respect to inter-cluster and intra-cluster distances [14,15]. The general thought is that clusters need to be separated enough; i.e., the inter-cluster distance should be sufficient so that clusters are formed to cover the entire network. If clusters formed are very close to one another, there is a possibility of overlapping cluster zones. Therefore, if there is a possibility of separating clusters in a balanced manner, it can avoid problems of overlapping cluster zones and insufficient network coverage. This problem has motivated the inception of the routing protocol Energy and Optimal Inter Cluster Head Distance (EOICHHD), where a great emphasis is given to separating the selected cluster heads with sufficient distance. EOICHHD not only focuses on cluster quality but also ensures that the selected cluster head has adequate residual energy to perform the tasks of sensing and data transmission. Another motivating factor is to check to what extent the cluster separation impacts the network's energy consumption pattern. Hence, this research article is about EOICHHD design and the comparison of EOICHHD protocol variants with well-known routing protocols.

The further sections of this article are structured as follows. Section 2 describes the recent developments and related work carried out in the field of cluster-based routing protocols of WSNs. Basic assumptions and network communication models used while designing the proposed research work are mentioned in Section 3. The operating process of the EOICHHD routing protocol is briefly described in Section 4. EOICHHD and its proposed variants are explained in Section 5. Detailed results and simulation parameters are shown in Section 6. Finally, the article's conclusion presented in Section 7.

2. Related Literature

Cluster-based routing protocol design has fascinated many researchers, and extensive research articles on hierarchical routing strategies for WSNs are available. Low-Energy Adaptive Clustering Hierarchy (LEACH) [16,17] is a famous and the most cited cluster-based protocol and is addressed as a legacy routing protocol in the field of WSNs. LEACH has given a great way of selecting CHs. However, LEACH suffers from several drawbacks, such as the selection of Cluster Heads (CH) among the set of nodes that may not have sufficient residual energy, the possible selection of CHs in close proximity, or even the possibility that no CH is selected. Such issues of LEACH protocol create instability in

the network, and nodes may die out quickly. In this section, we will present recent advancements made in LEACH and other cluster-based protocols.

Sibahee et al. in [18] proposed an improvement to the LEACH protocol termed as LEACH based on Three layers (LEACH-T). The authors have identified that LEACH indulges in long-distance data transmissions. The distance between CHs and sink could be reduced by introducing three-layer CH selection policies. According to these authors, CHs at the second layer select third-layer CH nodes near the sink, thereby decreasing the long-range data transmissions and ultimately conserving the energy of the network. Energy-influenced probability-based LEACH (EiP-LEACH) [19] is yet another protocol based on LEACH proposed by Bongale et al. In this method, authors have introduced energy-influenced probability-based CH selection scheme for basic LEACH protocol. EiP-LEACH takes into account the energy parameter while selecting CH nodes. The proposed method helps prolong the network lifetime. For the past several years, the LEACH protocol has been improved based on several parameters leading to better network energy utilization. Such variants of LEACH protocols are reviewed in [20].

Similarly to improvements on LEACH protocol, researchers have also contributed to a variety of clustering methods for WSNs. Based on the type of network topology and node deployment strategies, the network's energy consumption pattern varies. Lin et al. in [21] have proposed a Fan-Shaped clustering technique for large scale sensor network. Authors have given better CH selection methods, solutions to hot spot problems, etc., resulting in benefits such as reduced signaling cost, optimized intra-communication cost, etc. Another cluster-based routing protocol called the Distance-and-Energy Aware Routing with Energy Reservation (DEARER) is proposed in [22]. The DEARER protocol selects high-energy nodes as CHs that are close to the sink. DEARER also avoids energy shortage events at CH nodes by selecting the "enabler" nodes as CH nodes. While routing the data from CH nodes to the sink usually involves multi-hop transmissions, an inappropriate relay node selection could lead to inefficient energy consumption in the network. Wang et al. have identified such a problem and proposed a novel energy-aware hierarchical cluster-based (NEAHC) routing protocol in [23]. Their proposed work's main motto is to control the total energy consumption and ensuring optimal energy consumption between nodes. The nature of applications in WSNs also affects the performance and poses new challenges. One such application of WSNs can be found in Underwater Smart things. Rani et al. in [24] have proposed Energy-Efficient Chain-based Routing Protocol for underwater wireless sensor networks (E-CBCCP). Here, to ensure the uniform load on all nodes, authors have suggested a strategy to rotate the role of cluster coordinators, CH nodes, and relay nodes in an energy-efficient manner.

Apart from conventional clustering methods, a few authors have preferred to use fuzzy-based procedures for selecting CH nodes. Nayak and Devulapalli in [25] have proposed a fuzzy logic-based clustering algorithm for WSN to extend the network lifetime. Authors emphasized the need for additional CH nodes called Super Cluster Head (SCH). Here, SCHs nodes will take care of data transmission to mobile BS, while regular CH nodes will collect the data from cluster member nodes. For selecting SCHs, a Mamdani-based fuzzy inference engine is used, and fuzzy rules are formulated based on the parameters such as battery power, node centrality, etc. Similarly, Abidi and Ezzedine [26] have proposed a cluster head selection scheme using fuzzy logic. These authors have used parameters such as remaining energy, neighbors alive, and distance to BS to devise the fuzzy rules for selecting the CH nodes.

Though several articles are focusing on clustering strategies for WSNs, there are no ideal hierarchical routing protocols. Hence, there are a lot of opportunities in developing energy-efficient routing protocols for WSNs. EOICHD is another cluster-based routing protocol proposed in [27]. EOICHD is presented as an improvement over LEACH and LEACH-Centralized (LEACH-C) protocol, and it uses the concept of separating selected CH nodes by an optimal distance. The separation of CHs by a certain distance leads to a uniform distribution of CHs across the network. The hypothesis of the optimal distance

parameter mentioned in [27] needs further investigation. The motivation of the current research article is to understand the behavior of the EOICHD protocol. In this article, we are extending the work presented in [27] by proposing variants of the EOICHD protocol and checking the EOICHD protocol's behavior. EOICHD protocol is further described briefly in Section 4.

3. Basic Assumptions and Network Communication Model

3.1. Basic Assumptions

The work presented in this research article is based on certain assumptions so that the simulation model can be set up suitably. The assumptions and network communication model incorporated in this article are derived from [16,17]. Similar assumptions are made in [28].

- The sensing nodes are distributed in random order within the sensing region.
- The nodes have fixed coordinate positions; i.e., sensing nodes and BS are stationary.
- Each node initially has two Joules of energy. Generally, energy is utilized for sensing, communicating, and data transmission. A node is said to be dead if its energy is completely depleted and is considered non-operable.
- The BS has sufficient energy so that it can never run out of energy.
- Nodes are involved in sensing, transmission, and reception of data with surrounding nodes. A node has a fixed transmission range, beyond which it cannot establish direct communication.

3.2. Network Communication Model

Wireless communication can occur over various transmission mediums. To better understand the proposed routing techniques, the free space model and multipath channel radio propagation models are considered in this article. Using either of the mentioned propagation models depends upon the distance between the receiver and transmitter. If the distance between the receiver and transmitter is greater than or equal to a certain threshold distance (d_{thresh}) multipath propagation model is adopted; otherwise, the free space model is assimilated.

Each node consumes its battery energy for transmission and reception of data. A node can transmit a message of the size of r -bits, and energy consumed for transmitting, (E_{tr}) Joules, is calculated as per the Equation (1). Figure 1 shows the radio model considered in this research article that is the same as the one mentioned in [16]. Figure 1 emphasizes different components where energy is consumed for transmission and reception of data.

$$E_{tr}(r, d) = \begin{cases} r * E_{ele} + r * \epsilon_{fs} * d^2 & \text{if } d < d_{thresh} \\ r * E_{ele} + r * \epsilon_{mp} * d^4 & \text{if } d \geq d_{thresh} \end{cases} \quad (1)$$

Similarly, to receive a message of size r -bits, a node consumes (E_{rc}) Joules of energy and it is calculated as per Equation (2).

$$E_{rc}(r, d) = r * E_{ele} \quad (2)$$

where,

- E_{ele} is energy dissipated due to operation of hardware and selectronic components associated with a node. The typical operations on a circuit board are modulation and demodulation of signals, encoding and decoding, signal filtering, etc.
- $(r * \epsilon_{fs} * d^2)$ and $(r * \epsilon_{mp} * d^4)$ indicate the amplifier energy.

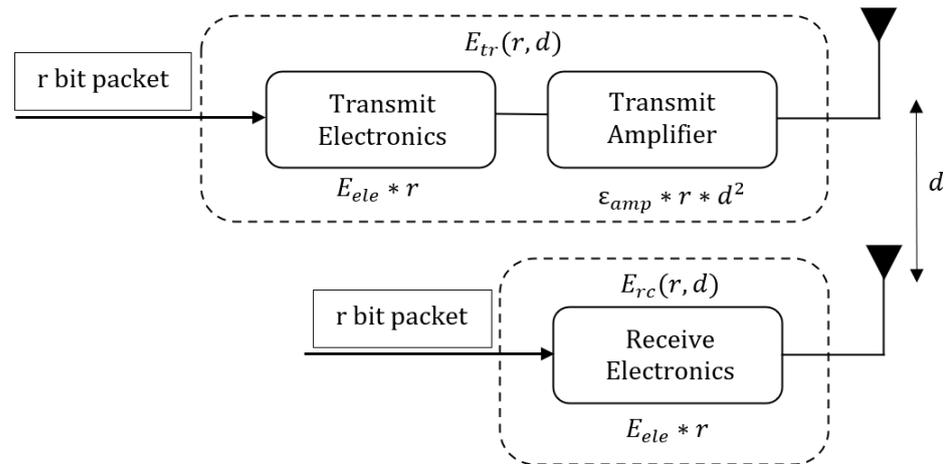


Figure 1. Radio Model. Reprinted with permission from [16]. Copyright 2000 IEEE.

4. Brief Overview of EOICHD Protocol

In this section section, a clustering protocol termed as EOICHD, a cluster-based routing protocol, is proposed to address the drawbacks of LEACH protocol in [27]. This protocol is similar to LEACH protocol, and it operates in rounds. In each round, nodes (also termed as normal nodes) sense information and send the sensed information to respective CHs, and further data are transmitted to BS. Each round comprises a CH setup phase and a data transmission phase. The EOICHD protocol ensures selecting the nodes that have considerable larger residual energy as CH nodes. It also ensures that the selected CHs are separated by certain predetermined distance. CH selection is carried out based on two crucial parameters such as residual energy and inter-cluster head distance.

As per EOICHD, a node is considered a candidate CH if its residual energy is greater than the rest of the nodes' average residual energy. Let there be m nodes in the network, and every node has a transmission range R . Let n be an arbitrary node participating in the CH selection process. It will be selected as CH if its residual energy e_n is greater than average residual energy of the entire network as per the condition (3).

$$e_n \geq \left(\frac{1}{(m - 1)} \times \sum_{k=1}^m e_k \text{ (where, } k \neq n \text{)} \right) \tag{3}$$

To better understand the condition (3), two cases of node distribution are considered as shown in Figures 2 and 3. Let there a be set of nodes $\{n_0, n_1, n_2, n_3, n_4, n_5\}$, and assume residual energy of each node is represented by $\{e_{n_0}, e_{n_1}, e_{n_2}, e_{n_3}, e_{n_4}, e_{n_5}\}$. Table 1 shows the residual energy of each node per case. The average residual energy of the network e_n for case 1 and case 2 is 1.53 and 1.75, respectively. Based on the observations, it is quite obvious that the nodes with a residual energy more than the average residual energy are suitable candidates to be selected as CH. In case 1, $\{n_0, n_2, n_5\}$ have their residual energy greater than the average remaining energy of the network, i.e., 1.53. Hence, $\{n_0, n_2, n_5\}$ are ideal candidate CH nodes with reference to remaining energy. Similarly, in case 2, $\{n_0, n_5\}$ have residual energy greater than the average remaining energy of the network, i.e., 1.75. Hence, $\{n_0, n_5\}$ are ideal candidate CH nodes with reference to remaining energy. The strategy of choosing a node based on the residual energy ensures that the nodes with high residual energy are preferred as CH over low-residual-energy nodes. Based on the example scenarios as described in Figures 2 and 3, the condition mentioned is very much needed while choosing CH.

Table 1. Remaining energy of nodes in Case-1 and Case-2.

| Node ID | Case 1 | | Case 2 | |
|---------|--|----------------|--|----------------|
| | Remaining Energy of Node (e_{n_i}) | Remarks | Remaining Energy of Node (e_{n_i}) | Remarks |
| n_0 | 2.5 | Candidate CH | 4 | Candidate CH |
| n_1 | 1.5 | – | 1.5 | – |
| n_2 | 1.8 | Candidate CH | 1.6 | – |
| n_3 | 1 | – | 1 | – |
| n_4 | 0.5 | – | 0.5 | – |
| n_5 | 1.9 | Candidate CH | 1.9 | Candidate CH |
| – | 1.53 | Average energy | 1.75 | Average energy |

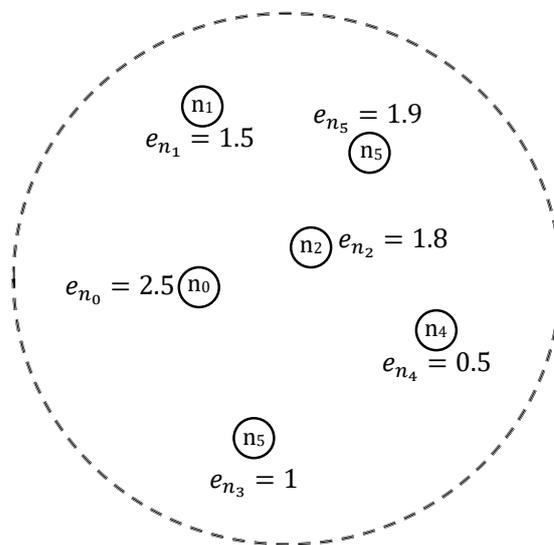


Figure 2. Case1: Nodes $\{n_0, n_2, n_5\}$ are candidate cluster head nodes.

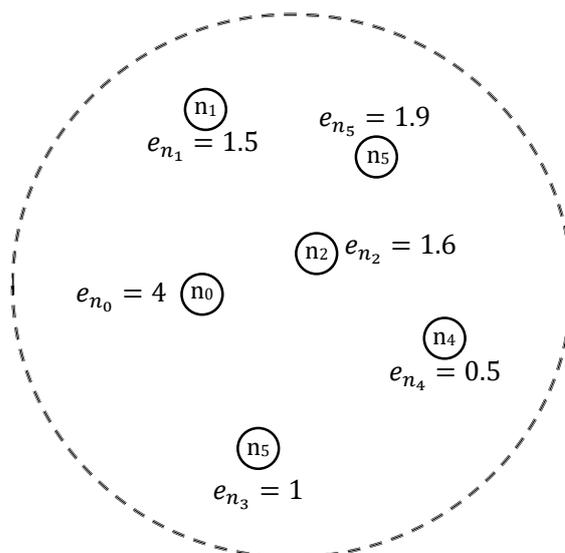


Figure 3. Case2: Nodes $\{n_0, n_5\}$ are candidate cluster head nodes.

Another criterion for selecting the CH nodes is estimation of inter cluster head distance (d_{opt}). For a given wireless sensor network, d_{opt} has to be estimated before network begins

to operate. Figure 4 represents a simple network. Here, Figure 4b is a sample sensing region where sensor nodes are assumed to be deployed. Considered sensing region is segregated into several zones such as $\{z_{1,1}, z_{1,2}, \dots, z_{1,u}\}$ $\{z_{2,1}, z_{2,2}, \dots, z_{2,u}\}$ $\{z_{v,1}, z_{v,2}, \dots, z_{v,u}\}$ depending on the requirement of WSN applications. The dimension of sensing region is $(x \times y)$ m² and dimension of each zone is $(\frac{x}{u} \times \frac{y}{v})$ m². An arbitrary sensing zone Z_{v_0, u_0} is shown in Figure 4a. If length of the diagonal of each zone is considered as optimal inter cluster head distance, then the selected CH node covers sensing area of four neighbouring zones. Once a node residing at particular zone is selected as CH, then no node should be selected as CH in its neighbour zones. In this manner, CHs are separated by an optimal distance and are able to be separated from one another by a distance of d_{opt} meters. Optimal inter cluster head distance (d_{opt}) can be calculated as per Equation (4).

$$d_{opt} = \sqrt{\left(\frac{x}{u}\right)^2 + \left(\frac{y}{v}\right)^2} \tag{4}$$

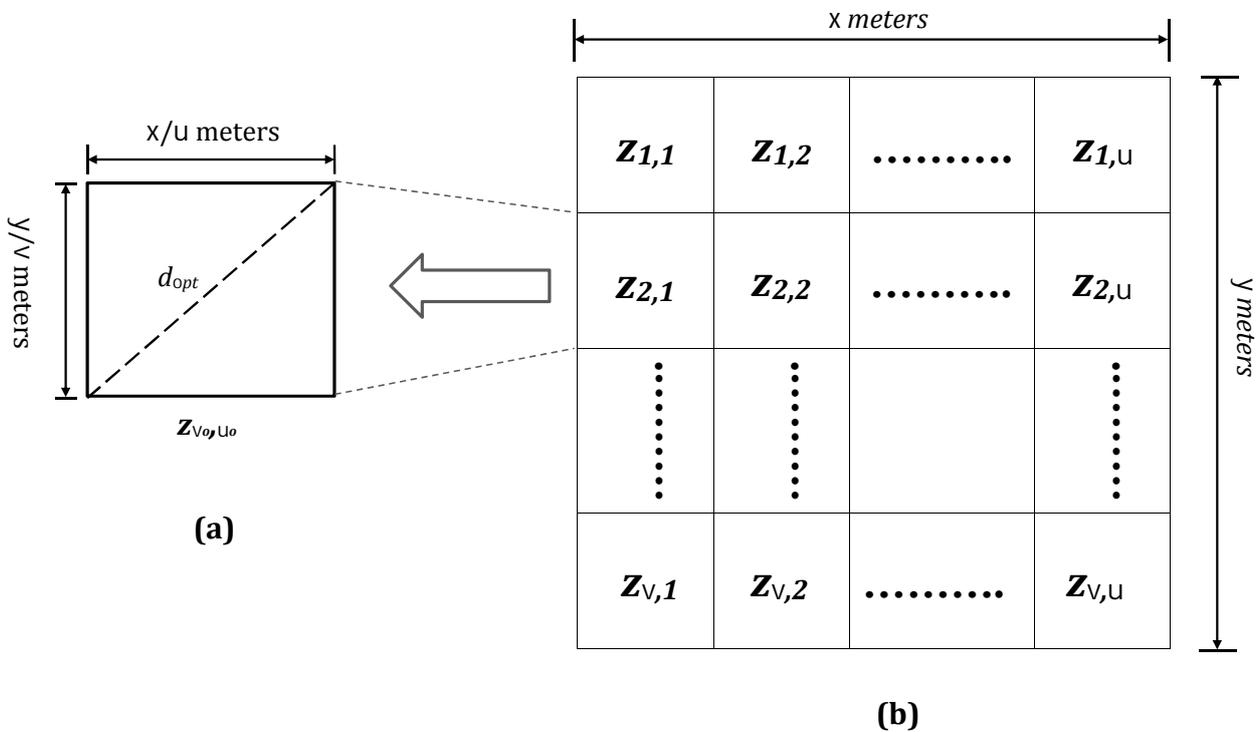


Figure 4. (a) An arbitrary sensing zone (b) Sensing region divided in $v \times u$ zones.

Thus, a candidate CH node n is selected as the final CH for the current round if it satisfies all the criteria mentioned so far. The CH selection process of EOICHD is described in the flowchart given in Figure 5. Once the CHs are selected for the current round, all the normal nodes join to appropriate CH nodes to form clusters. The last phase of the EOICHD protocol is the data transmission phase. The data transmission phase is similar to the procedure of the LEACH protocol. For more details of EOICHD, readers can refer to [27].

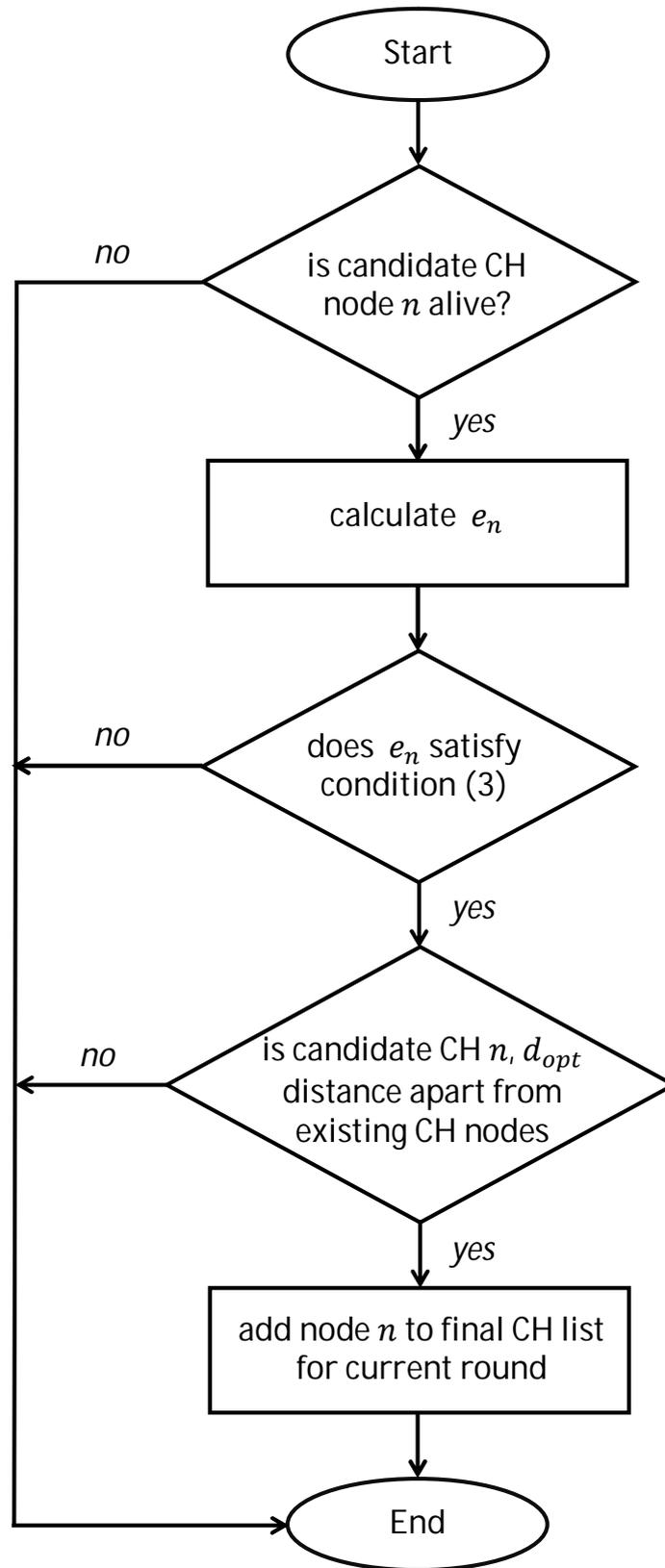


Figure 5. Cluster Head Selection Procedure of Energy and Optimal Inter Cluster Head Distance (EOICHD).

5. Variants of EOICHD Protocol

In [27], authors compared EOICHD protocol with well-known cluster-based routing schemes, namely LEACH and its variant LEACH-C based on network lifetime, energy consumption, etc. The observations implied that the performance of EOICHD is far better compared to LEACH and LEACH-C. It was also understood that every CH node needs to be d_{opt} distance apart from one another so that the network's energy could be prolonged. However, the behavior of EOICHD for different values of d_{opt} is not understood well. To have a better understanding of the EOICHD protocol, in this paper, we extend the work presented in [27] by considering the three variants of EOICHD. In this paper, we have considered a network of randomly dispersed nodes over a network area of dimension $100 \times 100 \text{ m}^2$. The variants of EOICHD are determined by dividing the network into zones of different sizes. We are proposing three variants of EOICHD protocol by dividing the network area into (5×5) , (4×4) , and (3×3) zones. The variations in the number of zones result in distinctions in the value of d_{opt} . The variants of EOICHD and estimations of d_{opt} values of the corresponding EOICHD variant are described further below.

5.1. EOICHD 5×5

The first variant is named "EOICHD 5×5 ". Here, we assume that the network area has dimensions of $100 \times 100 \text{ m}^2$ and is divided into 5×5 zones. Based on the number of zones, the expected distance to be maintained among all the selected cluster heads for the case "EOICHD 5×5 " is calculated as

$$\begin{aligned} d_{opt} &= \sqrt{\left(\frac{100}{5}\right)^2 + \left(\frac{100}{5}\right)^2} \\ &= 28.28 \end{aligned} \quad (5)$$

From the calculations shown above, it can be observed that optimal distance between the cluster head nodes is approximately 28.28 m.

5.2. EOICHD 4×4

The second variant is named "EOICHD 4×4 ". Here, we assume that network area dimensions of $100 \times 100 \text{ m}^2$ and is divided into 4×4 zones. Based on the number of zones, the expected distance to be maintained among all the selected cluster heads for the case "EOICHD 4×4 " is calculated as

$$\begin{aligned} d_{opt} &= \sqrt{\left(\frac{100}{4}\right)^2 + \left(\frac{100}{4}\right)^2} \\ &= 35.35 \end{aligned} \quad (6)$$

From the calculations shown above, it can be observed that optimal distance between the cluster head nodes is approximately 35.35 m.

5.3. EOICHD 3×3

The third variant is named "EOICHD 3×3 ". Here, we assume that network area has dimensions of $100 \times 100 \text{ m}^2$ and is divided into 3×3 zones. Based on the number of zones, the expected distance to be maintained among all the selected cluster heads for the case "EOICHD 3×3 " is calculated as

$$\begin{aligned} d_{opt} &= \sqrt{\left(\frac{100}{3}\right)^2 + \left(\frac{100}{3}\right)^2} \\ &= 47.14 \end{aligned} \quad (7)$$

From the calculations shown above, it can be observed that optimal distance between the cluster head nodes is approximately 47.14 m.

6. Results

Section 5 describes the three variants of the EOICHD protocol. This section compares the EOICHD variants and the legacy routing protocols—LEACH and LEACH-C. Several comparative parameters are used to understand the EOICHD variants' efficiency, and briefly, the comparative parameters are described as follows.

- *Energy consumption of the network*: From this parameter, the entire network's energy depletion can be observed.
- *Number of alive nodes*: The number of operational nodes, i.e., the nodes that are not dead, is measured using the parameter number of alive nodes.
- *Data received by BS*: The data sensed by nodes will be transmitted to BS as packets. BS keeps track of the number of data packets received by all the nodes over a period of time. A larger number of data indicates better performance of the routing protocol.
- *Stability period*: Based on the number of dead nodes, the stability of the network can be verified. In this context, the time instance at which the first node that becomes dead (FND), half of the nodes of the network becoming non-operational (HND), and the last node dead (LND) will help in understanding network lifetime.

All the simulations were conducted using Network Simulator (NS) version 2.34 [29], and simulation parameters are mentioned in Table 2. We considered 100 nodes randomly dispersed over $100 \times 100 \text{ m}^2$ simulation area. Figure 6 shows the location of all nodes. Tiny circles in Figure 6 represent nodes of the network. The simulations were carried out over two scenarios, as mentioned below.

- **Scenario #1**: Given the simulation area $100 \times 100 \text{ m}^2$, the position of the base station is located at (50, 50) of simulation area (the base station is at the center of simulation area).
- **Scenario #2**: Given the simulation area $100 \times 100 \text{ m}^2$, the position of the base station is located at (50, 175) of simulation area (the base station is located out of the simulation area).

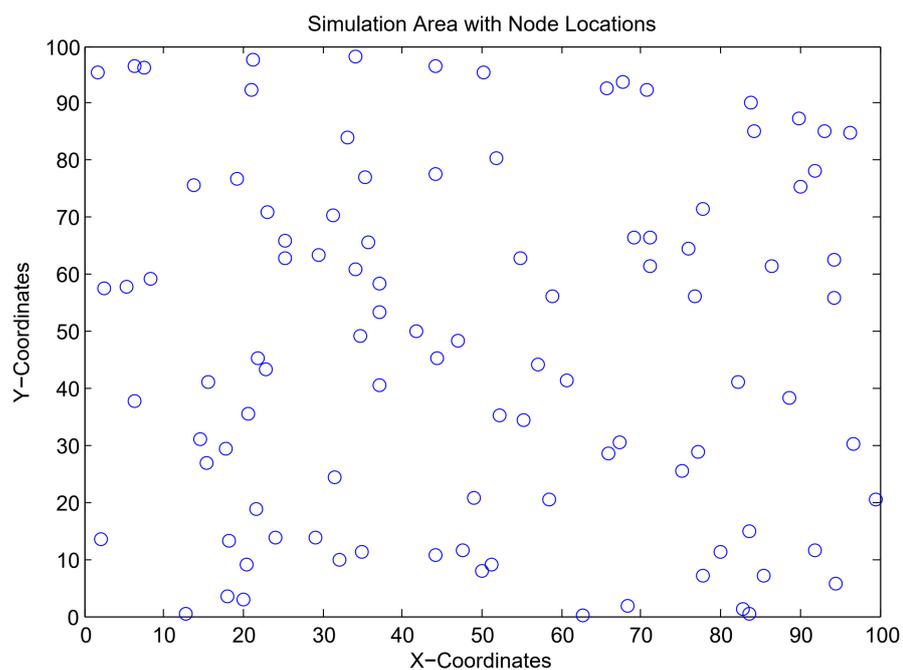


Figure 6. Simulation Area with Node Locations.

Table 2. Network Simulation Setup.

| Criteria | Values |
|---------------------------------|-------------------------------------|
| Number of nodes | 100 |
| Size of the simulation area | $100 \times 100 \text{ m}^2$ |
| Starting Energy of Node | 2 J |
| Total Initial Energy of Network | $2 \times 100 = 200 \text{ J}$ |
| Scenario#1 | Base station is located at (50,50) |
| Scenario#2 | Base station is located at (50,175) |
| E_{elec} | 50 nJ/bit |
| ϵ_{fs} | 10 pJ/bit/m ² |
| ϵ_{mp} | 0.0013 pJ/bit/m ⁴ |

6.1. Number of Alive Nodes

Figures 7 and 8 show the plot of the number of alive nodes for all three variants of EOICHD, LEACH, and LEACH-C for Scenario#1 and Scenario#2, respectively. This parameter is crucial to understand network stability and the pattern of nodes becoming dead. It is observed that EOICHD 3 × 3 is able to extend the network life, and its performance is better than other variants, LEACH and LEACH-C protocols. Energy efficiency and network life prolongation are vital issues. Routing protocol should focus not only on packet transmission but also on an energy-efficient approach to ensure the maximum number of nodes operating at any given point in time. The main reason for the under performance of LEACH and LEACH-C protocols is that nodes very close to one another are selected as CHs, random and improper distribution of CHs, which may not cover some part of the network. Such problems are avoided in the EOICHD protocol and its variants.

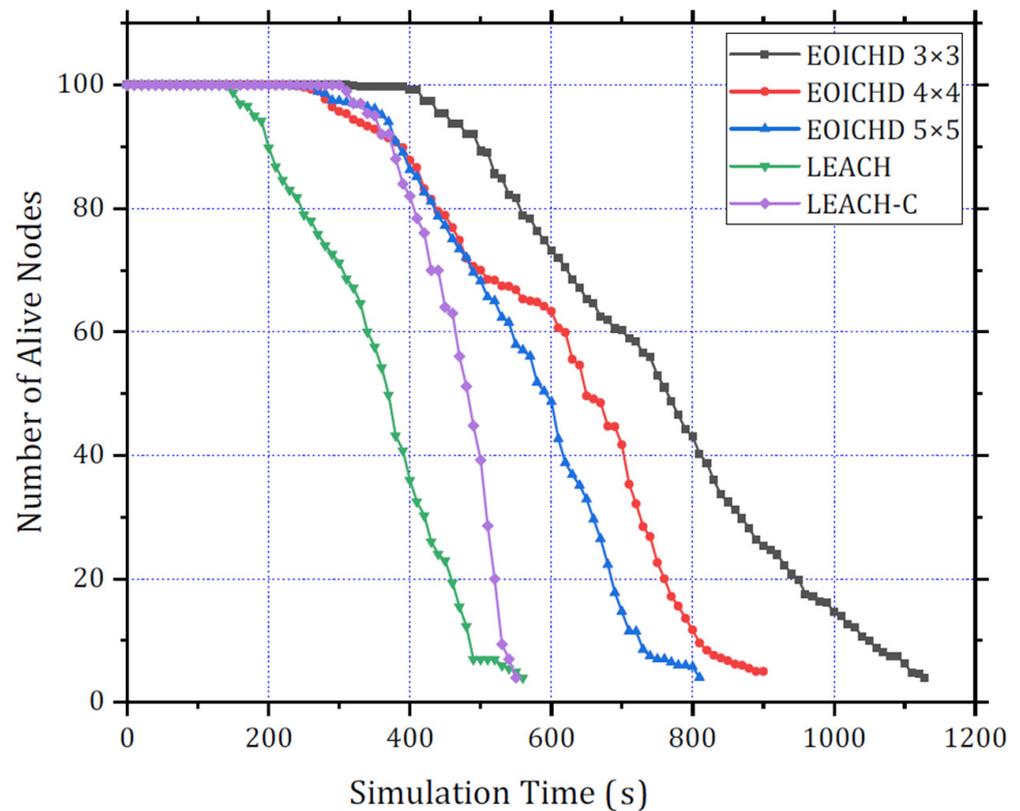


Figure 7. Number of alive nodes over simulation period Scenario #1.

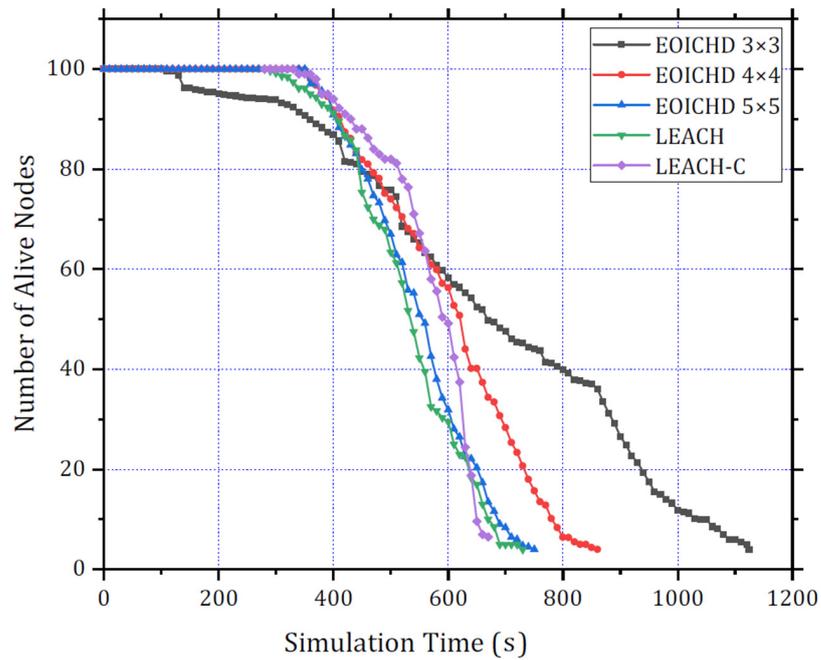


Figure 8. Number of alive nodes over simulation period Scenario #2.

6.2. Average Energy Consumption

Average energy consumption of the network for Scenario #1 and Scenario #2 of all three variants of EOICHD, LEACH, and LEACH-C is shown in Figures 9 and 10, respectively. The figures show the energy consumption pattern of the network over the simulation period. As per the simulation setting, each node is equipped with 2 Joules of energy. As the simulation progresses, the energy of nodes depletes due to sensing, data transmission, communication with other nodes, etc. The plots shown in Figures 9 and 10, show the cumulative energy of the nodes that is getting utilized as the simulation progresses. From Figures 9 and 10, it is observed that EOICHD 3 × 3 is capable of extending the network lifetime up to 1128 s and 1124 s for Scenario #1 and Scenario #2, respectively. It clearly shows that the energy consumption pattern of EOICHD 3 × 3 is more efficient than other variants.

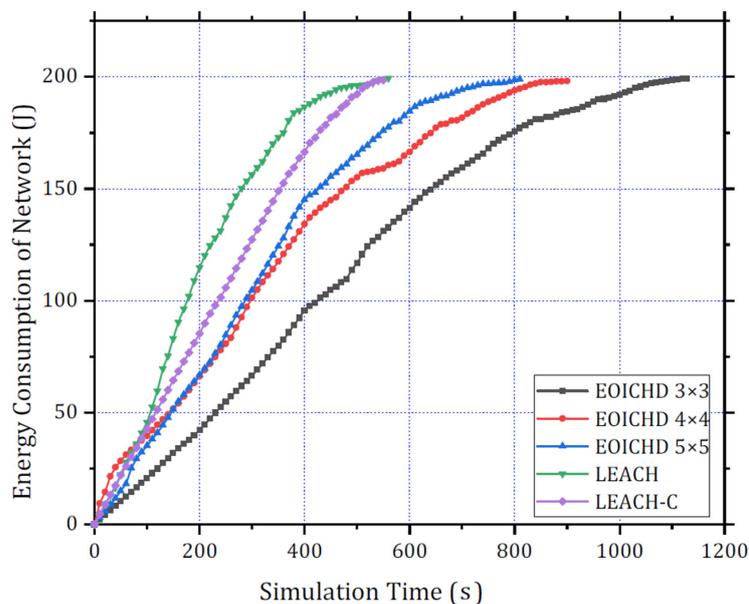


Figure 9. Energy consumption of network over simulation period Scenario #1.

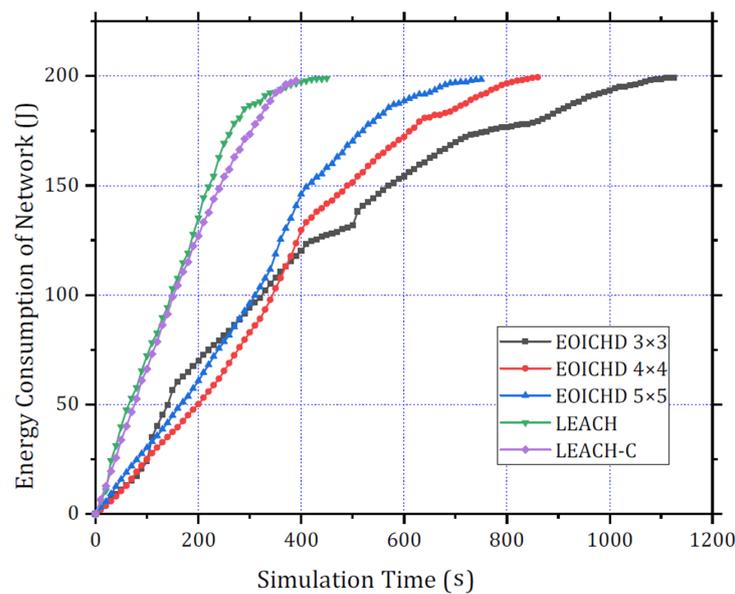


Figure 10. Energy consumption of network over simulation period Scenario #2.

6.3. Average Data Packets Received by BS

Another crucial comparative parameter is the number of data packets received by the base station. The role of each node is to sense and transmit the information to the base station. The total number of data received at the base station helps judge the routing technique’s quality. The number of data packets received by BS during the execution of LEACH, LEACH-C, and EOICHD variants for Scenario #1 is 27,493, 43,217, 52,319, 54,253, and 60,450, respectively. Similarly, the number of data packets received by BS during the execution of LEACH, LEACH-C, and EOICHD variants for Scenario #2 is 38,650, 45,350, 51,915, 54,955, 56,479, respectively. Based on the data, it can be understood that EOICHD variants outperform LEACH and LEACH-C protocols. The number of data received at the base station is directly proportional to the network lifetime. As EOICHD variants can prolong network lifetime by keeping a significantly large number of nodes operating, the data received at BS are also comparatively large. From Figure 11, it is evident that the EOICHD 3 × 3 has transmitted maximum data packets to the base station in both the scenarios among all the EOICHD variants.

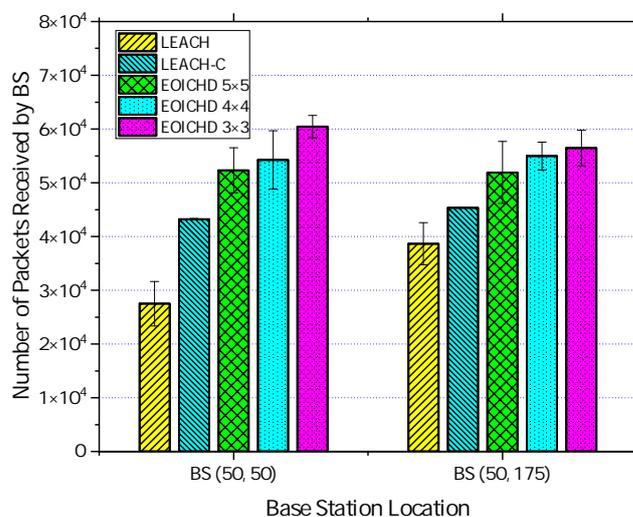


Figure 11. Average data packets received at the Base Station (BS) for Scenario #1 and Scenario #2.

6.4. Stability Period

In WSNs, the reliability of data received by BS is of the highest importance. Data received by BS become unreliable as soon as the first node of the network dies, meaning that information cannot be sensed around the vicinity of the dead node. As more and more nodes become non-operable due to dead batteries, the credibility of data received by BS is compromised. Hence, it is essential to know that a routing protocol is prolonging network lifetime and extending the time by which the first node and half of the network nodes are dead. The BS data's credibility could be understood well through parameters such as FND, HND, and LND. This paper has compared all three variants of EOICHD protocol with LEACH and LEACH-C for network stability and statistics are mentioned in Tables 3 and 4 for Scenario #1 and Scenario #2, respectively. From the tables, it is found that *EOICHD* 3 × 3 can perform better and prolong FND, HND, and LND in Scenario #1. However, in Scenario #2, *EOICHD* 3 × 3 loses the first node at 112 s of simulation time. HND and LND indicate that over the simulation period, the *EOICHD* 3 × 3 recovers and performs well compared to its other variants, LEACH and LEACH-C.

Table 3. First node that becomes dead (FND), half of the nodes of the network becoming non-operational (HND), and the last node dead (LND), Scenario #1.

| Routing Protocols | FND | HND | LND |
|---------------------|-------|-------|-------|
| <i>EOICHD</i> 3 × 3 | 321.3 | 774 | 1128 |
| <i>EOICHD</i> 4 × 4 | 240.2 | 654.2 | 903 |
| <i>EOICHD</i> 4 × 4 | 172 | 602 | 813 |
| LEACH | 153 | 371.2 | 564 |
| LEACH-C | 311 | 493.2 | 552.4 |

Table 4. FND HND LND, Scenario#2.

| Routing Protocols | FND | HND | LND |
|---------------------|-------|-------|--------|
| <i>EOICHD</i> 3 × 3 | 112 | 672 | 1124.3 |
| <i>EOICHD</i> 4 × 4 | 353.4 | 620 | 863 |
| <i>EOICHD</i> 4 × 4 | 355 | 551.7 | 754 |
| LEACH | 293 | 543 | 734.3 |
| LEACH-C | 344 | 603.4 | 671 |

7. Conclusions

In this research article, three variants of EOICHD protocol, namely *EOICHD* 5 × 5, *EOICHD* 4 × 4, and *EOICHD* 3 × 3 are proposed. The basic EOICHD protocol's main idea is to split the entire network of dimension ($x \times y$) m² into $u \times vs$. zones. An optimal inter-CH distance (d_{opt}) is identified based on the Equation (4). The variants of EOICHD proposed in this article are formed by making variations in the network's number of zones. As observed from Section 5, as the number of zones of the network increases, the value of d_{opt} decreases. It is found from the results that *EOICHD* 3 × 3 has given better results compared to its other variants, LEACH and LEACH-C protocols. From the results, it is also observed that reducing the number of zones for the EOICHD protocol increases the network lifetime.

Author Contributions: Conceptualization, A.B. (Anupkumar Bongale) and K.B.; Funding acquisition, A.B. (Anupkumar Bongale); Methodology, A.B. (Anupkumar Bongale); Writing—original draft, A.B. (Anupkumar Bongale); Writing—review & editing, A.B. (Arunkumar Bongale), S.K., R.J., and K.B.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding authors.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Liu, X. Atypical Hierarchical Routing Protocols for Wireless Sensor Networks: A Review. *IEEE Sens. J.* **2015**, *15*, 5372–5383. [[CrossRef](#)]
2. Akyildiz, I.; Su, W.; Sankarasubramanian, Y.; Cayirci, E. Wireless sensor networks: A survey. *Comput. Netw.* **2002**, *38*, 393–422. [[CrossRef](#)]
3. Abbasi, A.A.; Younis, M. A survey on clustering algorithms for wireless sensor networks. *Comput. Commun.* **2007**, *30*, 2826–2841. [[CrossRef](#)]
4. Sunny, A.I.; Zhao, A.; Li, L.; Kanteh Sakiliba, S. Low-Cost IoT-Based Sensor System: A Case Study on Harsh Environmental Monitoring. *Sensors* **2021**, *21*, 214. [[CrossRef](#)]
5. Rashvand, H.F.; Abedi, A. Wireless sensor systems for extreme environments. In *Wireless Sensor Systems for Extreme Environments: Space, Underwater, Underground, and Industrial*; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2017; p. 5.
6. Gupta, V.; Pandey, R. An improved energy aware distributed unequal clustering protocol for heterogeneous wireless sensor networks. *Eng. Sci. Technol. Int. J.* **2016**, *19*, 1050–1058. [[CrossRef](#)]
7. Mo, Y.; Wang, B.; Liu, W.; Yang, L.T. A Sink-Oriented Layered Clustering Protocol for Wireless Sensor Networks. *Mob. Netw. Appl.* **2013**, *18*, 639–650. [[CrossRef](#)]
8. Ehsan, S.; Hamdaoui, B. A Survey on Energy-Efficient Routing Techniques with QoS Assurances for Wireless Multimedia Sensor Networks. *IEEE Commun. Surv. Tutor.* **2012**, *14*, 265–278. [[CrossRef](#)]
9. Chatei, Y.; Ghoumid, K.; Hammouti, M.; Hajji, B. Efficient coding techniques algorithm for cluster-heads communication in wireless sensor networks. *AEU-Int. J. Electron. Commun.* **2017**, *82*, 294–304.
10. Moh'd Alia, O. Dynamic relocation of mobile base station in wireless sensor networks using a cluster-based harmony search algorithm. *Inf. Sci.* **2017**, *385*, 76–95. [[CrossRef](#)]
11. Muthukumaran, K.; Chitra, K.; Selvakumar, C. An energy efficient clustering scheme using multilevel routing for wireless sensor network. *Comput. Electr. Eng.* **2018**, *69*, 642–652.
12. Sirdeshpande, N.; Udupi, V. Fractional lion optimization for cluster head-based routing protocol in wireless sensor network. *J. Frankl. Inst.* **2017**, *354*, 4457–4480. [[CrossRef](#)]
13. Akkaya, K.; Younis, M. A survey on routing protocols for wireless sensor networks. *Ad. Hoc Netw.* **2005**, *3*, 325–349. [[CrossRef](#)]
14. Arjunan, S.; Pothula, S. A survey on unequal clustering protocols in wireless sensor networks. *J. King Saud-Univ.-Comput. Inf. Sci.* **2019**, *31*, 304–317. [[CrossRef](#)]
15. Shahraki, A.; Rafsanjani, M.K.; Saeid, A.B. A new approach for energy and delay trade-off intra-clustering routing in WSNs. *Comput. Math. Appl.* **2011**, *62*, 1670–1676. [[CrossRef](#)]
16. Heinzelman, W.; Chandrakasan, A.; Balakrishnan, H. Energy-Efficient Communication Protocols for Wireless Microsensor Networks. In Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, Maui, HI, USA, 7 January 2000.
17. Heinzelman, W.B.; Chandrakasan, A.P.; Balakrishnan, H. An application-specific protocol architecture for wireless microsensor networks. *IEEE Trans. Wirel. Commun.* **2002**, *1*, 660–670. [[CrossRef](#)]
18. Sibahee, M.A.A.; Lu, S.; Masoud, M.Z.; Hussien, Z.A.; Hussain, M.A.; Abduljabbar, Z.A. LEACH-T: LEACH Clustering Protocol Based on Three Layers. In Proceedings of the 2016 International Conference on Network and Information Systems for Computers (ICNISC), Wuhan, China, 15–17 April 2016; pp. 36–40.
19. Bongale, A.M.; Swarup, A.; Shivam, S. EiP-LEACH: Energy influenced probability based LEACH protocol for Wireless Sensor Network. In Proceedings of the 2017 International Conference on Emerging Trends Innovation in ICT (ICEI), Pune, India, 3–5 February 2017; pp. 77–81.
20. Singh, S.K.; Kumar, P.; Singh, J.P. A Survey on Successors of LEACH Protocol. *IEEE Access* **2017**, *5*, 4298–4328. [[CrossRef](#)]
21. Lin, H.; Wang, L.; Kong, R. Energy Efficient Clustering Protocol for Large-Scale Sensor Networks. *IEEE Sens. J.* **2015**, *15*, 7150–7160. [[CrossRef](#)]
22. Dong, Y.; Wang, J.; Shim, B.; Kim, D.I. DEARER: A Distance-and-Energy-Aware Routing With Energy Reservation for Energy Harvesting Wireless Sensor Networks. *IEEE J. Sel. Areas Commun.* **2016**, *34*, 3798–3813. [[CrossRef](#)]
23. Ke, W.; Yangrui, O.; Hong, J.; Heli, Z.; Xi, L. Energy aware hierarchical cluster-based routing protocol for WSNs. *J. China Univ. Posts Telecommun.* **2016**, *23*, 46–52. [[CrossRef](#)]
24. Rani, S.; Ahmed, S.H.; Malhotra, J.; Talwar, R. Energy efficient chain based routing protocol for underwater wireless sensor networks. *J. Netw. Comput. Appl.* **2017**, *92*, 42–50. [[CrossRef](#)]
25. Nayak, P.; Devulapalli, A. A Fuzzy Logic-Based Clustering Algorithm for WSN to Extend the Network Lifetime. *IEEE Sens. J.* **2016**, *16*, 137–144. [[CrossRef](#)]
26. Abidi, W.; Ezzedine, T. Fuzzy Cluster Head Election algorithm based on LEACH protocol for wireless sensor networks. In Proceedings of the 2017 13th International Wireless Communications and Mobile Computing Conference (IWCMC), Valencia, Spain, 26–30 June 2017; pp. 993–997.

-
27. A.M. Bongale and C.R. Nirmala. EOICHD: A Routing Scheme for Wireless Sensor Network Based on Energy and Optimal Inter Cluster Head Distance. *Int. J. Appl. Eng. Res.* **2016**, *11*, 7256–7266.
 28. Kavitha, A.; Guravaiah, K.; Velusamy, R.L. A cluster-based routing strategy using gravitational search algorithm for wsn. *J. Comput. Sci. Eng.* **2020**, *14*, 26–39. [[CrossRef](#)]
 29. Teerawat, I.; Hossain, E. *Introduction to Network Simulator NS2*; Springer: Boston, MA, USA, 2009; pp. 1–18.