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Research Article

Development and Performance Evaluation of a New Energy-Efficient Double Cluster-Head Routing (EEDCR) Protocol for Wireless Sensor Networks

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Utilization of energy and the lifetime increment are the big issues in designing of routing algorithms for wireless sensor networks (WSNs). Many routing algorithms have been developed by various researchers to achieve energy efficiency and to improve the lifetime of the network. But, the way to route the information from the sensor node (SN) to the base station (BS) and vice versa is an important issue, because of resource constraints. In this paper, we have proposed a low energy consumed, cluster-based routing protocol named an energy-efficient and double cluster-head routing (EEDCR) protocol, to increase the network lifetime and minimize the end-to-end delay. Selection of the cluster head (CH) is depending on random selection method, energy method, the total number of nodes, and its energy level. The performances of developed protocol were assessed using simulations and found that it provides successful outcomes in terms of energy-efficient and lifetime increment in routing for WSNs.

1. Introduction

WSNs usually constitute a number of small SNs and a sink. The problems include node misbehaviour caused by malicious, corrupted, or selfish motives, protection against various attacks, free or unprotected communications, limited resources, and hostile environments can compromise WSN security and overall efficiency [1–4]. SNs have finite and nonrechargeable energy resources that could be carefully handled to prolong their life span [5]. Since SNs have a finite number of resources, WSN applications and protocols should be carefully designed to extend the network's life span [6, 7]. This application determines whether the SNs are positioned at random or in a predetermined pattern to construct a network [8]. The nodes have sensing, self-control, computing, and wireless communication capabilities, and they can communicate with each other [9]. In most of the cases, there is no stronger quality of service (QoS) conditions for communicating scalar information than vector information. This is due to vector information is time-sensitive and takes a lot of band width and reliability to deliver useful information [10]. The WSNs have large applications in territory or location protection, civil surveillance or military, target tracking, weather monitoring, human health monitoring, forecasting natural disasters, etc. [2, 11]. Due to wide applications of WSNs and sensor constraint issues, it is necessary for an energy-efficient routing protocol with data aggregation [12]. Hence, proposing an energy-efficient algorithm is very significant and important.

The advancements in the field of science have led to the development of light-weight battery-powered sensors capable of detecting physical events like vibrations, temperature, seismic activity, and humidity [13–15]. Energy conservation plays a major role in design of any sensor network, and the hierarchical clustering design saves energy of the network [16, 17]. To achieve optimum results, SNs should cooperate;

however, node misbehaviour due to fraudulent compromised or selfish motives, as well as protection mechanisms towards various attacks, degrade overall WSN performance significantly [18–20]. As a consequence, network protection is a crucial necessity for WSNs, and it should be considered when developing a routing protocol. During deployment, the WSN should be able to run in most applications for a long time, even without the node maintenance and the replacement of their energy sources [21]. Therefore, a routing algorithm to be developed should absolutely be in such a way that the consumption of energy should be low at all phases of the protocol's operation. There are few challenges while designing new routing protocols for WSNs. The network partitions and topology changes are frequent as a result of node mobility. Packet losses may occur frequently, due to the unpredictable and variable capability of wireless links [22]. Sink (also known as destination) is the only data collection point in the traditional WSNs. When a related device (e.g., an on-path device) with the region of the sink or the sink alone experiences a serious problem, network efficiency can suffer. For example, an increase in data size can cause the centralised sink node to bottleneck, since it can cause congestion in the region [23]. Another problem is a single system of vulnerability with its connected device or perhaps a sink, which may occur as a result of channel jamming or energy reduction. WSN output can be harmed as a result of these problems, and QoS-oriented data transmission may be negatively impacted. The use of a multisink method, which can improve data collection points, is a fair solution to the problems described above.

In WSNs, the multisink method is useful to avoid congestion which is close to the sink node and avoid specific vulnerability problem [24]. Consequently, the multisink method distributes work around the sensor network which enables energy balance across the sink [25], resulting in a longer network lifetime [26]. Since it increases network throughput, the multisink approach is ideal for high-end applications like stream communication over the internet in WSNs [26, 27]. However, in multisink WSNs, one of the key challenges is determining the most cost-effective, end-to-end route among sink(s) and source [25]. The routing protocol proposed in this paper is intended to solve all of the WSN challenges listed above. We developed a cluster-based, energy-efficient double cluster-head routing protocol for WSNs with a fully distributed manner.

2. Background

This section delivers a brief discussion of the relative benefits and drawbacks of the most common routing protocols, which will assist researchers in selecting one protocol over the others based on its merits for WSNs. LEACH is a standard clustering protocol developed for continual data collection in WSNs [28]. It is easy and does not require a lot of communication. Since it chooses CHs without taking into account the node's residual capacity, this protocol performs poorly in heterogeneous networks. To resolve these issues, developers are forced to improve the LEACH and develop some new algorithms [29–31]. There are various methods to minimize the energy consumption of the SNs. One such technique is clustering. Clustering is an effective strategy for reducing SN energy usage in WSNs [32–35]. This saves communication bandwidth by limiting the transmission of redundant data across SNs [32]. The principle of data aggregation at CHs helps SNs preserve energy. It is a hierarchical method that improves WSN scalability [35]. In this process, SNs send data to CH and then send it to BS. CHs near the BS, on the other hand, may experience excessive energy consumption and drain out quickly, resulting in energy holes and hot spots in the network [33, 34]. Clustering can also be used to control huge sensor networks, because CHs are much easier to handle than the complete network [36].

In some protocols, the routing configuration is designed and viewed as a network flow problem, whereas end-to-end delay in QoS-aware protocols is the most important factor to consider while routing in the sensor network. The sequential assignment routing (SAR) protocol will be the first developed routing technique which involves the concepts of QoS in routing choice [37]. On each route in SAR, failure restoration is accomplished by imposing routing table continuity among upstream and downstream nodes. By considering the QoS metric, energy resource on each direction, and packet priority level, it generates trees, rooted from one-hop neighbours of its sink. By creating trees, SAR constructs several paths from source to sink. This undergoes from the complexity of retaining its routing states and table with every SNs [38]. By selecting the CH, several more approaches have been developed. The energy aware QoS routing algorithm is a multipath routing algorithm with embedded QoS [38, 39]. Toor and Jain [40] proposed an energy-oriented cluster-based multihop routing protocol for WSNs. When comparing low-energy SNs, only the highest energy SNs are chosen as CH in this protocol. Multihoping is used for intercluster connectivity, and sub-\clustering is used to cover a larger number of SNs, resulting in network access to all SNs. It improves efficiency by decreasing the energy utilization by SNs in a conservative manner, thus increases the lifetime of the network, band width (packets transferred to BS), and the number of dead SNs for each round in any simulation scenario.

The simulation results of energy efficient and QoS aware routing (EEQR) protocol were evaluated with the mobile sink (MS) and static sink (SS) protocols [41]. According to the findings, the EEQR protocol saves a significant amount of energy and thus extends the network life span. A hierarchical routing based on cluster method was suggested, and its findings showed that the built protocol reduces SN energy utilization and increasing network lifetime significantly [42]. The ML-MAC protocol's QoS assessment was proposed, and it was discovered that its SNs in ML-MAC seem to have a short listening or reading time, which would minimize energy consumption throughout the communication [43]. GMCAR is an energy efficient, QoS aware routing protocol which is suited for gridded sensor networks. This protocol achieved 23% energy saving when compared to other grid-based routing protocols [44].

Wang et al. [45] suggested a hierarchical cluster-oriented protocol that minimizes the energy utilization of sensors and increases the life span of the WSN. Zhang et al. [46] proposed unequal clustering which maximizes the sensor network lifetime by reducing the dead node's speed, and energy dissipation of the network is maintained constantly. The problem of network failure due to energy holes is the major constraint of WSN identified with routing. To achieve energy efficiency in any routing technique, it must have minimized energy utilization which increases WSN life span. Energy saving has become an important feature of the SNs to surge their lifetime in WSNs. To give reasonable energy utilization and to enhance the network lifetime of WSN, new and well-organized energy saving methods must be developed.

3. Hierarchical Clustering Architecture

The sensors are utilized to observe the surroundings and send the data to its BS. Because of flexibility and lower cost, SNs are rapidly deployed for various kinds of applications. But the SNs have restricted resources such as bandwidth, processing unit, memory unit, and power unit. It is essential to maintain till the end of the utilization period, which might be in a month or year based on their application. The energy utilization of any two SNs can be evaluated based on the transmission range since every SN has its own particular sensing capacity. So, the routing path for transmitting the information from SN to BS will influence its energy utilization.

If anyone SN fails in a WSN, the entire network will crash. To achieve scalability throughout this network, SNs are organized into several clusters depending on the region of coverage. One SN will act as CH on every cluster, while the other SNs will act as cluster members (CMs). CH seems to be in charge of data gathering, aggregation of data, and sending aggregated information from their cluster to BS, as well as forwarding BS information to the CM in each cluster. Similarly, CMs are in charge of monitoring and detecting data from the environment, along with getting messages from CH and acting on it. The clustering method has the following advantages [13]:

(i) It can reduce the energy consumption among all SNs, since CH will take care of the data collection, data aggregation, and routing of the information to its BS

(ii) It can significantly reduce the bandwidth utilization since the SNs are communicating with its CH and can reduce the redundant information

(iii) Managing the cluster is very easy, since it can localize the routing setup and needs little routing tables for the SNs. This will enhance the scalability of the network

Therefore, the CH selection procedure is more essential, since it requires additional energy than its members in order to send the information to its BS. It is important to sustain each sensor's energy till the network's lifetime as all the SNs have little energy to run. The method of grouping SNs into clusters has also been widely pursued by the researchers to achieve the goal of node scalability. In every cluster, one SN acts as a coordinator node (CN) and other SNs serve as CM at level one, as shown in Figure 1. This method is particularly helpful in WSN for producing energy-efficient coordinator heads (CNHs) and data transmission packets for safe transmission. Depending on the CN, which will have the maximum level and sensing time, an energy-efficient system produces CNH.

In each cluster designated $C_{i,j}$, one of the current SNs inside $C_{i,j}$ is chosen as $\mathrm{CN}_{i,j}$. Moreover, a CNH_i will be chosen amongst the $\mathrm{CN}_{i,1}, \mathrm{CN}_{i,2}, \cdots . \mathrm{CN}_{i,m}$. A cluster C_i, CN_j is in process of gathering sensed information about additional SNs associated with the cluster $C_{i,j}$ and transmitting it to the CNH. In cluster C, the CN is chosen iteratively from its SNs. Three methodologies for selecting a CN are recommended, and also, the parameters that used to select a CN are defined as follows: $A(\mathrm{SN})$ represents the number of active SNs in C, and $|A(\mathrm{SN})|$ signifies the total number of SN in $A(\mathrm{SN})$. $e(N_i)$ is the $\mathrm{SN}-N_i$ energy, and $t(N_i)$ is the number of times this specific SN in N_i was picked as a CN. Consider a cluster C, where the CN of C might be selected [47]. The lifetime of the SN is defined as follows:

Type 1: lifetime is evaluated when $e(\mathrm{SN}_i) >$ threshold value.

Type 2: average life span is calculated when $|A(\mathrm{SN})| > = 0$.

Type 3: others who do not fit into types 1 or 2 might be classified as type 3.

Each cluster contains a coordinator and several SNs. The coordinators can be split into several unrelated clusters, with one coordinator from each group chosen as the CNH.

3.1. Energy Model. The new energy of the nodes can be computed using Equation (1) after data communication

$$E_{\mathrm{Ne}} = E_{\mathrm{In}} - (E_{\mathrm{Tra}} + E_{\mathrm{Rec}}), \tag{1}$$

where E_{In} denotes the SN's initial energy, E_{Tra} is the consumption of energy during its data transmission, and E_{Rec} denotes consumption of energy during the data reception. Depends on its distance of receiver node, the SN can have its energy transmission. The energy model for SN is calculated based on the methodology described by Muruganathan et al. [48]. Equation (2) used for determination of how much energy is used to transmit the k-bit E_{Tra} over a distance (d).

$$E_{\mathrm{Tra}} = \begin{cases} k.E_{\mathrm{elect}} + k.\varepsilon_{\mathrm{fs}}.d^2 \text{ for } 0 \le d \le d_{\mathrm{crossover}}, \\ k.E_{\mathrm{elect}} + k.\varepsilon_{\mathrm{mp}}.d^4 \text{ for } 0 \ge d_{\mathrm{crossover}}, \end{cases} \tag{2}$$

where E_{elect} is the energy used by the device, $\varepsilon_{\mathrm{fs}}$ is a constant for free space propagation and is the energy utilized by an amplifier ($\varepsilon_{\mathrm{mp}}$) when transferring at a distance less than $d_{\mathrm{crossover}}$. Equation (3) evaluates how much energy is expended when sending a k-bit message. The nodes are

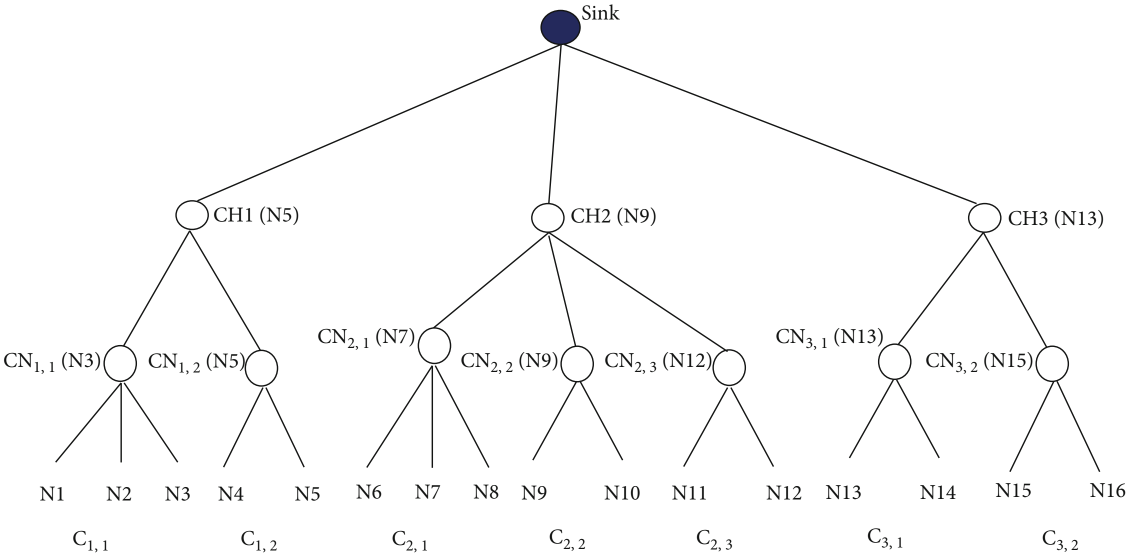


Figure 1: Hybrid hierarchical structure.

```
Input: Node's neighbour discovery message NEI_INFO
Output: Updating neighbour information
Var: NEI_INFO = ∅, SN_ID, NEI(P) =∅
Begin
Every node broad cast its neighbor discovery message by sending
<NEI_INFO, SN_ID>
        $SN\_ID_a \longleftarrow$ <NEI_INFO, $SN\_ID_b$>
        If ($SN\_ID_b \notin$ NEI (a)) then
        Begin
                NEI(a) ⟵ NEI(a) + $SN\_ID_b$
                If (NEI_INFOUPDATEa = false) then
                Begin
NEI_INFOUPDATEa⟵
Broadcast (NEI_INFO, SN_IDa);
// a is broadcasting NEI_INFO packet
                End
                Else
Drop the NEI_INFO packet;
        End if
        End
        Else
                Drop the NEI_INFO packet;
        End if
End
```

Algorithm 1: Neighbour node discovery

considered dead and removed from the sensing area, if the computed energy level does not reach the threshold (T) level (0.1 J).

$$E_{\text{Rec}} = K.E_{\text{elect}}. \tag{3}$$

3.2. Selection of CN and CNH. The assumptions are made for the selection of CN and CNH in WSN. The SNs are randomly scattered inside a sensing field and there is only one BS in this field. After deployment of SNs, the BS is static. Every SN knows the location of BS, CN, and CNH and can send the information to its CN via multihop in specific circumstances. It is assumed that the power level and sensing process are consistent. Depends on the received signal strength (RSS), SNs can calculate their relative distance to CN, BS and its communication is symmetric. To make a CN and CNH, three different techniques such as random selection method (R), energy method (E) and number of nodes and its energy (NE) are used.

3.2.1. Random Selection Method. The operation in the R method can occur in a number of rounds. Every round is

```
Assumption: The data is sent from CM to CN via a multi-hop routing route
Input: CN_INT, SN_ID //CN and CNH selected intimation to SNs
Output: CN_INT$_{ACK}$, updating of routing table (RT)
Var: ACK, NXT_NEI, CN_INTUPDATE
Begin
Every node receives the CN_INT message with their SN_ID of the sender and SN_ID of CN
        CN_INT: < CN_INT, SN_ID$_{b}$, SN_ID$_{CN}$>
        If (SN_ID$_{CN}$ = SN_ID$_{a}$) then
        Begin
Send info (ACK, SN_ID$_{a}$, NXT_NEI);
//Sent the ACK packet to CNH
End
Else if (CN_INTUPDATE = false)
Begin
Update the RT (a) by adding SN_ID$_{CN}$ as CN ID and next hop as SN_ID$_{b;}$
//broadcast CN_INT packet
Broadcast (CN_INT, SN_ID$_{a}$, SN_ID$_{CN}$);
End
    Else
Packet drop
    End if
ACK: < ACK, SN_ID$_{b}$, NXT_NEI >
    If (NXT_NEI == SN_ID$_{a}$) then
If (SN_ID$_{a}$ == SN_ID$_{CN}$) then
Time out false;
Else
Check RT (SN_ID$_{a}$) and find the next hop of SN_ID$_{b}$;
//Transfer that ACK packet to the CNH
Forward (ACK, SN_ID$_{b}$, NXT_NEI);
End if
If (SN_ID$_{a}$ == SN_ID$_{CNH}$) then
Time out false;
Else
Check RT (SN_ID$_{a}$) and find the next hop of SN_ID$_{b}$;
/*Forward the ACK packet towards the CNH*/
Forward (ACK, SN_ID$_{b}$, NXT_NEI);
    End if
Else
Packet drop;
End if
End
```

Algorithm 2: CN intimation.

started by a setup stage where clustering happens and a steady stage for information transmission. Each round starts with a selection of CN and CNH. Every node in the network decides whether to become the CN for the current round or not, depending upon the required percentage of CNs or CNHs for the network and also the number of times the SN has become a CN or CNH. For any node n, the threshold condition for the choice of CN or CNH is given in Equation (4).

$$T(n) = \begin{cases} \frac{q}{1} - q * \left(r mod \frac{1}{q} \right) & \text{if } n \in G \\ 0 \text{ other wise,} \end{cases} \tag{4}$$

where q represents the required percentage of CN or CNH in that particular round, r represents the current round, G represents the arrangement of SNs which have not been CH as in last $1/q$ rounds, and T is the threshold value. Every node in G selects a random number r between the intervals 0 to 1 and if the selected number is below the threshold value $T(n)$, then SN turns into a CN or CNH during the round. After the CN or CNH decision is made, an advertisement (ADV) message is communicated to their cluster. The CMs respond back through a join-request message to its CN. The CN will act as head in that cluster, and the CNH acts as a head between the clusters. The data transmission from SNs to the CN happens only in their assigned schedule slot. Every SN must be turned onto send or receive the information.

3.2.2. Energy Method. In addition to the basic assumptions, all CMs can send their data either to its CN or its intermediate neighbours towards CN. Every node identifies its

```
Assumption: The information is sent from CN to CNH via CN to CN multi-hop routing
Input: CN_INT, CNH_INT, SN_ID
//CN and CNH selected intimation to SNs
Output: $CNH\_INT_{ACK}$, updating of routing table RT
Var: ACK, NXT_NEI, CNH_INTUPDATE
Begin
Every CN receives the CNH_INT with their SN_ID of the sender and SN_ID of CNH.
CNH_INT: <CNH_INT, $SN\_ID_{CNj}$, $SN\_ID_{CNH}$>
If ($SN\_ID_{CNH} = SN\_ID_{CNi}$) then
Begin
Send info (ACK, $SN\_ID_{CNi}$, NXT_NEI);
//Sent the ACK to BS
End
        Else if (CNH_INTUPDATE==false)
                Begin
Update the RT (CNi) by adding $SN\_ID_{CNH}$ as CNH ID and next hop as $SN\_ID_{CNj;}$
        Broadcast (CNH_INT, $SN\_ID_{CNi}$, $SN\_ID_{CNk}$);
//broadcast CNH_INT packet
        End
Else
Packet drop
End if
End
```

Algorithm 3: CNH intimation.

neighbours only within range "*R*" at the time interval "*t*." Choose SN with the maximum energy of individuals within "*t*" as CN; CN sends ADV information to its CMs to verify it as CN for the next "*t*" rounds. Depending on the RSS, every node can send information back to its own CN and forms the intraclusters. Each one of the CMs receives a TDMA slot from the CNs, which they use to convey the detected information to respective CNs. CNs will keep track of all of their CMs' residual energy as well as their distance from the CNH. The received information is aggregated, and then it will be sent from CNs to the CNHs. The CNH is chosen depends on the maximum energy of intercluster CNs over "*t*." The CNH sends its ADV information to its inter-CNs to confirm it as a CNH for the next "*t*" rounds. Each CN in the intracluster sends back the data to its CNH and forms their interclusters. The CNHs maintain the data about the residual energy of all its CNs and its relative distance to the BS. Similarly, CNH broadcasts its ADV to all CNH to form a multipath in order to reach the BS. Data aggregated by every CN will be sent to the CNH and from CNH to its BS. The selection of CN is based on the highest energy of effective SNs in C_{ij} which is given in Equations (5) and (6).

$$\mathrm{CN} = \max \left\{E(N_i)\right\} \forall N_i \in C_{ij} \text{where } i, j = 1, 2, \cdots, n, \tag{5}$$

$$\mathrm{CNH} = \max \left\{\mathrm{CN}_j\right\} \forall CN_i \in C_{ij}\ i, j = 1, 2, \cdots, n. \tag{6}$$

3.2.3. Number of Nodes and Their Energy. In addition to basic assumptions, all SNs send their ADV information to the CN via the nearest neighbours. Every node recognizes its neighbours in "*t*" within the range "*R*." Choose the SN with highest energy of the CM in the cluster within "*t*" as CN; CN sends ADV messages to its CMs to confirm it as CN for the next "*t*" rounds. Depends on the RSS, every node sends back the data to its distinct CN and forms the intraclusters. The CNs send TDMA slot to every CMs in which they can communicate the detected information to their CNs. CNs will maintain the data about the residual energy of all its CMs and their relative distance to the CNH. The received information is aggregated, and then, it will be sent from CNs to the CNHs. The CNH is selected based on the product of inter-CNs energy as well as the maximum quantity of alive nodes in that intra-CN.

$A(C_{ij})$ is the quantity of alive SN. Select a SN as CNH_i among the set of $\mathrm{CN}_{i,1}, \mathrm{CN}_{i,2}, \cdots, \mathrm{CN}_{i,m}$ where maximum of all the nodes in $|A(C_{ij})|$ and the set of $\mathrm{CN}_{i,1}, \mathrm{CN}_{i,2}, \cdots, \mathrm{CN}_{i,m}$.

$$\mathrm{CN} = \max \left\{E(N_i)\right\} \forall N_i \in C_{ij} \text{where } i, j = 1, 2, \cdots, n, \tag{7}$$

$$\mathrm{CNH} = \left\{\mathrm{CN}_j\right\} \text{where } \left|A\left(C_{ij}\right)\right| * E\left(CN_{i,j}\right) \text{is maximum} \& i, j = 1, 2, \cdots n. \tag{8}$$

The highest value of usable SNs in C_{ij} determines which CN to use. The usable quantity of SN is $|A(C_{\mathrm{ij}})|$. Select a SN CNH_i from the list $\mathrm{CN}_{i,1}, \mathrm{CN}_{i,2}, .., \mathrm{CN}_{i,m}$ where maximum with all the nodes in $|A(C_{ij})|$ and $\mathrm{CN}_{i,1}, \mathrm{CN}_{i,2}, .., \mathrm{CN}_{i,m}$.

3.3. Neighbour Node Discovery. After deployment of SNs, the BS starts the neighbour node discovery phase. SN has to know whether the neighbouring node is in awake state or sleep state, before it starts the transmission of information into the time domain network. SN has to use synchronization mechanism which coordinates its neighbouring SN in

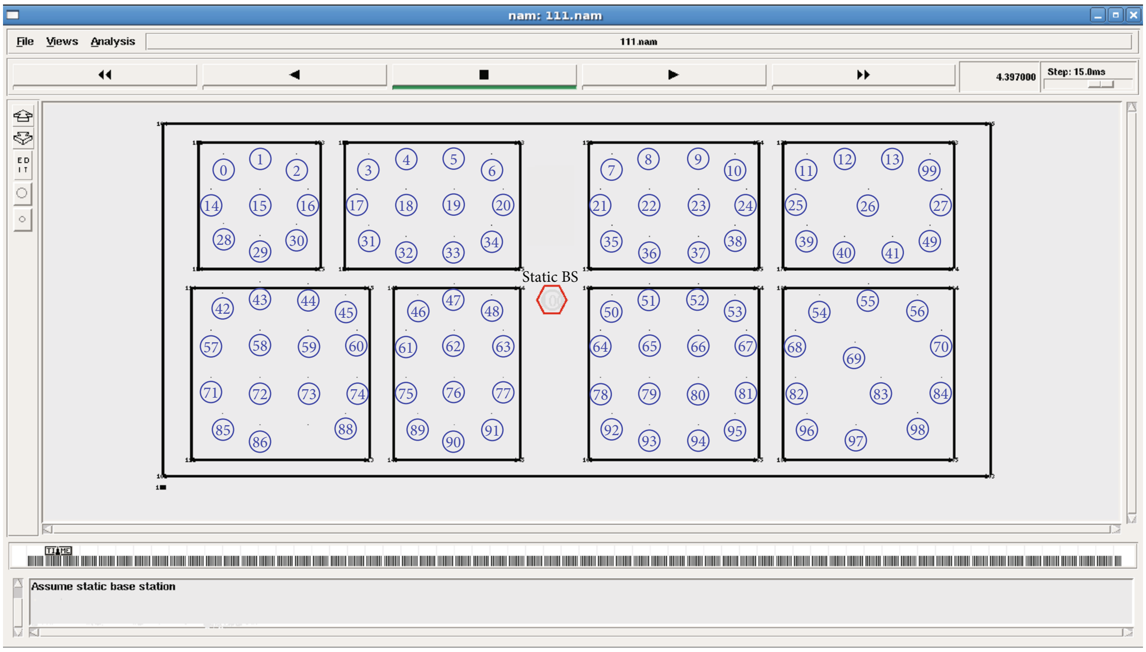
```
Input: CN_ADV, CNH_ADV, SN_ID, RSSI (SN_ID)
Output: Formation of cluster
Var: RSSI (SN_ID), CNselecteda, CNHselectedCN, CNMbr, CNHMbr
Begin
    RSSI(SN_ID) =$\emptyset$;
    CNselecteda = CNHselected=$\emptyset$;
    CNMbr=CNHMbr=$\emptyset$;
//Node ‘a’ receives CN_ADV message from node b: where a $\notin$ CN and b$\in$
CN_ADV:< CN_ADV, SN_IDb>;
RSSI(a) $\longleftarrow$ RSSI(a) $\cup$
//Node ‘a' selects the node only with maximum RSS as in its CN after//obtaining all CN_ADV.
CNselecteda$\longleftarrow$
Send info (CN_JOIN, SN_IDa, SN_IDcn);
//Send a request to enter to the CN.
//Node ‘q’ sends the following information to node ‘p’:
// ‘p’ is the CN of one cluster and ‘q’ is the CN of another cluster
CNH_ADV:< CNH_ADV, SN_IDq>;
RSSI(p) $\longleftarrow$ RSSI(p) $\cup$
//Node ‘p' selects the node with the maximum RSS as in its CNH after//obtaining all CNH_ADV.
CNHSelectedp$\longleftarrow$
Send info (CNH_JOIN, SN_IDp, SN_IDcnh);
//Join request will be send to the CNH
//The below mentioned packet is received by node a from node b: in which// a$\in$CN and b $\notin$
CN_JOIN: <CN_JOIN, idb, SN_IDcn>
If (SN_IDa == SN_IDcn) then
CNMbr(a) $\longleftarrow$ CNMbr(a) $\cup$
Node p transfers the CNHMbr(p) to BS after obtaining all CNH_JOIN.
The timeline should be broadcast to CN
    Else
    Packet drop;
    End if
The packet is received by node p from node q, whereas p is the CN of one cluster and q is the CN of another cluster.
    CNH_JOIN: <CNH_JOIN, SN_IDq, SN_IDcnh>
    If (SN_IDp == SN_IDcnh) then
        Begin
        CNHMbr(p) $\longleftarrow$ CNHMbr(p) $\cup q$;
Node p transfers the CNHMbr(p) to BS after obtaining the CNH_JOIN. The CN should be informed of the time slot schedule.
End
    Else
        Packet drop;
    End if
End
```

Algorithm 4: Cluster formation.

Table 1: Assumptions for node deployment.

Parameter	Values
Network size	100 m × 100 m
Location of SS (x, y)	(50 m, 50 m)
Required SNs	One hundred
SN energy (E)	2 J
Dead state	Energy level is lesser than 0.1 J
Deployment of SN	Random
E_{electro}	50 nJ/bit
Amplifying power	$\varepsilon_{\text{mp}} = 0.0013$ pJ/bit/m^4; $\varepsilon_{\text{fs}} = 10$ pJ/bit/m^2
Data aggregation	5 nJ/bit
Period of each round	4 s

order to achieve the smooth transmission. This mechanism needs to have more control packets which leads to control packet overhead. It may extend the time duration of SN’s active state and also which increase the energy consumption of the SN. In contrast, SN using asynchronous duty cycle mechanism does not require any previous synchronization, and it requires the retransmission of packets. Nodes in traditional unicast routing must wait for the destined node to wake up, which consumes more energy and time. Opportunistic routing, on the other hand, selects its receiver based on the situation and provides dynamic routing progress, which saves both energy and time. In this, every SN will broadcast neighbour information (NEI_INFO) packet once. After this phase, every SN has the information about its neighbour and communicates the NEI_INFO control packet. The



Assume static base station

Figure 2: Hybrid hierarchical architecture with 100 nodes.

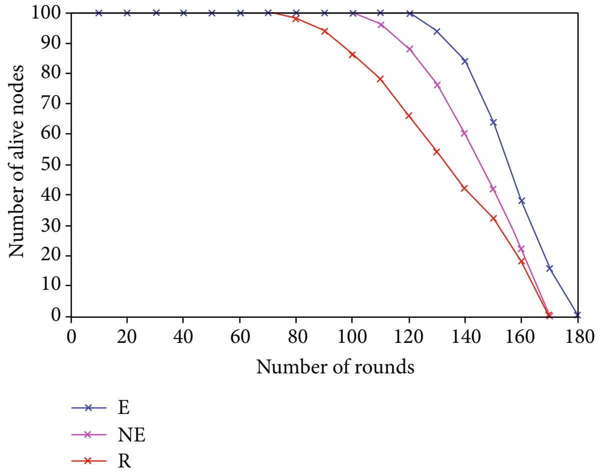


Figure 3: Number of SNs that are alive as a result of aggregation.

NEI_INFO packet comprises the ID of the sender. It performs the below operations after receiving the NEI_INFO packet:

(i) The current SN-ID is checked in the neighbour list. Include the sender ID if it is not included in the neighbour list; otherwise, drop it

(ii) If the neighbour SN updation variable (NEI_INFOUPDATE) is false, at that point, the receiver node sets NEI_INFOUPDATE to true and communicates the NEI_INFO packet

After the neighbour node discovery phase, cluster formation takes place. Initially, all SNs have the same energy level.

After the neighbour node discovery, the BS will monitor and calculate the residual energy of each SN. Initially, BS selects the CN and CNH based on the R method and then forms the intra- and intercluster. Since BS knows all SN neighbour information, it chooses the path between CN to CNH and CNH to BS depends on the remaining energy of the path (p) must be higher than the threshold value and also the energy consumed by the path must be a lower among the other path. The estimated quantity of node required among the intracluster is computed by using Equation (9).

$$\mathrm{SN}_{\mathrm{exp}} = \left\lceil \frac{\pi R^2}{|A|} \right\rceil * n, \tag{9}$$

where $\mathrm{SN}_{\mathrm{exp}}$ is the predicted number of nodes within the cluster range R. The CN's coverage area is πR^2, with "A" denoting its network region and n denoting the quantity of SN in the region. Equation (10) provides the proper number of CN to support the intracluster.

$$\mathrm{CN}_{\mathrm{req}} = \left(\frac{n}{1 + \mathrm{SN}_{\mathrm{exp}}} \right). \tag{10}$$

The quantity of SN inside the network is denoted by n. Equation (11) shows the necessary number of CNH to reach the intercluster.

$$\mathrm{CNH}_{\mathrm{req}} = \left(\frac{1}{5} \right) \mathrm{TCN}, \tag{11}$$

where TCN denotes the network's total count of CNs.

3.4. CN and CNH Intimation. After the CN and CNH selection, the selected CN and CNH will be intimated to the SNs

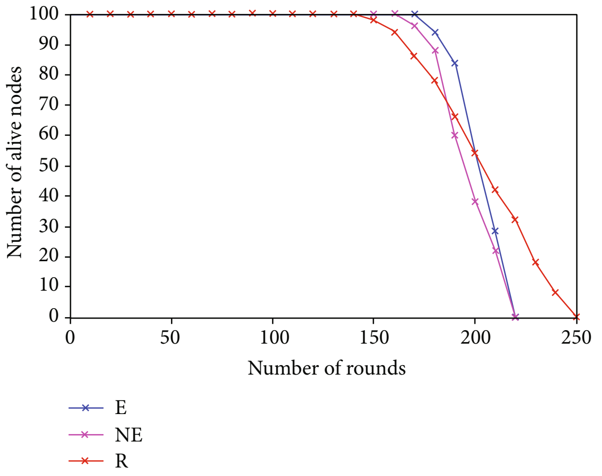


Figure 4: Number of SNs that are alive as a result of without aggregation.

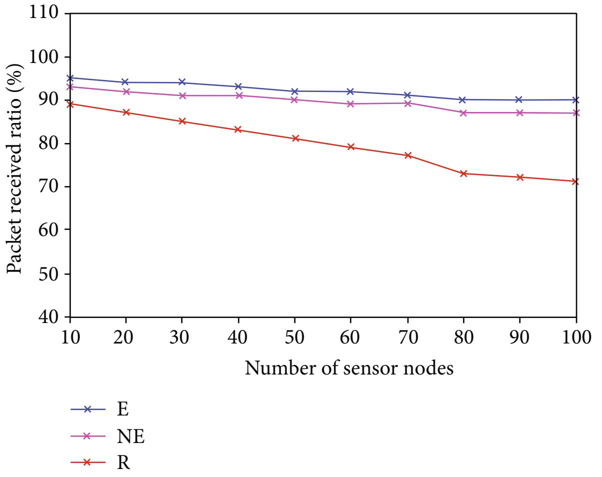


Figure 5: Packet received ratio with data aggregation.

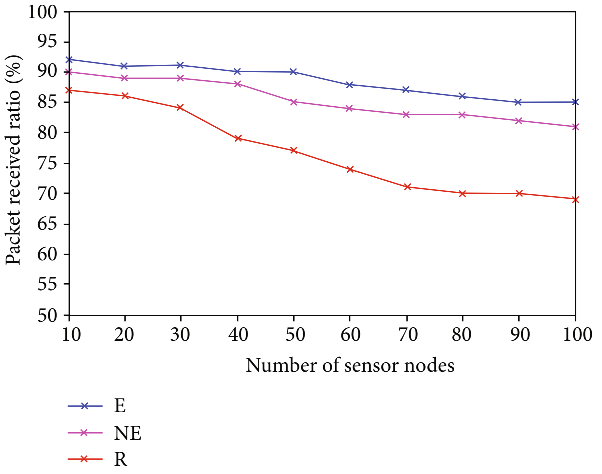


Figure 6: Packet received ratio without data aggregation.

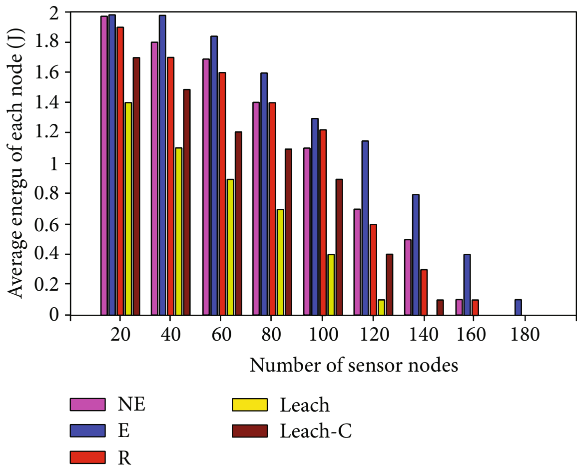


Figure 7: Average energy of each node with aggregation.

in the network. The BS sent the intimation (CN_INT and CNH_INT) to all SN via multihop. The CN_INT and CNH_INT packets reach the SN_ID$_{\text{CN}}$ and SN_ID$_{\text{CNH}}$ via finding the next neighbour (NXT_NEI), and the same reverse path will be used to send the CN and CNH intimation of acknowledgment (ACK) CN_INT$_{\text{ACK}}$ and CNH_INT$_{\text{ACK}}$. The BS will wait for the ACK packet within the time limit. If such ACK packet is not obtained within its time limit, then it resends the intimation packet again to avoid the block-hole problem.

3.5. Cluster Formation. SN chooses its CN based on more than one ADV message (CN_ADV) and the higher RSS indication. After choosing the CN, the SN sends the join request (CN_JOIN or CNH_JOIN) to CN or CNH. After receiving the CN_JOIN or CNH_JOIN request, the CN or CNH sends the join request ACK message (CN_JOIN$_{\text{ACK}}$ or CNH_JOIN$_{\text{ACK}}$) to the requested SN. To avoid the congestion, CN and CNH allot the time slot to their members depends on TDMA and send it to their members.

3.6. Data Transmission. CM transmits its generated information to the CN depends on the specified time slot. The CN compiles the information and transfers it to its CNH. After receiving the information from CN, the CNH transfers an ACK message to CN. If CN does not get the ACK from the CNH, then it retransmits the information. CNH collects all the information and assesses the message by using the CN ID. If CN ID is within its table, then it accepts the data packet and sends the ACK to the CN. Otherwise, CNH informs to the BS about the intruder then BS reforms the cluster by using new cluster ID. The CN, CNH, and BS monitor the residual energy of intramember or intercluster node in the network topology.

3.7. Rerouting and Reclustering. The BS starts the reclustering and rerouting process. It keeps track of every SN's lingering energy in order to balance the load across the network. If any CN or CNH's remaining energy gets low, the BS starts reclustering or rerouting, depending on its position. This

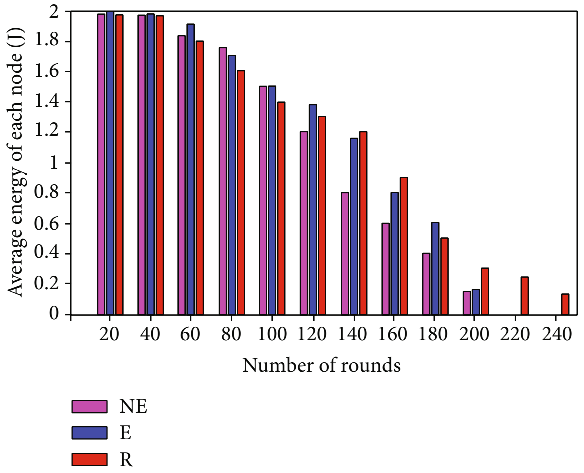


Figure 8: The node's average energy without aggregation.

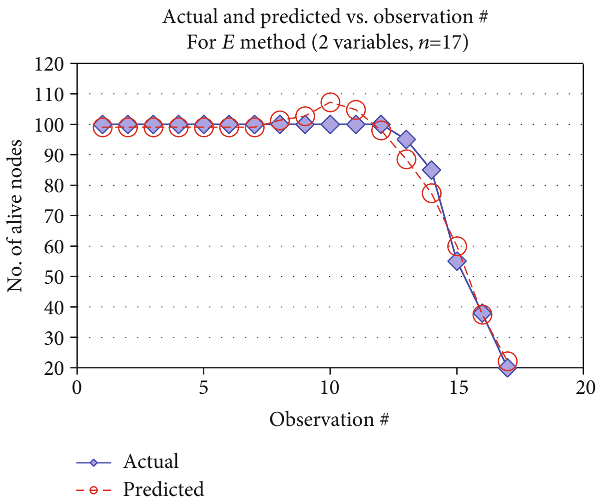


Figure 9: Typical time series graph (actual and predicted nodes).

strategy increases the lifetime of the WSNs. If the SN's residual energy falls below a certain level, it will not take part in CN or CNH role; only it will act as a CM.

4. Results and Discussion

There are 100 SNs uniformly deployed in the rectangular region of 100 m × 100 m with BS is situated at the middle of the region. Before starting the simulation, data packet size is initialized with 512 bytes and the SN energy is initialized with 2 J. The proposed hybrid hierarchical secure clustering method's performance is evaluated, and the performance is compared with the LEACH protocol. The quantity of SNs active without and with aggregation, packet delivery ratio, and average energy dissipation are used to assess efficiency.

4.1. Node Deployment. Table 1 shows the assumptions that have been made for the node deployment.

The node deployment and indication of the CN and CNH are shown in Figure 2. In the figure, node numbers 15, 27, 33, 66, and 76 are CNs and node numbers 22, 69, and 72 are the CNH. The node numbers 22, 69, and 72 act as CN for its clusters as well as acting as CNH 2 or more clusters.

4.2. Network Lifetime. Figure 3 shows how the *E*, *R*, and NE strategies' routing is carried out through data aggregation. According to the results, 75% of SNs are active, for the *E* method, it is up to round 145, for the NE, it is up to round 130, and for the *R* method, it is up to 110 rounds. Furthermore, for method *E*, all SNs are active up to 120 rounds, while for the *R* and NE types, all SNs are active only up to 70 and 100 rounds. As a result, it can be inferred that *E* has more SNs alive and so the NE method is a more effective WSN routing method than the *R* method.

Figure 4 presents the total number of SNs active in comparison to the number of cycles without data aggregation. All SNs are active through to round 170 for the method *E* when transmission is done without data aggregation. It is also discovered that all SNs are active for NE and *R* methods, which have a lesser number of cycles than the *E* method. All SNs are active through 170 cycles for the NE and *R* methods, which is 96% and 86%, respectively, and is still less than that of the *E* metho, that has all SNs alive up to 160 cycles, which is 100%. As a result, even without data aggregation, the *E* approach is found to be a more robust routing method for WSNs.

4.3. Packet Received Ratio. The packet received ratio refers to the proportion of packets which might meet the BS. Equation (12) can be used to measure the packet received ratio.

$$\text{Packet received ratio} = \frac{\text{The quantity of packets that BS has received.}}{\text{Data packets sent through all SNs combined}}. \tag{12}$$

Figure 5 depicts the packet received ratio for data aggregation type. From this, *E* and NE methods receive more packets than *R* method by utilizing the data aggregation type. Either the number of nodes is lesser or greater, this algorithm receives a greater number of packets in the *E* and NE methods than *R* method. The packet received ratio for without data aggregation method is shown in Figure 6. From this, it is found that the *E* and NE methods receive more packets than *R* method by utilizing the without data aggregation type. Either the number of nodes is less or greater, this algorithm receives more packets in the *E* and NE methods than the *R* method.

4.4. Energy Utilization. Figure 7 demonstrates the effect of various proposed routing approaches with data aggregation on the average energy consumption in every node. The suggested methods use very little energy when compared to LEACH-C and LEACH routing protocols, as can be seen in the figure. The suggested NE, *E*, and *R* approaches are analysed for average energy consumption of each SN without conducting the grouping process, and hence, this performance is compared with the existing protocols. Figure 8 illustrates the comparisons of proposed routing approaches

Table 2: Descriptive analysis.

Descriptive statistics	Method name	# fitted	Mean	Median	Std. Dev.	Root.M. Sqr.	Std.Err. mean	Minimum	Maximum	Skewness	Kurtosis
Number of nodes alive with data aggregation	*E*	17	87.824	100.000	24.998	91.110	6.063	20.000	100.000	-2.036	3.048
	NE	17	81.000	100.000	31.723	86.650	7.694	0.000	100.000	-1.677	1.805
	R	17	73.588	92.000	33.081	80.282	8.023	0.000	100.000	-1.046	-0.136
Number of nodes alive without data aggregation	*E*	23	89.130	100.000	26.995	92.959	5.629	0.000	100.000	-2.556	5.701
	NE	23	84.391	100.000	30.711	89.577	6.404	0.000	100.000	-1.867	2.230
	R	23	82.478	100.000	27.528	86.761	5.740	19.000	100.000	-1.335	0.274
Packet received ratio without data aggregation	*E*	10	88.700	89.500	2.497	88.732	0.790	85.000	92.000	-0.270	-1.630
	NE	10	85.900	85.500	3.071	85.949	0.971	81.000	90.000	-0.228	-1.129
	R	10	77.000	75.500	6.583	77.253	2.082	69.000	87.000	0.520	-1.354
Packet received ratio with data aggregation	*E*	10	92.500	92.000	1.316	92.514	0.543	91.000	96.000	0.990	0.208
	NE	10	91.500	91.500	1.754	91.509	0.628	90.000	94.000	0.504	-0.468
	R_-	10	80.700	81.000	5.677	80.880	1.795	72.000	89.000	-0.109	-1.174

Table 3: Time series analysis.

Confidence interval 95%	Method name	*R* -squared	Adj.*R*-Sqr.	Std.Err. Reg.	Std.Dep. Var.	# fitted	# missing	Critical *t*	Confidence
Number of nodes alive with data aggregation	*E*	0.978	0.974	3.999	24.998	17	1	2.145	95.0%
	NE	0.962	0.991	3.082	31.723	17	1	2.145	95.0%
	R	0.966	0.961	6.531	33.081	17	1	2.145	95.0%
Number of nodes alive with data aggregation	*E*	0.982	0.925	7.408	26.995	23	2	2.086	95.0%
	NE	0.930	0.978	4.548	30.711	23	4	2.086	95.0%
	R	0.948	0.943	6.556	27.528	23	4	2.086	95.0%
Packet received ratio with data aggregation	*E*	0.860	0.819	0.729	1.316	10	0	2.365	95.0%
	NE	0.836	0.789	0.623	1.754	10	0	2.365	95.0%
	R	0.851	0.847	2.220	5.677	10	0	2.365	95.0%
Packet received ratio without data aggregation	*E*	0.917	0.893	0.818	2.497	10	0	2.365	95.0%
	NE	0.931	0.912	0.912	3.071	10	0	2.365	95.0%
	R	0.905	0.878	2.298	6.583	10	0	2.365	95.0%

without data aggregation. From the figure, it can be seen that the LEACH protocol consumes 50% of energy during the 60th round, and LEACH-C consumes the same energy during the 80th round, while the NE and *R* approach consumes 50% during 100th round, and method *E* consumes 50% during 120th round. The proposed method *E* operates up to 180 rounds, and this is greater than that of any other approach. The *E* and NE methods would outperform than *R* method, according to the results.

4.5. Time Complexity Analysis. In time complexity analysis, the CN and CNH intimation for time complexity are considered, because the time complexities of other phases are simple and can be ignored. The time complexity of EEDCR is $O(n \log H)$ where n is number of SN that needs to be clustered and H is set of CN. From the simulation results, it is seen that the number of CH during each round distribution is between 5 and 25, and the average number is 5 so the theoretical value is 5. As a result, the EEDCR time complexity is small, and its speed is high.

4.6. Time Series Analysis. Time series analysis, also known as trend analysis, is a statistical approach for analysing the properties of an independent variable across time and is used in a variety of applications to make time-based predictions. Figure 9 shows the typical time series analysis of the number of alive nodes with respect to number of observations. From the graph, it is seen that the actual and predicted values are lying in line with 95% confidence interval. Table 2 lists the regression statistics about the proposed *E*, NE, and *R* methods with data aggregation. From the table, it is known that method *E* is acceptable compared with NE and *R* methods because of high mean value and less standard deviation. Time series analysis is presented in Table 3. From this table, it is confirmed that the method *E* outperforms the NE and *R* methods with 95% confidence interval.

5. Conclusion

The performances of the proposed NE, *E*, and *R* methods are analysed based on the factors including lifetime of the SN, packet received ratio, SN's average energy, and by changing the number of SNs and number of rounds. From this analysis, it is found that the NE and *E* approaches succeeded in outperforming with and without aggregation than the *R* method. Our proposed protocol (EEDCR) uses cluster-based routing, where the source node inserts the information about the path in the data packet, enabling it to push the intermediate nodes to attain the optimum target. The data packet's header contains only a decreased integer number rather than the entire sequence of intermediate node, unlike other approaches. That value serves as a description of the transit path, containing all of the information necessary for its data packet to arrive at the destination. In this paper, the proposed EEDCR protocol was analysed with the help of time series analysis by considering only SS. The performance of this protocol will be analysed by considering the MS in future.

Data Availability

The sensor node's average energy data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The corresponding author confirms that there is no conflict of interest on behalf of all authors.

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