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ARTICLE

A Traffic-Aware and Cluster-Based Energy Efficient Routing Protocol for IoT-Assisted WSNs

Hina Gul[1], **Sana Ullah**[1], **Ki-Il Kim**[2,*] **and Farman Ali**[3]

[1]Department of Computer and Software Technology, University of Swat, Mingora, 19130, Pakistan

[2]Department of Computer Science and Engineering, Chungnam National University, Daejeon, 34134, Republic of Korea

[3]Department of Applied AI, Sungkyunkwan University, Seoul, 03063, Republic of Korea

*Corresponding Author: Ki-Il Kim. Email: kikim@cnu.ac.kr

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ABSTRACT

The seamless integration of intelligent Internet of Things devices with conventional wireless sensor networks has revolutionized data communication for different applications, such as remote health monitoring, industrial monitoring, transportation, and smart agriculture. Efficient and reliable data routing is one of the major challenges in the Internet of Things network due to the heterogeneity of nodes. This paper presents a traffic-aware, cluster-based, and energy-efficient routing protocol that employs traffic-aware and cluster-based techniques to improve the data delivery in such networks. The proposed protocol divides the network into clusters where optimal cluster heads are selected among super and normal nodes based on their residual energies. The protocol considers multi-criteria attributes, i.e., energy, traffic load, and distance parameters to select the next hop for data delivery towards the base station. The performance of the proposed protocol is evaluated through the network simulator NS3.40. For different traffic rates, number of nodes, and different packet sizes, the proposed protocol outperformed LoRaWAN in terms of end-to-end packet delivery ratio, energy consumption, end-to-end delay, and network lifetime. For 100 nodes, the proposed protocol achieved a 13% improvement in packet delivery ratio, 10 ms improvement in delay, and 10 mJ improvement in average energy consumption over LoRaWAN.

KEYWORDS

Internet of Things; wireless sensor networks; traffic load; clustering; routing; energy efficiency

1 Introduction

The Internet of Things (IoT) network is comprised of smart, autonomous, and heterogeneous devices that are interconnected and can freely exchange information with each other. The concept of IoT evolved from the integration of several technologies such as wireless communication, real-time data processing and transmission, and machine learning supported by advancements in network technology and ubiquity of wireless sensors. IoT provides convenience by automating daily life tasks and optimizes decision-making by real-time data analysis. By connecting daily life objects like home accessories, automobiles, and industrial machinery, IoT ensures smooth interaction between people and devices that revolutionize lifestyles. IoT applications cover numerous domains that include smart homes, where devices can optimize household activities; smart hospitals, where patients can be monitored remotely; industrial IoT, where processes can be made automatic; and smart cities, improving urban life by developing smart infrastructures for utilities, transportation, and people's safety [1–4]. By exploiting numerous IoT technologies, people can also monitor the behavior of things using remote systems distantly [5]. The demand for IoT devices is increasing day by day and it is estimated that the quantity will reach 75 billion by 2025 [6].

IoT can be integrated with conventional Wireless Sensor Networks (WSNs) to improve the processing capabilities and functionalities of the IoT-assisted nodes. IoT-assisted WSNs facilitate data processing closer to the source, unlike traditional WSNs which gather data from various sensor nodes and send it to a central Base Station (BS) for processing. This local processing in IoT-assisted networks which is enabled by fog and edge computing technologies minimizes traffic load over the network and also reduces latency. By processing data near the sources, these networks can improve energy utilization and extend network lifetime. Moreover, they can efficiently make real-time decisions [7,8].

Additionally, IoT-assisted WSNs are interoperable and can support devices with different standards [9,10]. One of the key challenges in IoT-assisted networks is to successfully deliver the data to the BS. Compared to homogeneous WSN, efficient and reliable data routing in IoT-assisted WSN is more challenging due to the heterogeneous nature of IoT-assisted nodes, different energy levels, and traffic rates [11]. Routing protocols are important to guarantee timely data delivery according to the Quality of Service (QoS) requirements. Most IoT-assisted devices have limited resources in terms of power, computation, and storage. The routing protocol should focus on efficient energy utilization when sending data to the BS. One of the solutions is to divide the IoT networks into clusters, where data is collected within the cluster by the Cluster Heads (CHs) using a Medium Access Control (MAC) protocol. The CHs then route the data packets by selecting the less congested and shortest path towards the destination. The clustering-based approach is widely used for routing in traditional WSNs because clustering reduces traffic overhead in the network keeping the traffic flow restricted mainly inside the clusters. Another reason is it minimizes bandwidth utilization and energy consumption. Energy consumption can be reduced by selecting optimal CHs like one with high Residual Energy (RE). Network lifetime can also be improved due to efficient clustering, however, in conventional clustering, route selection is usually based on limited attributes. The clustering-based approach can be extended to accommodate heterogeneous IoT-assisted nodes. Here, the heterogeneous nodes with different energy resources can be divided into clusters. A node with high RE can be selected as a CH only. The other nodes with low RE can become cluster members. This strategy can extend the cluster lifetime and minimize energy consumption due to less clustering overhead. In IoT-assisted networks, the next hop selection can depend on multiple attributes like distance to the BS, hop counts, queue and buffer lengths, RE, and traffic load.

In this paper, we propose a Traffic-Aware, Cluster-Based, and Energy-Efficient (TCER) routing protocol that allows various IoT-assisted nodes to successfully deliver data to the BS. Initially, the TCER protocol categorizes the network into super and normal nodes based on their REs, where super nodes have higher energy resources than normal nodes. This categorization is done to select only the high RE nodes as CHs. The protocol supports an algorithm that selects a CH having high RE values among super and normal nodes. Once the CH is selected, the TCER protocol allows the CH to collect data from the child nodes using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. The protocol then delivers the data collected at each CH to the BS by selecting the next hop based on three parameters, i.e., distance, traffic load, and residual energy. These parameters for selecting the next hop significantly optimize the route for delivery of data packets towards the BS. For different numbers of nodes, packet size, and traffic rates, we evaluate and compare the performance of the proposed protocol using NS3.40 with a low-power and wide area routing protocol called LoRaWAN [12] in terms of end-to-end Packet Delivery Ratio (PDR), end-to-end delay, energy consumption and network lifetime. The main contributions of this paper are summarized below:

- Formation of clusters, based on RE values of super and normal nodes, leading to the creation of stable clusters. Reduction of clustering overhead by re-selecting CHs within the clusters, thus avoiding re-clustering of the entire network.
- Optimal routing decisions by incorporating multi-criteria attributes such as energy, distance, and traffic load of the neighboring nodes in the route selection process.
- Detailed evaluations and analysis of the proposed protocol using NS3.40 under various scenarios and demonstrating its effectiveness over LoRaWAN in terms of end-to-end PDR, end-to-end delay, energy consumption, and network lifetime.

The remainder of this paper is organized as follows: Section 2 presents related work in IoT and WSN routing protocols, highlighting existing challenges and opportunities. Section 3 presents the proposed protocol. Section 4 presents the simulation results and discussion with evaluation metrics employed to assess the performance of the proposed protocol. Finally, Section 5 concludes the paper.

2 Related Work

Various low-power routing protocols have been developed for IoT networks to handle the particular difficulties posed by IoT devices. Of all the most common is the Routing Protocol for Low-Power and Lossy Networks (RPL) proposed for IoT networks [13,14]. The protocol could build the network routes quickly using Destination-Oriented Directed Acyclic Graph (DODAG) by consuming less power. But it had some limitations too such as low throughput, limited flexibility to dynamic data traffic and having no support for non-stationary nodes. The authors of [15] proposed another protocol called Cognitive Radio Opportunistic Forwarding Protocol that retained the same DODAG approach as in RPL and also introduced improved modifications to enable its use in Cognitive Radio environments. The reactive hop-by-hop routing protocol known as Ad-hoc On-demand Distance Vector (AODV) was proposed [16] that employed a Route Request- (RREQ-) Route Reply- (RREP-) cycle which was initiated each time a packet needed to be routed to an unknown location.

Low Power Wide Area Network (LP-WAN) routing protocols provided an alternative solution to short-range IoT connections. Both the standard and proprietary LP-WAN routing protocols were used in IoT applications and could accommodate the needs of these applications [17]. The spread spectrum modulation technique known as long range (LoRa) provided secure data transmission, low battery-life consumption, and wide area coverage [18]. LoRa used a Carrier Activity Detection (CAD) mechanism to detect an incoming signal. However, CAD is not efficient because it can detect a wrong signal that could create problems in decoding. Baker et al. [19] proposed an energy-aware routing protocol to optimize power usage for data transmission to cloud servers and evaluated the experimental outcomes using linear programming techniques. However, when used in large-scale networks, the protocol could encounter scalability issues. In 2018, Baker et al. [20] proposed another power-aware routing mechanism for vehicular networks based on the AODV protocol. The protocol's shortcoming was that it depended on the underlying AODV protocol, which could have issues with adapting to changing network circumstances. The authors in [21] proposed an energy-efficient routing protocol for cognitive radio networks that used IEEE 802.11 MAC protocol. The algorithm selected routes that had minimum forwarding nodes with sufficient RE. This increased per node capacity to fulfill the requirements of IoT applications while conserving the energy of the nodes. Dhumane et al. [22] proposed an energy-aware routing technique for IoT networks; however, the algorithm's complexity affected its real-time performance and deployment in resource-constrained IoT devices. A clustering technique was proposed by Preeth et al. [23] to improve the energy efficiency of routing protocols in WSN-assisted IoT. The scalability of the immune-inspired routing algorithm in large-scale IoT installations might be impacted by higher cluster communication cost. A partly energy-aware routing technique was presented by Wang et al. [24] in order to balance WSN nodes' energy usage in the AODV protocol. The drawback was that not all nodes in the network might have had their dynamic energy consumption patterns completely addressed by the partial energy-aware routing technique.

Most of the previous research work on routing protocols exploited a number of cluster-based routing techniques for homogeneous networks that reduced power consumption and increased network lifetime. Low-energy adaptive clustering hierarchy (LEACH) [25] is one of the pioneering cluster-based routing protocols that were developed. In this protocol, all nodes, regardless of their REs, have an equal chance of being elected as CHs by random selection. In order to cope with the RE problem, an advanced algorithm [26] was proposed called region-based low energy adaptive clustering hierarchy (R-LEACH). Here, the node with the highest RE is chosen to be the CH for that round, and so on, until all of the network's nodes used their energies. In contrast to other methods proposed for IoT-based WSN, such as Cycle-based Data Aggregation Scheme for Grid-based Wireless Sensor Networks, Improved Grid-based Hybrid Network Deployment, and Grid-based Hybrid Network Deployment, R-LEACH extended the network lifetime. To balance the energy load in the network, the CH equation was updated by the authors in [27]. Here, the LEACH-Modified (LEACH-M) approach was used to choose CHs, which took network address and RE into account. Simulations revealed that the suggested algorithm performed better in terms of energy consumption and network lifespan than LEACH, LEACH-Centralized (LEACH-C), and ENERGY-Efficient LEACH. LEACH-C and LEACH-R were hybridized in the work presented in [28] called as LEACH-CR for energy-efficient LEACH. Simulation results showed that the proposed protocol performed better in terms of energy consumption, network lifetime and packets sent to BS as compared to LEACH and its previous variants. The Stable Election Protocol (SEP) was a cluster-based routing protocols for heterogeneous networks proposed by Smaragdakis et al. [29]. In this protocol, CHs were chosen using a weighted election probability based on node energy levels, giving preference to advanced nodes with greater energy percentages. The authors in [30] presented a hybrid routing protocol for heterogeneous networks called Zonal-SEP (Z-SEP) which combined normal nodes that delivered packets to the BS in a single hop and advance nodes that used clustering techniques such as SEP. Although Z-SEP was more stable and performed better than LEACH and SEP, it had a problem in that normal and advance nodes were not taken at random positions. The authors in [31] introduced Hy-IoT, an energy-aware clustering communication protocol with the goal of bridging the gap between heterogeneous IoT settings and homogeneous WSN. The protocol selected CHs according to the degree of heterogeneity in the region using weighted election probabilities. Although Hy-IoT performed better than SEP, LEACH, and Z-SEP, the uneven distribution of nodes remained a limitation. Haseeb et.al, proposed a Reliable Cluster-based Energy-aware Routing (RCER) protocol for heterogeneous WSN that increased network lifetime and decreased routing complexity [32]. RCER made use of energy of heterogeneous nodes to create clusters. Furthermore, the protocol defined multi-criteria for next hop selection that included RE, hop count and round trip time.

Other important routing techniques for IoT networks are traffic-aware routing techniques, which can dynamically adapt to changing traffic patterns. The authors in [33] proposed a congestion-aware routing protocol called Queue Usage Routing Protocol for Low Power and Lossy Networks (QU-RPL). The protocol took the queue usage of neighboring nodes into account when selecting a parent node. In order to lower the likelihood of selecting a busy node for the subsequent hop, it incorporated queue manipulation. Although the static congestion threshold of QU-RPL worked well in real-world test-beds for load balancing under high traffic, it may not be as flexible for dynamic traffic. The protocol proposed in [34] presented a traffic-aware and load-balancing routing scheme aimed for industrial IoT. The protocol handled high traffic loads efficiently. The technique involved the selection of optimal routing paths proactively which could balance the network traffic load thus improving network robustness and efficiency. The authors in [35] introduced Energy and Congestion-Aware Routing Metric (ECRM), a unique adaptive parent selection technique, in the context of sophisticated metering infrastructure networks inside RPL. To reduce power consumption and improve PDR, ECRM used neighboring nodes' RE and queue usage as criteria for parent selection. The survey presented in [36] reviewed various congestion control strategies in RPL-based wireless sensor networks. The protocols addressed in the paper considered congestion detection metrics like queue utilization, packet losses and packet delivery ratios. The protocols also considered routing metrics such as expected transmission count and latency in order to improve network reliability. The authors in [37] proposed a new traffic-aware and cluster-based routing protocol named as Traffic-Aware Clustering based Routing Protocol for vehicular ad-hoc networks. The goal was to improve traffic management and to minimize energy consumption in the dynamically varying vehicular network using a traffic management unit. Table 1 briefly summarizes some of the key protocols proposed for IoT and WSNs. Based on the existing studies, it is observed that most of the routing protocols focused on WSNs, however, less efforts are dedicated towards the development of a routing protocol for IoT-assisted WSNs where multi-criteria attributes, such as traffic, energy, and distance are considered for next hop selection. The TCER protocol creates balanced clusters in the IoT-assisted networks and selects next hop based on the afore-mentioned multi-criteria attributes.

Table 1: Summary of different routing protocols for IoT and WSNs

Protocol	Problem addressed	Evaluation metrics	Simulator
RPL [13,14]	• Analysis of RPL routing protocol	• RPL overhead • Packet delay	Contiki/Cooja
CORPL [15]	• DODAG approach adaptation of RPL to enable its use in Cognitive radio environments	• PDR • Collision risk factor	MATLAB
LoRa [18]	• Demands of IoT fulfillment for long-range WLANs	• Network lifetime • Energy consumption	Real test-bed

(Continued)

Table 1 (continued)

Protocol	Problem addressed	Evaluation metrics	Simulator
Leach [25]	• Cluster-based routing for micro-sensor networks selecting CHs randomly	• Energy dissipation • Throughput • Network lifetime	MATLAB
R-Leach [26]	• Network lifetime improvement by selecting high RE nodes as CHs in WSNs	• Throughput • Network lifetime	MATLAB
Leach-M [27]	• Balanced network energy consumption by optimizing the CH threshold equation	• Network lifetime • Energy consumption	NS-2
SEP [29]	• Longer stability period for clustered heterogeneous WSNs	•Network lifetime • Throughput	MATLAB
Z-SEP [30]	• Enhancement of the network stability period, lifetime, and throughput by using hybrid approach	• Network lifetime • Throughput	MATLAB
Hy-IoT [31]	• Designing an efficient hybrid energy-aware clustering communication protocol for IoT network	• Network lifetime • Throughput	MATLAB
QU-RPL [33]	• Addressing the congestion and load-balancing problem of RPL	• Queue loss ratio • PRR	Real test-bed
ECRM [35]	• Enhancing network performance taking network's life time and PDR into consideration by selecting parent node with high RE	• PDR • Average power consumption • Lost packets	Contiki/Cooja

3 Proposed Protocol

This section presents a detailed description of the TCER protocol for IoT-assisted WSNs. TCER protocol basically exploits clustering for optimizing transmissions. It simplifies data exchange by grouping nodes into clusters. Subsequently, the optimized route selection phase utilizes the CHs constructed by the TCER protocol to identify potential next hops for forwarding packets. This phase determines the shortest and energy efficient routes. A weighted value of traffic load is also included into routing decisions to avoid overloaded nodes.

The three main phases of TCER protocol, i.e., clusters formation, data gathering and inter-cluster communication/routing are seamlessly integrated to achieve congestion-less routing with improved energy efficiency. These phases are presented in Fig. 1 and are defined as follows:

i) Initially, random clusters are created from the network field based on nodes' RE values. Super or normal nodes (if super nodes are not available) having high RE values are selected as CHs.
ii) Next, data is collected by the CHs inside each cluster from the cluster members using the CSMA/CA protocol.
iii) Subsequently, the optimized route selection phase utilizes the clusters constructed by TCER protocol to identify potential next hops for forwarding the data packets. This phase determines the shortest routes by considering distance and RE values of neighboring nodes. Moreover, a weighted traffic load is also included into routing decisions to measure the network traffic and avoid congested nodes.
iv) Finally, the data packets are forwarded on the optimal paths towards the BS.

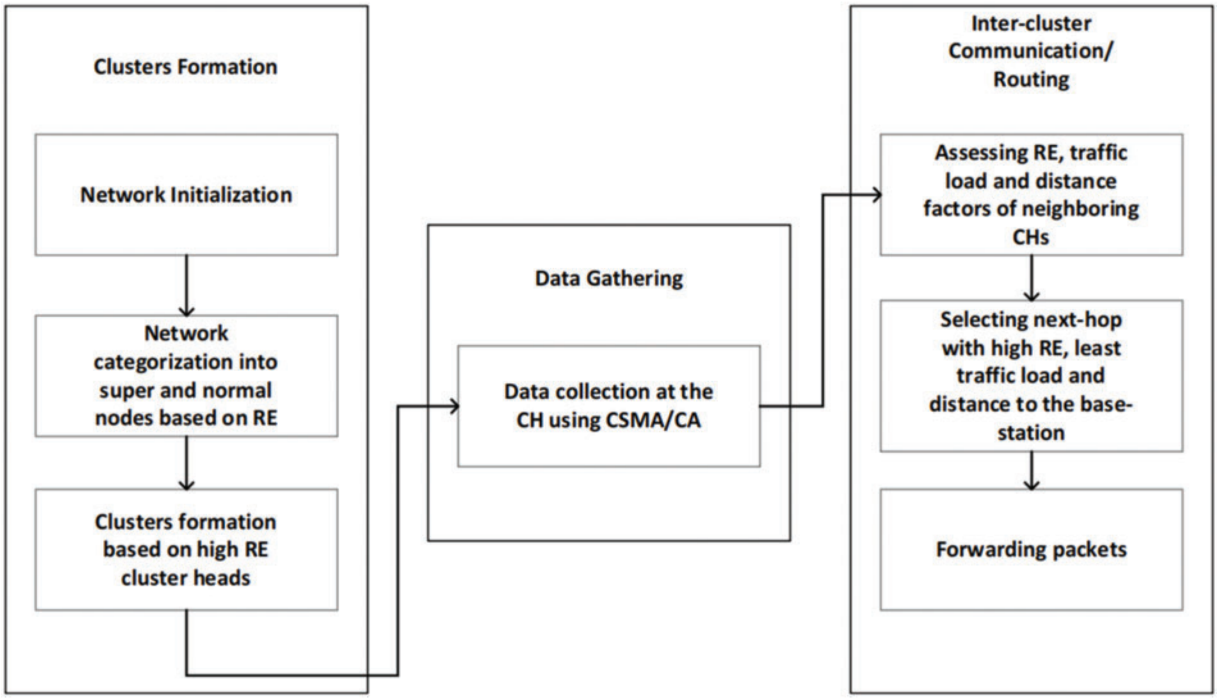

Figure 1: Architecture of TCER protocol

3.1 Clusters Formation

The proposed protocol focuses on achieving energy efficiency, increased network lifetime and minimized delay for data transmissions using a clustering technique. Non-clustered networks usually face a number of difficulties in IoT-assisted WSN that limit their effectiveness. Here, direct communication between individual nodes and the BS leads to increased energy consumption, congestion, end-to-end delay, among other problems. To address these shortcomings and improve network performance, clustering technique emerges as a promising solution. By grouping nodes into clusters, and enabling localized decision-making and data gathering, clustering significantly improves energy efficiency and resilience in the network. Moreover, it minimizes the amount of traffic overhead in the network by gathering data within clusters before forwarding it to the BS.

In the TCER protocol, the clustering round consists of set-up and steady-state phases. In the set-up phase total alive nodes represented by N, having different energy values, are initialized and positioned randomly in the network field. The protocol categorizes the network nodes into set of normal nodes represented by N1 and N2 and super nodes represented by S based on their RE values. S has more energy resources than N1 and N2. The network is categorized in order to select high RE nodes as CHs. The whole procedure of CH selection and cluster formation is addressed in Algorithm 1 (that is called form the main Algorithm 2, after network initialization). During the initial steps of the Algorithm 1, S is selected where RE is above Eth1 (energy threshold for super nodes). Normal nodes that are further categorized into N1 and N2 where N1 are the nodes having RE between Eth2 (Energy threshold for normal nodes) and Eth1. N2 are normal nodes whose RE is less than Eth2 and are added directly to the set of non-cluster heads represented by SNCH. The nodes S and N1 are the candidates for CHs due to their high RE values. After passing through the decision statements they are added to the set of cluster heads represented by SCH. Subsequently, during the following steps, each CH broadcasts a message to all nodes within its clusters, and the node responds to this message using CSMA/CA MAC protocol. After receiving advertisements from all the CHs, each non-cluster head node calculates the Received Signal Strength Indicator (RSSI) of all the broadcasted messages. The node then joins the CH from whom it receives signal with highest RSSI values. In this way, all the clusters are formed.

In IoT-assisted WSNs, the frequency of transmissions and receptions is quite higher which contribute to higher energy consumption, leading to rapid depletion of nodes' batteries. Along with this, the job of CHs also contribute to increased energy consumption since they frequently handle data gathering and forwarding duties, which puts additional load on their batteries. In order to handle this issue Algorithm 1 adds another condition, in which it regularly checks RE of CHs. If a CH's RE drops below the threshold Eth_min, another higher RE member node within the cluster is selected as a CH. Here the protocol reduces clustering overhead by executing the cluster setup phase precisely once at the beginning of network initialization. Subsequently, the CH's position rotates within the area of each cluster, which reduces overall overhead, contributing to an improved network lifetime. After the initial setup is over, the network enters the steady-state phase where it continues to operate normally. Member nodes transmit data packets to their respective CHs using CSMA/CA protocol. Table 2 defines all the parameters used in Algorithm 1, Algorithm 2 and the upcoming flowchart represented in Fig. 2.

Table 2: Parameters with description

Parameter	Description	Parameter	Description
N	Set of all alive nodes	BS	Base station
SNCH	Set of non-cluster heads	Ei	Initial energy
SCH	Set of cluster heads	RT	Routing table
S	Set of super nodes	N_Id	Node id
N1	First set of normal nodes	IP_Add	IPv4 address
N2	Second set of normal nodes	TL	Traffic load
NCH	Non cluster head node	D	Distance to the BS
CH	Cluster head node	Econ	Total energy consumed
Eth1	Energy threshold for super nodes	Etrans	Energy consumed during transmission
Eth2	Energy threshold for N1 nodes	Erecieve	Energy consumed during reception
Eth_min	Energy threshold for CH selection	Eidle	Energy consumed during idle/sleep state
RE	Residual energy	N_Hop	Next hop

(Continued)

Table 2 (continued)

Parameter	Description	Parameter	Description
Limit	Limit of cluster heads	LCH	Leader cluster head
Count	Cluster heads' counter		

Algorithm 1: Clusters Formation (N)

```
Input: Set of alive nodes
Output: Set of cluster heads SCH
BEGIN
while true do
    for Each N do
        Calculate RE of N
        if $RE(N) \geq Eth1$ then
            N becomes S
        end if
        if $RE(N) \geq Eth2$ and $RE(N) < Eth1$ then
            N becomes N1
        end if
        if $RE(N) < Eth2$ then
            N becomes N2
        end if
    end for
    while $RE(S) \geq Eth\_min$ and $count \leq Limit$ do
        S adds to SCH
        $count \leftarrow count + 1$
    end while
    while $count \leq Limit$ do
        if $RE(N1) \geq Eth\_min$ then
            N1 adds to SCH
            $count \leftarrow count + 1$
        Else
            N1 adds to SNCH
        end if
    end while
    for Each CH do
        Broadcast Advertisement message (High power)
        for Each NCH do
            Calculate RSSI (Received Broadcast Advertisement)
            if $RSSI(Sender) = Highest\ RSSI$ then
                NCH joins the cluster
            end if
```

(Continued)

Algorithm 1 (continued)

```
        end for
    end for
      for $i = 0$ to $count - 1$ do
          if $RE(SCH[i]) < Eth\_min$ then
            Sort $SNCH$ w.r.t. Descending_RE inside a cluster
            $SCH[i] \leftarrow Sorted\_SNCH\,[0]$
          Else
            $CH$ will continue
          end if
      end for
end while
return $SCH$
end BEGIN
```

3.2 Data Gathering

After the creation of clusters, the data gathering phase in TCER protocol involves the collection of data packets from individual member nodes within a cluster. During this phase, each member node performs necessary computation and processing, and sends information to its respective CH for further transmission. CH plays a vital role in coordinating the communication and data exchange within the cluster. It collects data from the member nodes using CSMA/CA MAC protocol. The whole process of data gathering at the CH is mentioned in Algorithm 2. Only active member nodes generate data packets. A node that has pending packets first listens to the communication channel. If the channel is free, it sends the packets to the CH. If it is busy, it waits for random back-off time and listens to the channel again. This whole process is repeated unless the channel becomes free. The CH receives the packets from all active member nodes one by one. After all the nodes send their packets, CH gathers them for further forwarding.

3.3 Inter-Cluster Communication/Routing

This is the final phase of the proposed protocol where data is routed towards the BS. Primarily, TCER protocol employs a cluster-based approach to enhance routing efficiency and reliability. The conventional protocols lack procedures for adapting to the heterogeneous nature of IoT-assisted WSNs, where devices have varying capabilities and energy constraints. TCER protocol addresses these limitations by introducing traffic-aware and energy-efficient routing techniques that can handle delivery of data packets collected by CHs.

Prior to clusters formation, TCER protocol involves setting up the network, where configurations are precisely defined and routing tables are established to facilitate data communication as illustrated in Algorithm 2. Nodes are assigned specific attributes, like unique identifiers along with others. Then, in order to determine optimal CHs in the network, TCER protocol initiates the clusters formation process, by calling Algorithm 1. Subsequently, the selected CHs accept packets from the active members of their clusters as addressed in Algorithm 2. When data is completely gathered at the CH, TCER protocol enters into the forwarding phase as mentioned in the algorithm. Here, CHs are involved in relaying data towards the BS. Packets are forwarded in a multi-hop way in TCER protocol, i.e., from CH to CH and then to the BS. Here, determining the next hops is a continuous process for delivering data towards the BS. In order to choose next hops and make routing decisions, the protocol frequently assesses attributes of the CHs, including RE values, Traffic Load (TL), and distance to the BS (D). Specifically, when selecting the next hop, TCER protocol gives top priority to the CH with the minimum amount of TL, high RE values, and the shortest path to the BS. High RE of the CH contributes in keeping it alive for a long time which avoids re-clustering and the rapid change of CH and sustains the selected path for a long time. Low traffic load of the next hop node ensures minimum congestion. Moreover, optimal path is also determined by considering shortest distance of the next hop node towards the BS. The selected CH called as the Leader Cluster Head (LCH) serves as a central node to gather packets from other CHs and forward them to the BS. Fig. 2 represents the overall flow of TCER protocol that includes clustering, data gathering, and routing phases.

Algorithm 2: Routing

```
Input: Set of alive nodes N
Output: Leader cluster head
BEGIN
  Initialize $N$ nodes in the network
  for Each $N$ do
      Assign $Ei$
      Configure RT: Set N_Id, IP_Add, TL, RE, D
  end for
  $SCH \leftarrow$ CLUSTERS FORMATION ($N$)      {Call Algorithm 1 for clusters formation}
  for Each $CH$ do
        Scan available channels()
        Select best channel()
        if Channel is clear() then
            Packet = Generate data packet()
            Send_packet()
            Wait_for_ ack()
            Handle_errors()
      else
            Perform random backoff()
      end if
  end for
  for Each $CH$ do
      $TL \leftarrow$ packets received per second at the $CH$
      $RE \leftarrow Ei - Econ$ where $Econ = Etrans + Ereceive + Eidle$
      $D \leftarrow$ Shortest distance
  end for
   for Each $CH$ do
      if $RE(N\_Hop)$ is Highest and $D(N\_Hop)$ is Lowest and $TL(N\_Hop)$ is Lowest then
            $LCH \leftarrow N\_Hop$
        Else
            $LCH \leftarrow$ Previous $N\_Hop$
      end if
```

(Continued)

Algorithm 2 (continued)

```
end for
Forward packets to $LCH$
$LCH$ forwards packets to $BS$
end BEGIN
```

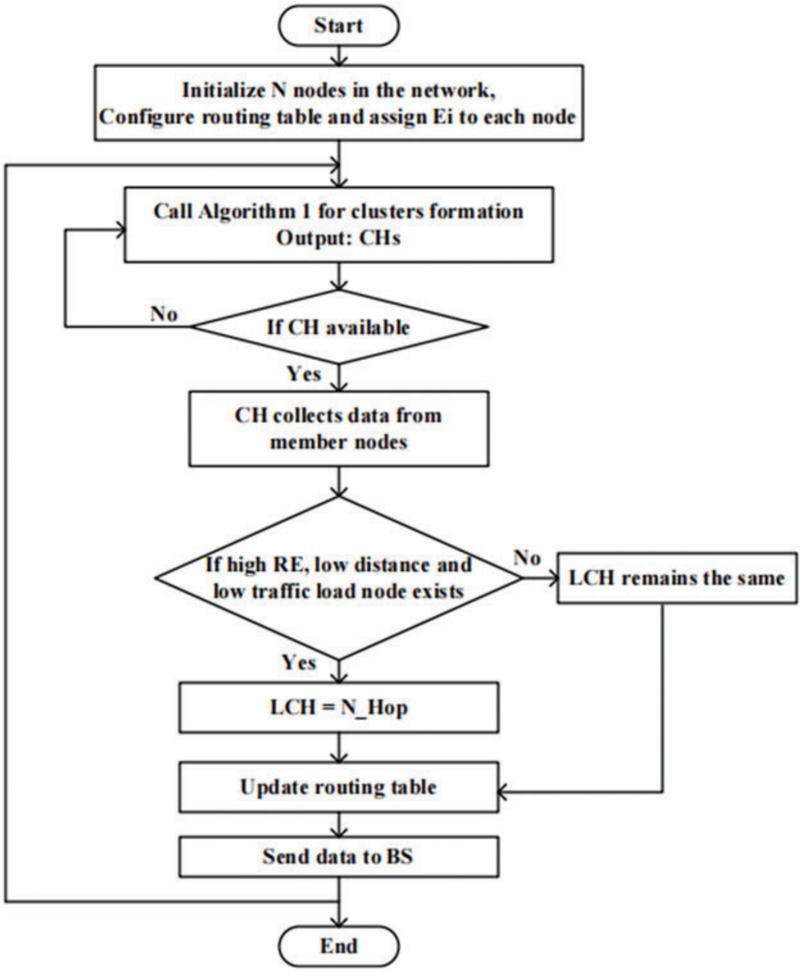

Figure 2: Flowchart of TCER protocol

4 Simulation Results and Discussion

The routing performance of TCER protocol is thoroughly evaluated and compared against LoRaWAN using the latest network simulator, NS3.40. NS3 is a state-of-the-art discrete event network simulator that provides built-in support for different protocols. It is an open source simulator written in C++. Unlike other network simulation tools, such as OMNET++ and OPNET, NS3 is more efficient in terms of computation time and memory utilization. In the NS3 simulation setup, the nodes are assumed to be static, randomly deployed within a network field of 500 × 500 square meters. Since the TCER protocol selects CH among super and normal nodes, we assume a network consisting of super and normal nodes where super nodes have high RE than normal nodes. RE is the remaining/residual energy of a node. RE of the nodes is considered by the protocol in order to categorize the network energy wise. This categorization assists the protocol in selecting high RE CHs improving the cluster lifetime and ultimately the network lifetime. The nodes with RE above 0.8 J are considered as super nodes while the others are normal nodes. CHs are selected among these super and normal nodes with RE above 0.8 J and between 0.7 and 0.8 J, respectively. These high RE CHs also contribute in path selection where these CHs are the candidates for next hop selection. Other parameters such as D and TL are also considered for the decision of next hop selection. D determines the shortest path towards the BS and TL can improve the routing of packets by avoiding congested paths. Packet size is varied for different scenarios of traffic where PDR, delay and energy consumption are assessed against varying traffic load. Simulation time is set as 100 s for each round. Total rounds reach 140 and nodes are varied up to 150. Table 3 briefly outlines the simulation parameters.

Table 3: Simulation parameters

Parameter	Value
Network field	500 m × 500 m
Packet size	256, 512, 1024 B
Simulation time	100 s
Number of rounds	140
Number of nodes	150
RE threshold for super nodes	Above 0.8 J

The evaluation of the proposed protocol involves a series of simulations with varying node counts, traffic loads and different packet sizes. We do a comparison between TCER protocol and LoRaWAN, looking at metrics such as PDR, average energy consumption, and end-to-end delay across scenarios with different number of nodes. Furthermore, we investigate how varying traffic loads (packets per second) affect the network's efficiency. We also consider different packet sizes on different performance metrics like PDR, end-to-end delay, and average energy consumption.

4.1 Packet Delivery Ratio

Fig. 3 shows the PDR (in %) of TCER protocol compared to LoRaWAN as a function of numbers of nodes. The results show that the TCER protocol outperforms LoRaWAN by 13% in terms of PDR. Initially, when the network contains only 10 nodes, both TCER protocol and LoRaWAN achieve maximum PDR of 90% and 82%, respectively. When the nodes gradually increase to 50 in number, a decline for the LoRaWAN can be observed. It is due to the poor scalability of the LoRaWAN which causes delays and thus PDR gets affected. With more increase in number, for example for 100 nodes, the TCER protocol achieve 63% PDR while the LoRaWAN's PDR drops to 50%. Since the TCER protocol considers shorter distances, low traffic nodes, and CH with high RE values that result in less packets drop. This enhances the reception of packets at the BS which results in improved PDR.

To study the network's response for different packet sizes, we analyze the performance of TCER protocol for varying traffic loads. Fig. 4 shows the PDR of TCER protocol for different packet sizes, i.e., 256, 512, and 1024 B, as a function of traffic load. The results show that when the traffic load in packets per second (pps) and packet sizes increase, PDR decreases measurably. This decrease is because high traffic load increases overall traffic on the network, which may further increase chances of packet losses. The figure further shows that the PDR is high for smaller packets compared to that of larger packets. This is because larger packets are most vulnerable to losses compared to smaller packets. Such packet losses cause re-transmissions, which further affect the PDR.

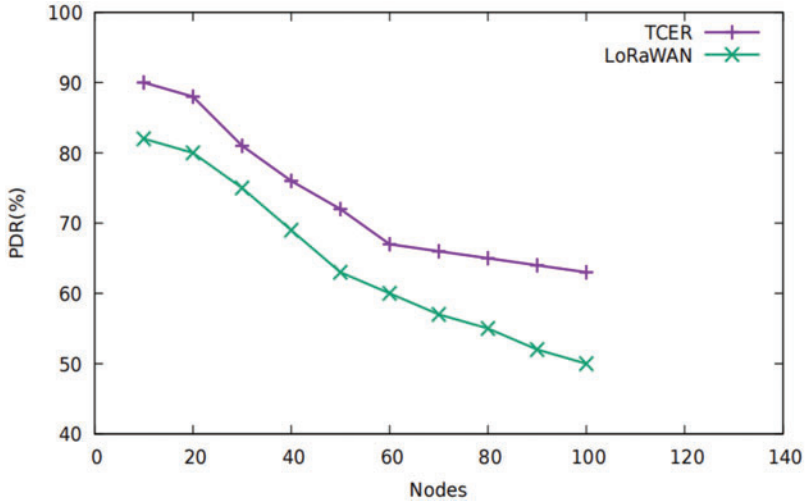

Figure 3: PDR for TCER protocol and LoRaWAN for varying number of nodes

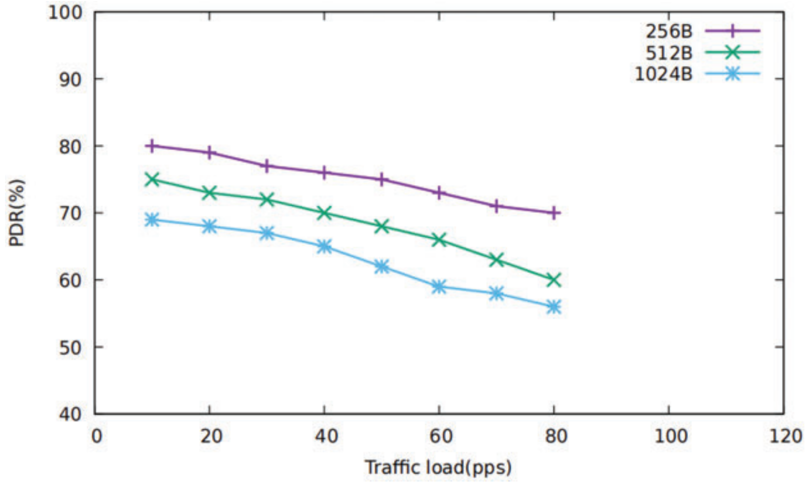

Figure 4: PDR for TCER protocol for different packet sizes under varying traffic loads

4.2 End-to-End Delay

TCER protocol's performance evaluation is also conducted in comparison with LoRaWAN with respect to end-to-end delays. Fig. 5 shows the end-to-end delay of TCER protocol and LoRaWAN for different number of nodes. At the start for less number of nodes both the protocols show fewer delays. But as the number of nodes increases, LoRAWAN shows an upward trend for the delay as can be seen in the figure. For example, for 100 numbers of nodes, the TCER protocol and LoRaWAN achieve 35 and 45 ms end-to-end delays, respectively. The overall results show a significant reduction in average end-to-end delay of TCER protocol compared to that of LoRaWAN. The delays' difference becomes more obvious with increase in number of nodes. This is because LoRaWAN is not scalable and its performance degrades for larger number of nodes compared to that of TCER protocol. The reason is LoRaWAN rely on a central gateway where all other nodes are connected to it. This topology does not scale well for large number of nodes. The nodes communicate with this gateway without multi-hop routing. So, when nodes increase in number the gateway can get overloaded and can create delays in forwarding the data. On the other side, the TCER protocol takes use of independent clusters where each CH collects data from their members inside the clusters and the CHs then forward it towards the BS using multi-hopping. Large number of nodes can be accommodated easily here due to the clustering technique without increasing delay in transmissions.

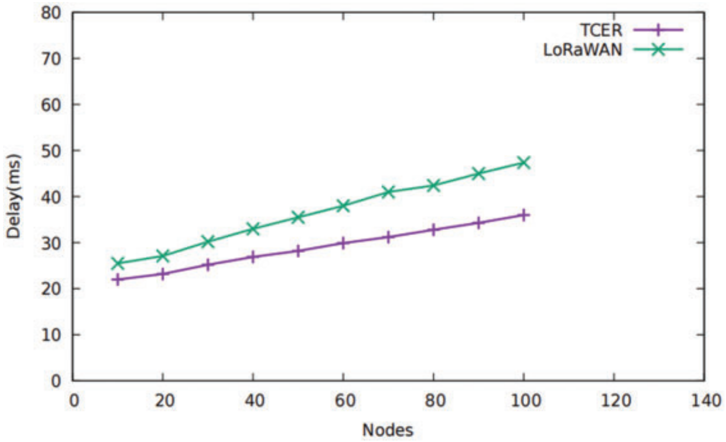

Figure 5: End-to-end delay of TCER protocol and LoRaWAN for varying number of nodes

Fig. 6 presents the end-to-end delay of TCER protocol for different packet sizes under varying traffic loads. As expected, delay shows an increasing trend when the traffic load and packet sizes are increased. It is due to the extended transmission time of larger packets. Another reason is that larger packets may enhance queuing delay, affecting the overall end-to-end delay. Also when traffic increases in the network it overloads the buffers of the forwarding nodes and the pending packets wait for longer before it can be forwarded thus degrading the end-to-end delay.

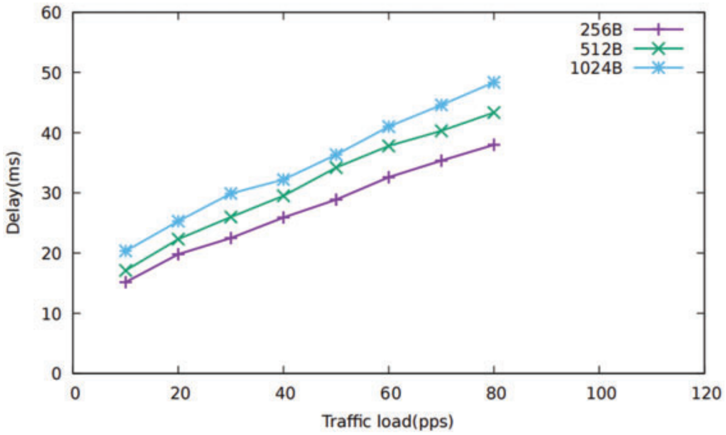

Figure 6: End-to-end delay of TCER protocol for different packet sizes under varying traffic loads

4.3 Average Energy Consumption

The behavior of the TCER protocol in terms of average energy consumption is illustrated in Fig. 7 with different number of nodes. The results indicate that the protocol reduces network energy consumption compared to that of LoRaWAN. This is because the TCER protocol ignores nodes with low RE values to be selected as CHs. Only nodes with high RE values among super and normal nodes are selected as CHs. This reduces unnecessary energy consumption since only CHs actively participate in reception, gathering and forwarding of data packets. This strategy effectively balances energy consumption throughout the network. Initially when only 10 nodes are configured in the network, nodes in both the protocols, i.e., TCER protocol and LoRaWAN consume 8.66 and 12.9 mJ energy on average, respectively. With increase in the size of the network the average energy consumption reaches 101.3 mJ for TCER protocol and 120.3 mJ for LoRaWAN for a total of 60 nodes. Finally the figure shows a 10 mJ improvement for TCER protocol over LoRaWAN for a total of 100 nodes. This improvement is attributed to the selection of less congested and shorter paths during routing which minimizes re-transmission of packets and consequently achieves efficient energy consumption.

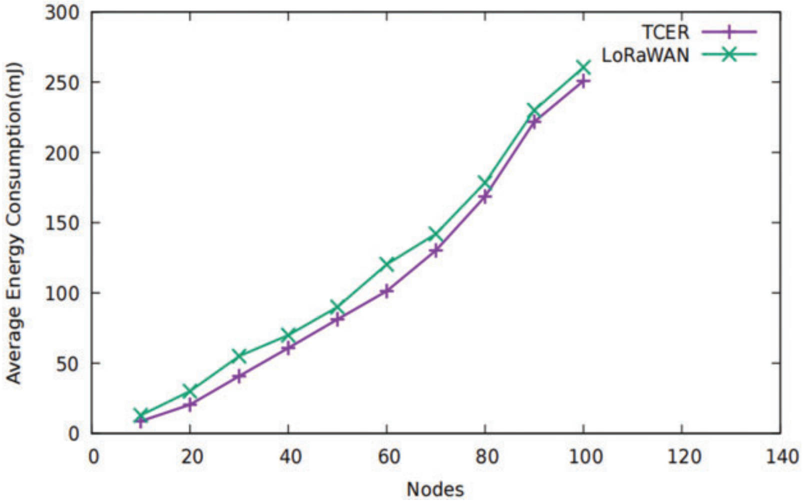

Figure 7: Average energy consumption of TCER protocol and LoRaWAN for varying number of nodes

Fig. 8 shows the average energy consumption for varying packet sizes as a function of traffic load. The figure shows that an increase in traffic load increases overall energy consumption. This is because when more packets are generated by the nodes more packets will be forwarded and more energy will be consumed by the nodes. Additionally, larger packets require more energy because such packets are vulnerable to losses that may cause re-transmissions. For a packet size of 1024 bytes, the average energy consumption of TCER protocol is approximately 80 and 160 mJ for a traffic load of 20 and 80 pps, respectively. While for smaller packet sizes, the average energy consumption is comparatively lower. The figure puts light on how energy consumption is affected by varying traffic load and packet sizes.

The performance evaluation of network lifetime of the TCER protocol is shown in Fig. 9. TCER protocol involves clustering technique where CHs have high RE values. These CHs can remain alive for extended period thus prolonging network lifetime. Additionally, the TCER protocol ignores high traffic nodes having low RE values during routing which may achieve significant improvement in network lifetime. In the figure, the network lifetime is considered using the remaining energy of nodes and is represented in the form of alive nodes against number of rounds. At the end of each round, some nodes get their batteries exhausted, going to a dead state.

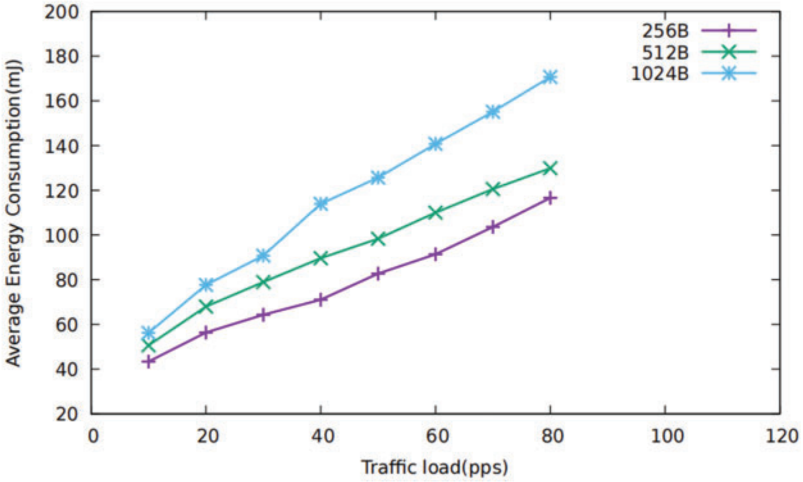

Figure 8: Average energy consumption of TCER protocol for different packet sizes under varying traffic loads

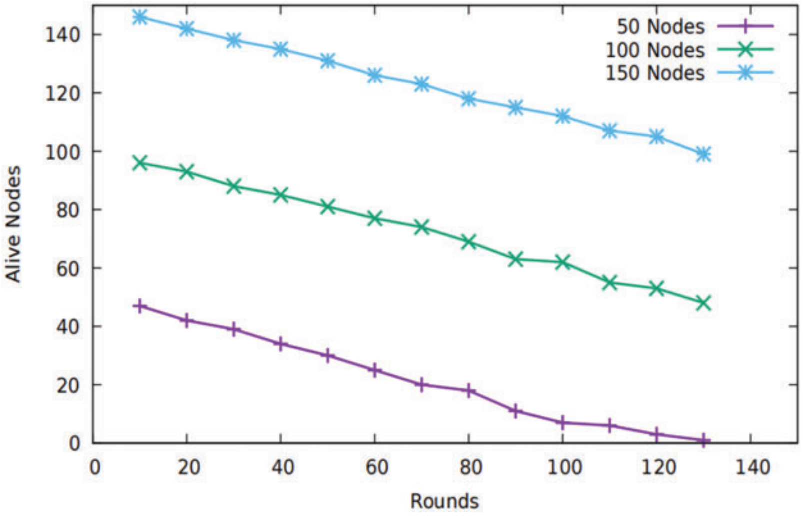

Figure 9: Alive nodes *vs*. number of rounds

As the number of rounds increases, alive nodes whose batteries get depleted, start dying. This can be observed in Fig. 9 where all the curves for different number of nodes show a decline. For smaller networks with 50 number of nodes, the number of alive nodes decreases more quickly as a function of number of rounds compared to that of larger networks. This is because in smaller networks, majority of nodes are engaged in CH selection, transmission and reception process, utilizing their batteries more. In larger networks with 150 number of nodes, few nodes die for different number of rounds. This is because, in such networks, more nodes participate in route selection process, and paths may variate every time during next hop selection by the TCER protocol.

5 Conclusion

Most of the traditional routing algorithms do not consider multi-criteria attributes when selecting the next hop for delivery of data, severely degrading the QoS of the network. We proposed a TCER protocol for IoT-assisted WSNs that considered multi-criteria attributes to select the next hop. The protocol is based on traffic-aware and energy-efficient algorithms that exploit clustering techniques for routing data packets towards the destination. TCER protocol constructed optimal clusters by selecting CHs with high RE values among super and normal nodes. After the clusters are created, the TCER protocol selects the next hop based on RE, traffic load, and distance. The proposed protocol outperformed the LoRaWAN in terms of PDR, end-to-end delay, and low energy consumption. For a network with 100 nodes, the TCER protocol achieved 63% PDR with a 35 ms end-to-end delay, while for the same network, the LoRaWAN achieved 50% PDR with a higher delay of 45 ms. The results obtained from simulations may be used to determine optimum bounds for several applications. For example, the analysis of TCER protocol against varying packet size and traffic load may be used to calculate the optimum packet size for multimedia traffic in IoT-assisted WSNs.

In the future, the TCER protocol can be improved to use machine learning techniques to adjust parameters for next-hop selection based on real-time traffic information. This may reduce the overhead of next-hop selection and optimize routing performance. Other techniques, such as dynamic slot allocation based on traffic requirements of member nodes, may be incorporated in the TCER protocol to support the collection of multimedia data, such as video, voice, and images from member nodes and deliver them to the BS.

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Availability of Data and Materials: Not applicable.

Ethics Approval: The study is conducted using computer simulations and no human or animal subjects are involved.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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