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PAPER

A New Approach for Cluster Head Selection in Wireless Sensor Networks

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ABSTRACT

The proliferation of mobile devices and the spread of IoT devices have increased the tendency to use wireless sensor networks (WSNs), especially since the implementation of the 5G communication system has begun in most countries. This type of network does not require any infrastructure or additional cost, making it a good alternative for use in disasters, environmental monitoring, military, and rescue operations. However, WSNs suffer from some limitations, such as mobility and battery lifetime. Significant research has been conducted to overcome the limitation of battery lifetime by developing routing methods and reducing the required communications among wireless mobile nodes. In this research, we utilize the low-energy adaptive clustering hierarchy (LEACH) concept to minimize communication between the nodes and the base station. A new approach has been developed to form clusters in WSN nodes and select the optimal cluster head by facilitating the election of a new cluster head (CH). When the current cluster head's energy depletes, a new one is selected, ensuring continuous operation. The simulation results demonstrate that the proposed algorithm outperforms the existing LEACH clustering algorithm in terms of energy consumption, packet delivery ratio (PDR), and latency time.

KEYWORDS

cluster-head (CH), low energy adaptive clustering hierarchy (LEACH) clustering, QoS, wireless sensor networks (WSNs), packet delivery ratio (PDR)

1 INTRODUCTION

Wireless sensor networks (WSNs) are a recent type of network that has been deployed. They do not require any infrastructure and can support activities that are challenging for humans to perform. These networks are utilized in various fields, such as military applications, rescue operations, health activities, automation, and more. WSNs consist of multiple sensor nodes powered by batteries, enabling easy deployment and communication within a specific area. However,

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unfortunately, WSNs suffer from several issues, including energy consumption, sensor node deployment, routing algorithms, energy efficiency, robustness, and cluster-head (CH) selection [1]. The radio communications in WSNs consume most of the stored energy in their batteries. Since the primary objective of WSNs is to collect environmental data and transmit it to the base station [2], there is a critical need to design an appropriate routing or communication protocol to minimize energy consumption and reduce the number of communication steps in WSNs. Several communication technologies are used in WSNs, such as IEEE 802.3, IEEE 802.11, and ZigBee.

Several types of research are conducted to overcome and mitigate energy consumption issues in WSNs. One of the most well-known and important methods to address the limitations and deployment of WSN is clustering. Clustering is a topology control method based on virtually optimizing the network topology by dividing the network into groups (clusters). Each group consists of a CH node designated as the primary node responsible for the other group or cluster nodes (CN) [3, 4]. WSNs routing techniques are classified into flat, hierarchical, and location-based networks. But most of them are typically formed using a hierarchical approach [5].

Low-energy adaptive clustering hierarchy (LEACH) is considered the foundation for most hierarchical protocols in WSNs as it is based on data fusion. Many new hierarchical protocols have evolved from it, including TEEN, APTEEN, and PEGASIS [6]. CH selection plays a crucial role in energy conservation. As the distance between interconnected nodes increases, energy consumption also increases. To achieve an effective data transmission approach with minimal battery consumption, it is essential to optimize cluster head selection. This optimization aims to reduce energy consumption, time delay, and latency. The time delay is proportional to the distance between the WSN nodes and the base station. The time delay depends on the path transmission delay, which is directly proportional to the number of hops between the sender and sink. It also depends on the waiting time spent waiting for the sink or receiver to wake up [7].

$$t_{delay}(i,j) = \frac{\sum_{n=0}^{N} q_{ij}(1-q_{ij})^n (t_j - t_i + nT)}{\sum_{n=0}^{N} q_{ij}(1-q_{ij})^n} \tag{1}$$

Where t_{ij} represents the expected delivery delay from node *ni* to node *nj*, and *q* represents link quality.

Equation 1 shows that the delay time is proportional to the distance between nodes and the base station. Therefore, the selected cluster head should be close to the base station and the sensor nodes [8].

Several pivotal clustering frameworks have been developed to address energy consumption challenges, with LEACH being a cornerstone, selecting CHs to optimize data aggregation. The two-level LEACH (TL-LEACH) introduces a two-level hierarchy. LEACH-centralized (LEACH-C) centralizes CH selection, while LEACH-cluster estimate (LEACH-CE) employs a single-hop model to enhance energy efficiency [9]. LEACH-R incorporates relay nodes for multi-hop communication, while MG-LEACH focuses on eliminating redundant data [10]. FL-LEACH utilizes fuzzy logic for intelligent cluster head selection, while distance, degree, and residual energy-based LEACH (DDR-LEACH) incorporates distance, degree, and residual energy criteria [11]. In this context, our proposed approach is developed by initiating clusters based on distance, using norm vector-based cluster head selection, implementing dynamic cluster head handoff, and incorporating the k-clustering algorithm. This methodology is validated through extensive simulations using Python and MATLAB, demonstrating superior performance in latency, packet delivery ratio (PDR), and energy consumption, thereby contributing a substantial advancement to the field [12].

This paper makes a remarkable and innovative contribution to the field of WSNs, utilizing distinctive features that demonstrate a significant advancement in the field. One key novelty lies in the initiation of cluster groups based on the distance similarity of nodes from the base station, departing from traditional random selection methods. This distance-centric cluster formation strategy optimizes network topology, promising more energy-efficient communication. Additionally, the norm vector-based cluster head selection introduces a systematic and theoretically grounded approach, departing from heuristic-based or random selection methods prevalent in existing frameworks. The incorporation of a dynamic cluster head handoff mechanism represents a departure from static approaches, ensuring continuous adaptability to changing network conditions. The integration of the k-clustering algorithm into the cluster formation process adds a methodical layer to the organization of nodes into clusters. These unique insights and methodologies collectively position the proposed approach as a pioneering and transformative contribution to WSNs, offering a more sophisticated and efficient solution to address the challenges of energy consumption and cluster head selection. This paper is organized as follows: related work on clustering and cluster head selection; discussion and analysis of the proposed approach;, and conclusion and future work.

2 RELATED WORK

Wireless sensor networks are a crucial component of various applications, and efficient clustering and data aggregation strategies are essential for optimizing their performance. LEACH is renowned for its energy-saving capabilities compared to flat clustering techniques [13]. LEACH utilizes distributed principles, creating clusters without centralized control. CHs are selected randomly over multiple rounds, with CNs transmitting data to their CHs for aggregation before transferring it to the sink node. Building upon LEACH's foundation, several extensions and variations have been proposed to further enhance its efficiency and effectiveness [10, 14].

The TL-LEACH protocol offers a hierarchical structure with primary and secondary CHs, which helps in minimizing energy consumption and communication costs by optimizing data routing paths. However, concerns over energy consumption led to the development of LEACH-C. This was due to frequent messaging with the base station upon CH selection [15].

In contrast, LEACH-CE adopts a single-hop approach and selectively assigns nodes to enter sleep mode, thereby prolonging battery life while maintaining network connectivity [15]. LEACH-completely controlled by base-station (LEACH-CCB) further reduces energy consumption by managing node communications with the base station and optimizing energy usage throughout the network. To address energy consumption concerns, LEACH-R utilizes relay nodes based on residual energy and distance to the base station, effectively reducing energy consumption during data transmission [16]. Additionally, MG-LEACH improves energy efficiency by minimizing redundant information before transmission, using a single-hop mechanism, and incorporating node redundancy to decrease power consumption [17].

Researchers have explored various extension protocols to enhance LEACH clustering, focusing on factors such as distance and energy optimization [18]. FL-LEACH employs fuzzy logic to choose super cluster heads (SCHs) to enhance data transmission efficiency [19]. Furthermore, the distributed fuzzy clustering algorithm employs fuzzy logic controllers (FLCs) to organize WSNs into clusters, enhancing network lifetime through multi-hop routing of data packets [20].

Distance, degree, and residual energy-based low-energy adaptive clustering hierarchy addresses CH selection challenges by prioritizing nodes with the highest residual energy and degree. It also incorporates blockchain-based node authentication to enhance network security [21].

Recent advancements include the integration of energy harvesting techniques with LEACH (EHT-LEACH), utilizing energy harvesting capabilities to dynamically adjust clustering parameters, thereby increasing the network lifespan [22]. Cognitive radio-inspired LEACH (CR-LEACH) enhances spectrum utilization and reduces interference through dynamic frequency and channel adaptation [23]. Furthermore, Secure LEACH (S-LEACH) enhances network security by utilizing cryptographic techniques and secure authentication methods [24, 25]. LEACH for mobile sensor networks (LEACH-MSN) incorporates mobility-aware clustering mechanisms to accommodate dynamic node movement, ensuring efficient data collection and network connectivity [26].

Table 1 provides a concise summary of the discussed clustering protocols in WSNs, highlighting their key features and contributions.

Table 1. A summary of clustering protocols in wireless sensor networks

Protocol	Description	Key Features
LEACH	Hierarchical clustering protocol based on distributed principles.	Random selection of cluster heads (CHs), data aggregation at CHs, multi-hop data transmission to sink.
TL-LEACH	The two-level hierarchical clustering protocol with primary and secondary CHs is available.	Reduced energy consumption, enhanced data routing paths.
LEACH-C	The centralized version of LEACH with frequent messaging to the base station upon CH selection.	High energy consumption due to centralized control.
LEACH-CE	Single-hop approach with a selective node sleep mode.	Lack of battery life, maintained network connections.
LEACH-CCB	Implementation of node communications with the base station to reduce energy consumption.	Regulated node sleeping to increase energy utilization.
LEACH-R	Using relay nodes based on residual energy and distance to the base station is utilized.	Reduction in energy consumption during data transmission.
MG-LEACH	Reducing redundant information transmission through single-hop mechanism.	Minimized power consumption, leveraging node redundancy.
FLLEACH	The selection of Super Cluster Heads (SCHs) is based on Fuzzy Logic.	The efficiency of data transmission through fuzzy logic is increased.

(Continued)

Table 1. A summary of clustering protocols in wireless sensor networks *(Continued)*

Protocol	Description	Key Features
Distributed Fuzzy Clustering	Fuzzy Logic Controllers (FLCs) are used for multi-hop routing of data packets.	Enhanced network longevity through fuzzy logic-based clustering.
DDR-LEACH	Selects CHs from residual energy, degree, and blockchain-based node authentication.	Enhanced network security, improved CH selection mechanism.
EHT-LEACH	Integrates energy harvesting techniques to dynamically alter clustering parameters.	Energy harvesting increases the lifespan of network.

Clustering of WSNs should focus on the following challenges: developing energy-efficient, scalable, and robust algorithms in clustering techniques; integrating heterogeneous networks; enhancing security and privacy measures; leveraging machine learning and artificial intelligence techniques; and prioritization. Real-world deployment and validation. Addressing these challenges is critical for developing WSN clusters, enhancing network performance, and facilitating seamless integration into various applications and environments.

This paper proposes a new approach based on LEACH clustering. The new approach distributes networks into clusters based on their distances from the base station. It selects the CH with the shortest distance to CNs and the sink or base station, as indicated below.

3 METHODS

The methodology proposed in this paper is based on presenting a novel approach that focuses on extending the battery life of nodes within WSNs by strategically reducing communication activities. Unlike traditional methods, our approach operates across three distinct levels, each of which enhances the overall efficiency and longevity of the network.

- Dynamic cluster formation: We form cluster groups dynamically using a novel concept of distance similarity from the base station, which helps establish a hierarchical structure. This innovative clustering technique, as shown in Figure 1, improves network organization and resource allocation.
- Parameter-based optimization: By utilizing innovative broadcast messages exchanged between WSNs and the base station, we accurately determine the fundamental parameter values of each node. This includes not only traditional metrics such as distance (di) and energy (ei), but also a new study of the number of neighboring nodes (nei), reflecting a comprehensive understanding of node dynamics.
- Adaptive cluster head selection: Our methodology offers a dynamic approach to selecting cluster heads, ensuring resilience to node failure and energy depletion. By utilizing advanced mathematical models, such as the k-clustering algorithm and standard vector calculations (as outlined in Equations 2 and 3), we enhance the selection of cluster heads according to real-time network conditions. Through rigorous evaluation and validation, our methodology promises to significantly enhance the operational efficiency and lifespan of WSNs, thereby paving the way for sustainable and reliable IoT applications in various domains.

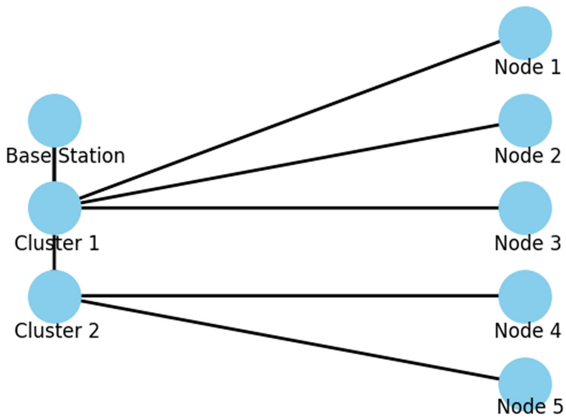

Fig. 1. Hierarchical structure for dynamic cluster head formation

3.1 Energy saving proposed method

Saving the battery's energy can be achieved by reducing node activities. Communication is the most battery-consuming activity. Therefore, we need to reduce the number of communications between nodes.

For each node, the following parameters are determined:

- di: the distance from the node to the base station
- ei: the node energy
- nei: the number of neighboring nodes

These parameters are collected through the broadcasting messages exchanged between WSNs and the base station. The idea behind forming a cluster is based on the k-clustering algorithm [27]. The cluster groups are formed after assigning centroid clusters, as detailed below. The mathematical model based on the norm vector is used to determine the optimum cluster head:

1. Determine the number of cluster heads based on the number of nodes.
2. Randomly select a node and assign it to the centroid cluster.
3. Compute the centroids of the clusters.
4. Repeat steps 2 and 3 until the ideal centroid cluster is found.
5. Calculate the sum of squared distances between nodes and the centroid of the cluster.
6. Allocate each node to the centroid cluster that is closest to it among the other centroid clusters.
7. Compute the centroid cluster for the nodes by averaging all the nodes in the centroid cluster.
8. Calculate the sum of squared distances between nodes and the centroid of the cluster.

The CH selection is determined by calculating the norm of the differences between the nodes after generating the data for each node, as explained in Equation 3. Subsequently, the minimum difference between the WSNS nodes is computed as the shortest distance between the WSN nodes and the base station, as elaborated in reference [28].

$$\|Ni - Nj\|2 = \left\{ \sqrt{\sum_{i=1}^{n} Nii - Nij} \right\} \text{ and } \|Ni - Nj\|\infty = \max_{1 \le i \le n} |Ni - Nj| \qquad (2)$$

Where "N" represents cluster node norm parameters.

$$N = \begin{bmatrix} di \\ ei \\ nei \end{bmatrix} \qquad (3)$$

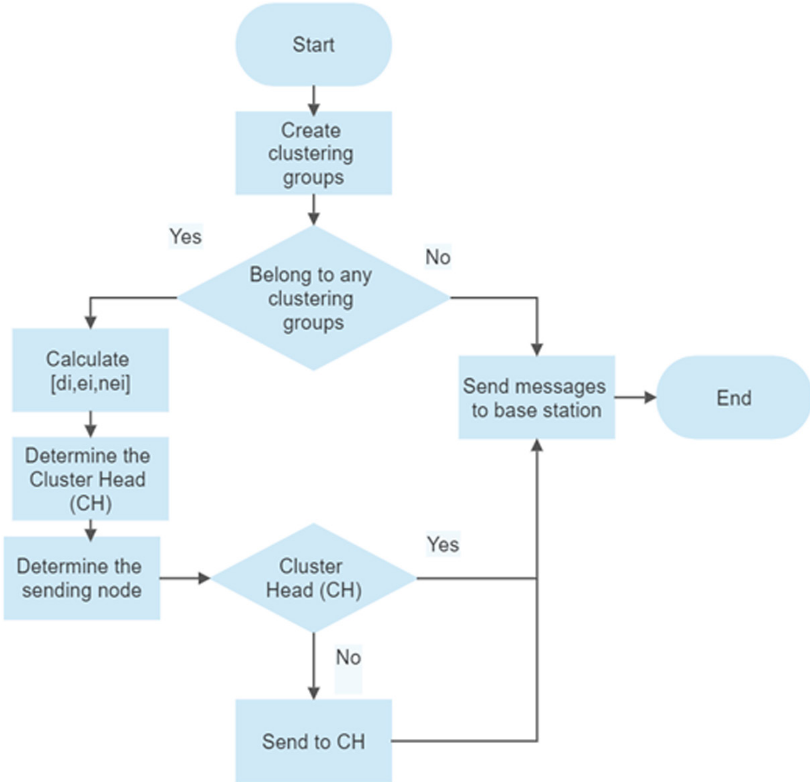

Fig. 2. The main steps for sending by the proposed clustering algorithm

When the CH begins to die and its energy reaches a certain threshold, it starts to hand off information to other nominated CHs. The process of selecting a new CH is repeated based on the previous steps. The detailed steps for data transmission by the proposed clustering algorithm are illustrated in Figure 2. Once the cluster groups are established, if a node intends to transmit data to the base station or sink, it is verified whether it is a CH or not. If a node does not belong to any cluster head, it can exchange data directly with the base station without the need for the cluster head's involvement. If a node has a cluster head, it must send the information to the CH, which will then aggregate the data and send it to the base station.

The energy consumption of WSNs is expected to decrease. Reducing packet exchange will minimize the traffic in interconnect channels and the bandwidth consumption [29]. Also, minimize the processing time. This will enhance the QoS parameters.

4 SIMULATION RESULTS AND ANALYSIS

A simulation is conducted using Python and MATLAB R2015b to test the performance of the proposed approach for cluster formation and cluster head selection. Then the obtained results will be compared with LEACH. Table 2 displays the simulation parameter values utilized in testing the proposed approach.

Table 2. Simulation parameters values

Simulation Parameter	Tested Values	Simulation Parameter
Simulation Area	500 m × 500 m	Simulation Area
Number of Nodes	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200	Number of Nodes
Node Placement	randomly	Node Placement
Nodes initial energy	10.5 j	Nodes initial energy
Transmitting power of the node	0.660 w	Transmitting power of the node
Receiving power of the node	0.395	Receiving power of the node
Packet size	512	Packet size

The following QoS parameters are tested to compare the results with the LEACH protocol:

- Latency or delay: This is calculated by computing the difference between the generation time of a packet in the WSN node and the sink.

$$d_{average} = \frac{1}{n}\sum_{i=0}^{n} di \tag{4}$$

- Packet delivery ratio: This is calculated by computing the percentage result of the packets received to the sent packets.

$$PDR_{average} = \frac{\sum Number\ of\ received\ packets}{number\ of\ sent\ packets} \times 100\% \tag{5}$$

- Energy consumption (E-consumption): This is calculated by computing the consumed energy by the WSNs transmitter to transmit and receive a set of l bits of data [21].

$$E_{transmitted} = \begin{Bmatrix} lx(E_{elec} + \varepsilon_{fs} d^2), & d < d_0 \\ lx(E_{elec} + \varepsilon_{mp} d^4), & d \geq d_0 \end{Bmatrix} \tag{6}$$

$$E_{recieved} = lxE_{elec} \tag{7}$$

Where,

E_{elec} represents the energy consumption per bit for the transmitter or receiver circuit, d represents the distance between the transmitter and receiver, and ε_{mp} represents the energy factor per bit.

Figure 3 represents the delay analysis for the proposed approach and the LEACH clustering algorithm. The nodes are randomly distributed, with their numbers varying between 10 and 200 WSN nodes. It is noted that the delay or latency increases when the number of WSN nodes in the network rises, as the processing and overhead time will also increase when the network becomes dense. The proposed approach yields better results than the LEACH protocol because the cluster head is selected using a more optimal method.

The PDR represents the data successfully received by the sink and base stations. Figure 4 displays the relationship between PDR and the number of nodes. The successfully delivered data for the proposed approach is proportional to the increasing number of WSN nodes. In the figure, we can observe that the proposed approach offers an advantage over the LEACH clustering protocol, with approximately a 10% higher PDR compared to the LEACH clustering protocol.

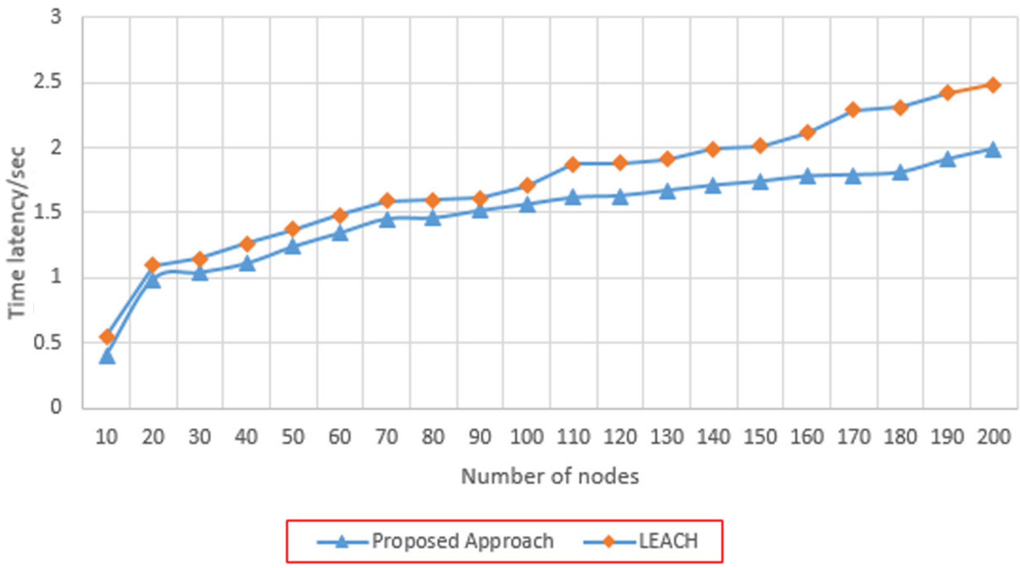

Fig. 3. Delay comparison between proposed approach and LEACH

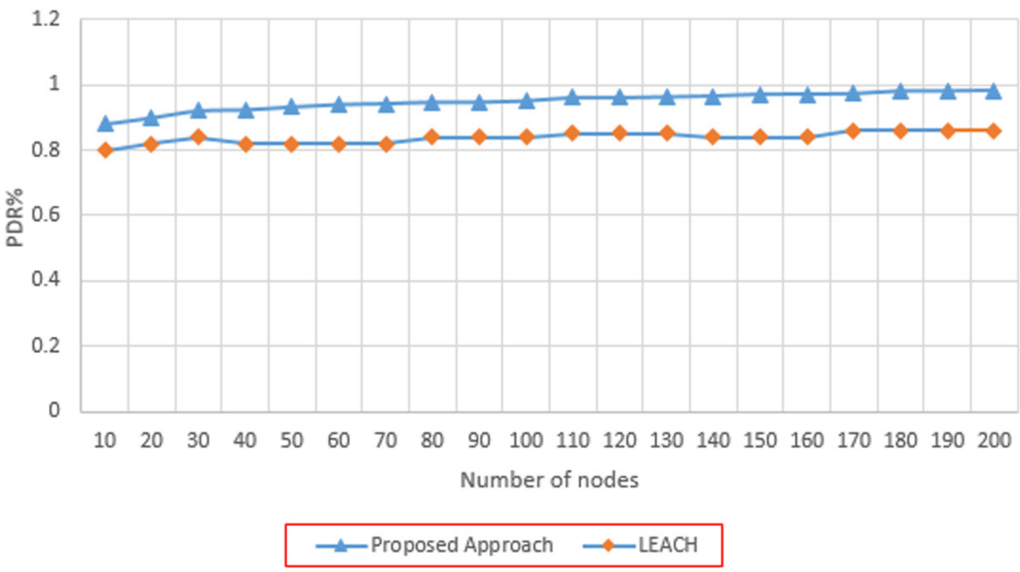

Fig. 4. Packet delivery ratio % comparison between proposed approach and LEACH

Figure 5 represents the energy consumption analysis for the proposed approach and the LEACH clustering protocol. Due to the elimination of unnecessary or redundant data packets through clustering, energy consumption is minimized by the LEACH clustering protocol and the proposed approach. The proposed approach has lower power consumption compared to the LEACH clustering protocol because the selection of the CH is more accurate and it has a better position. This results in a reduction in the number of sent and received packets.

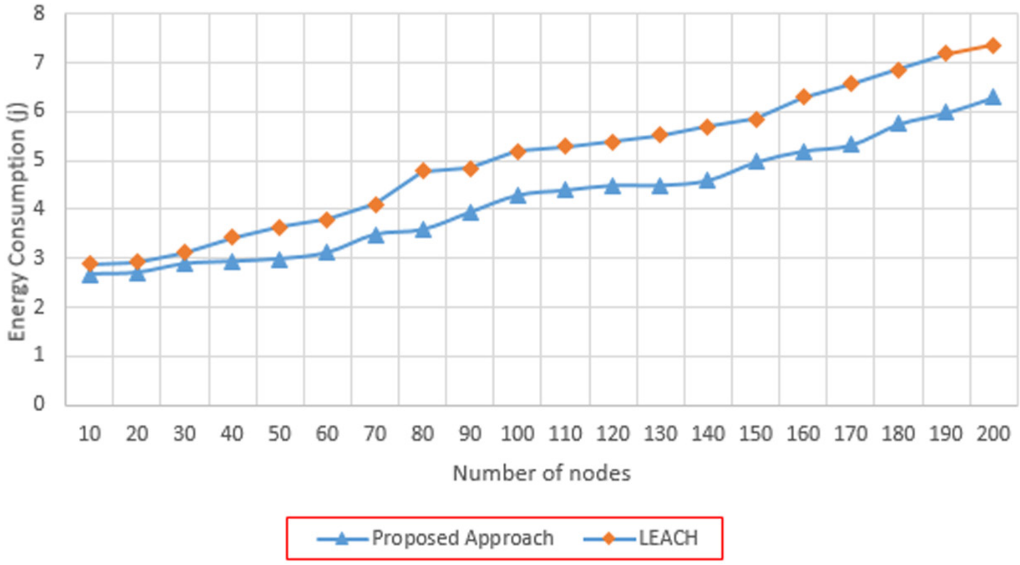

Fig. 5. Energy consumption comparison between proposed approach and LEACH

5 CONCLUSION AND FUTURE WORK

Clustering is one of the most effective solutions developed in WSNs. Since the application of WSNs has increased with the proliferation of IoT devices, their capacity to efficiently sense and process data, and their effective wireless communication in 5G applications. Clustering is used to overcome the power limitation in WSNs nodes. Selecting a cluster head node is the main challenge. However, there are still some challenges in clustering, such as cluster formation methods, mobility, heterogeneity, and CH selection [22]. In this paper, we have developed a new approach that extends the LEACH clustering protocol. It has been developed to address the issues of cluster formation and cluster head selection through mathematical heuristics and software simulation. The results obtained from the simulation demonstrate that the proposed approach outperforms the LEACH algorithm in terms of time latency, PDR %, and energy consumption.

A future objective of this research is to expand this study to address mobility management in WSNs, explore additional QoS parameters, and employ artificial intelligence techniques to determine the optimal number of cluster heads based on the size and layout of wireless sensor networks.

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