International Journal of Computer Applications Technology and Research
Volume 13–Issue 10, 84 – 89, 2024, ISSN:-2319–8656
DOI:10.7753/IJCATR1310.1008

LEACH-based Resilient Transmission Rounds LEACH

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Abstract: Amidst the swift advancement of technologies encompassing sensors, wireless communication, and cloud computing, the Internet of Things (IoT) connects various physical devices, sensors, and systems through the internet, enabling smart interconnection and data sharing. Wireless Sensor Networks (WSN) are a key component of the IoT, responsible for data collection and preliminary processing. WSN consists of numerous autonomous sensor nodes that transmit data to a central system or the cloud via wireless communication, commonly used for monitoring environmental information such as temperature, humidity, and vibration. However, since sensor nodes are typically powered by limited batteries, the network's lifespan and energy consumption balance become major challenges in research. Therefore, developing efficient clustering algorithms to extend the network's lifespan is crucial for the advancement of WSN. The LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol is a classic adaptive clustering routing protocol designed for Wireless Sensor Networks (WSN), aimed at extending network lifetime by reducing energy consumption. It achieves load balancing within the network by dynamically selecting Cluster Head (CH) nodes, thereby decreasing the energy consumption of individual nodes. However, LEACH encounters issues such as data loss and network failures due to Cluster Head malfunctions and energy depletion. In response to these challenges, this paper proposes RLEACH, which particularly addresses the problem of Cluster Head energy depletion leading to network failures. Instead of adhering to a fixed number of data transmission rounds, RLEACH flexibly modifies the transmission rounds based on the energy levels of the Cluster Heads. Data transmission occurs only when the energy of the Cluster Head meets the requirements for all member nodes to transmit data in the next phase; otherwise, the network will initiate a re-clustering process. A comparison between the proposed RLEACH and LEACH demonstrates improvements of 119%, 148%, and 141% in terms of First Node Death (FND), Half Node Death (HND), and Last Node Death (LND), respectively. Additionally, RLEACH shows significant enhancements in energy consumption per round and overall network energy residual.

Keywords: IoT; WSN; LEACH; RLEACH

1. INTRODUCTION

Amidst the rapid evolution of technologies such as sensors, wireless communication, and cloud computing, a diverse array of devices has attained intelligent interconnectivity and data sharing capabilities. The Internet of Things (IoT) connects various physical devices, sensors, and systems through the internet, enabling them to communicate, share data, and perform intelligent management and automated operations.

Wireless Sensor Networks (WSN) are a key component of the IoT, responsible for data collection and preliminary processing within IoT systems. A WSN is an autonomous, self-organizing network composed of numerous distributed sensor nodes powered by limited batteries. These nodes are often deployed in various application scenarios to monitor diverse information in the physical environment, such as temperature, humidity, vibration, light intensity, and air pollution, and transmit the collected data to a central system or the cloud via wireless communication. In the IoT architecture, WSN typically operates at the perception layer, providing the real-time environmental data required by the IoT and connecting with the internet and other smart devices, thereby facilitating comprehensive perception and interoperability.

With the rise of IoT technology, WSN, as one of the key infrastructures of IoT, has made significant progress in research over the past few years but also faces numerous challenges. Since sensor nodes in WSN are often powered by limited batteries, network lifetime and energy consumption balance have been persistent issues.

In WSN, clustering algorithms are commonly used to balance the energy consumption of network nodes. By clustering the sensor network, the sensor nodes are grouped into different clusters, with each node sending its collected data to the Cluster Head (CH) of its respective cluster. The CH then collects and preprocesses the information from all nodes within the cluster before forwarding it to the Base Station (BS), which further processes and analyzes the data. Each node consumes a certain amount of energy during the collection, processing, transmission, and reception of data. When a node depletes its energy, it is defined as dead. Therefore, developing effective clustering algorithms to balance the energy consumption of sensor nodes in the sensor network is crucial.

In other sections of this paper: Chapter 2 discusses the necessary background for the research. Chapter 3 describes the proposed RLEACH algorithm. Chapter 4 compares the performance of the proposed RLEACH algorithm with that of LEACH. Chapter 5 provides a conclusion for this study.

2. RELATED WORK

The LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol is an adaptive clustering routing protocol used for Wireless Sensor Networks (WSN), aimed at reducing network energy consumption and extending network lifetime by randomly selecting Cluster Heads and performing data fusion. In 2020, Safa'a S. Saleh et al. [1] enhanced LEACH by determining Cluster Heads based on the lowest energy consumption, thereby extending the lifespan of WSN and improving its performance. In 2021, Ajmi, N. et al. [2] introduced a multi-weight chicken swarm-based genetic algorithm for energy-efficient clustering (MWCSGA), with performance evaluation results indicating that MWCSGA performed well in energy efficiency, packet drop rates, and network throughput. In 2020, A. Verma et al. [3] proposed a fuzzy logic-based effective clustering for homogeneous wireless sensor networks with mobile sinks (FLEC), which utilized average energy-based probability and average threshold concepts to select appropriate Cluster Heads (CHs), addressing issues associated with existing fuzzy logic-based clustering algorithms in WSN (LEACH-Fuzzy). In 2019, Chandirasekaran, D. et al. [4] designed and implemented a protocol using a new evolutionary technique called Cat Swarm Optimization (CSO) in real-time to minimize the distance between cluster members and their Cluster Head, optimizing energy distribution in WSN. In 2022, Zhixin, Z. et al. [5] proposed the Linear Round-numbered Segmentation Multi-hop Clustering Protocol (LRSMCP) for linear environments, which improved overall operational strategies based on stochastic resonance, maximizing node energy efficiency and extending network lifetime. In 2020, X. Tang et al. [6] introduced a non-uniform clustering routing algorithm based on an improved K-means algorithm, employing clustering methods to form and optimize clusters while selecting appropriate Cluster Heads to balance network energy consumption and extend the lifecycle of WSN. In 2019, Y. Deng et al. [7] proposed an Adaptive Sub-unit Clustering Multi-hop Protocol (ASCMP), which improved WSN performance through enhancements in Cluster Head (CH) election, network transmission, and node energy settings. In 2021, Gaurav Kumar Nigam et al. [8] proposed an enhanced algorithm named ESO-LEACH, where a meta-heuristic particle swarm optimization algorithm was used for initial clustering of sensor nodes, and advanced node concepts and enhanced rule sets for CH election were employed to minimize the randomness of the algorithm. In 2023, Bilal Saoud et al. [9] introduced a new WSN routing protocol based on the Firefly Algorithm, which improves the lifetime of WSN by considering the energy of each sensor node to find optimal Cluster Head (CH) selection.

In this context, this paper proposes an innovative algorithm, RLEACH (Resilient Transmission Rounds LEACH), which effectively balances the network load in WSN. The proposed RLEACH can be widely applied in industrial automation, smart cities, smart agriculture, environmental sensing, health monitoring, and other fields.

In traditional load balancing protocols, re-clustering occurs after each round of data transmission or after a specified number of data transmission rounds. In contrast, the proposed RLEACH fully utilizes the characteristics of WSN by establishing a flexible clustering approach. Each clustering round for data transmission is adjusted based on the results of the current clustering, allowing for more efficient use of the limited energy of sensor nodes during data transmission. Through this setting, RLEACH can effectively prevent data loss during node data collection and make better use of the limited energy of the nodes.

3. RESILIENT TRANSMISSION ROUNDS LEACH

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The proposed RLEACH algorithm is structured into two phases: the cluster formation phase and the steady-state phase.

Cluster Formation Phase: In this phase, Cluster Heads (CHs) that meet certain criteria are identified based on a specific formula. Member nodes select the nearest CH to join and establish communication with it.

Steady-State Phase: In this phase, member nodes transmit the collected data to their respective CHs, which then perform data aggregation before sending the aggregated data to the Base Station (BS).

Cluster Formation Phase: Before the new round begins, nodes determine whether they will become CHs based on specific criteria. Each sensor node generates a random number between 0 and 1. If the generated random number is less than the threshold T(n), the node becomes a CH. This threshold is defined as follows:

$$T(n) = \begin{cases} \frac{P}{1 - P \times \left(r \bmod \frac{1}{P}\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

In Equation 1, P represents the expected proportion of Cluster Heads, r is the current round, and G is the set of nodes that have not become Cluster Heads in the past. This formula ensures that each node has the opportunity to become a Cluster Head approximately once every 1/P rounds, thereby balancing network energy consumption. Nodes that become Cluster Heads broadcast their status to other nodes, while non-Cluster Head nodes choose to join a specific cluster based on the signal strength of the Cluster Head and send a join request to that Cluster Head.

Steady-State Phase: In this phase, member nodes transmit information to their assigned Cluster Heads, which then relay this information to the Base Station (BS). The steady-state phase consists of multiple rounds of communication. In each round r, member nodes collect data during their assigned time slots and send it to the Cluster Head, which aggregates the data and forwards it to the BS.

During the steady-state phase, this paper introduces the concept of dynamic rounds: there is no predetermined number of data transmission rounds before initiating the next clustering. Instead, the rounds are dynamically adjusted based on the energy levels of the Cluster Heads. If any Cluster Head does not have sufficient energy to support the data transmission from all its member nodes to the BS in the next round, re-clustering will be initiated.

The flowchart of the proposed RLEACH algorithm is shown in Figure 1.

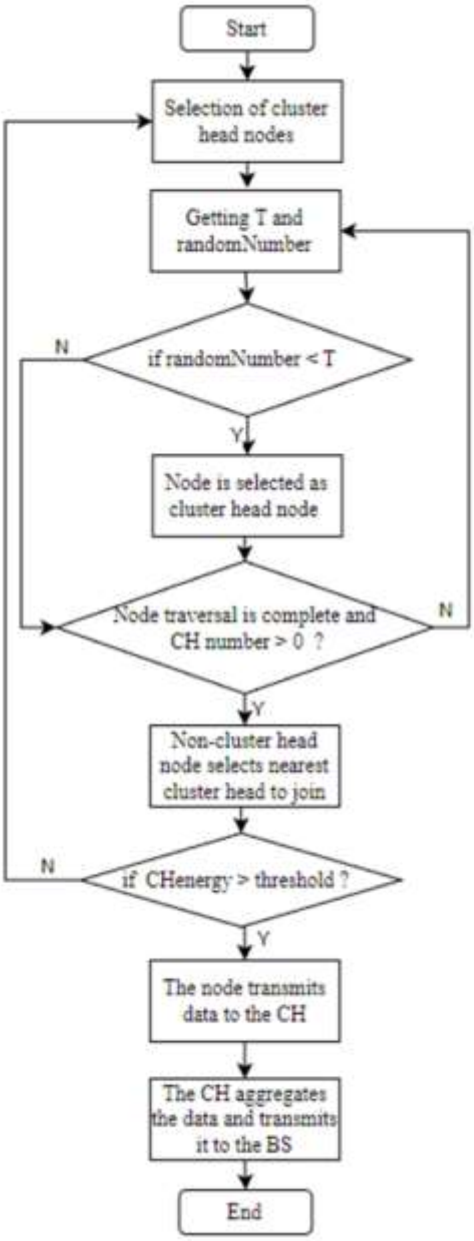

Figure 1. Flowchart of the RLEACH Algorithm Implementation

3.1 Energy Model

In a Wireless Sensor Network (WSN), the energy consumption of the transmitter involves both the transmitter circuit and the power amplifier, while the energy consumption of the receiver takes into account the receiver circuit. The power amplifier for the transmitter utilizes both the free-space model and the multipath fading model. If the distance between the transmitter and the receiver is less than a certain threshold, the power amplifier uses the free-space model; otherwise, the multipath model is applied. The specific energy consumption for the transmitter and receiver can be calculated as follows:

$$E_T(m, d) = \begin{cases} m * E_{elec} + m * \varepsilon_{fs} * d^2, & d \le d_0 \\ m * E_{elec} + m * \varepsilon_{mp} * d^4, & d > d_0 \end{cases} \quad (2)$$

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\epsilon_{mp}}} \quad (3)$$

Where m is the number of bits, and d is the distance between the transmitter and the receiver, ε_{fs} and ε_{mp} are the energy parameters of the radio amplifier for the free-space and multipath fading models, respectively. E_{elec} is the energy consumed by the device to transmit or receive each bit, and d0 is the distance threshold. Overall, $E_T(m, d)$ represents the energy required for the transmitter to send m bits of data to a receiver located at a distance d.

$$E_R(m) = m * E_{elec} \quad (4)$$

$E_R(m)$ is the energy consumed by the receiver to receive m bits of data.

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3.2 Cluster Formation

The formation of clusters is divided into two phases. In the first phase, nodes are selected to act as cluster heads in the upcoming round of data transmission, and their status is updated to cluster head. These nodes will broadcast their status as cluster heads to other nodes within the Wireless Sensor Network (WSN). In the second phase, the nodes that are not elected as cluster heads will, upon receiving the broadcast message from the cluster head node, choose the nearest cluster head to join and notify the corresponding cluster head to establish a connection. The pseudocode is illustrated in Algorithm 1.

Algorithm 1 Cluster Formation

Input: *nodes*
Output: *Clusters = { Clusters1, Clusters2, …, ClusterS}*
The cluster head node is selected according to the formula
for *node in nodes* **do**
$$T(n) = \begin{cases} \frac{P}{1-P\times\left(r \bmod \frac{1}{P}\right)} & if\ n \in G \\ 0 & otherwise \end{cases}$$
randomNumber = random.random()
if *randomNumber < T* **then**
Select the nodes that fulfill the conditions as cluster heads
end if
end for
for *node in nodes* **do**
if *nodes are non-cluster head nodes* **then**
Select the closest cluster head to join
end if
end for
return *Clusters = { Clusters1, Clusters2, …, ClusterS}*

3.3 Resilient Transmission Rounds

After the formation of clusters, member nodes will transmit the collected data to the Cluster Head (CH) during their assigned time slots. The CH will then aggregate the data and send the aggregated data to the Base Station (BS). Before each data transmission, the CH assesses its own energy level. Data transmission will only occur if the energy is sufficient to support the transmission of data from all member nodes to the BS; otherwise, the clustering process will restart. It is important to note that the energy threshold being compared by the CH is not a fixed value, but rather a dynamically changing value determined during each round of clustering.

$$CH_{BS} = E_R * X + E_T * X * c \quad (5)$$

In the above equation, CH_{BS} represents the energy required for the Cluster Head (CH) to receive and aggregate the data from all member nodes within the cluster before transmitting it to the Base Station (BS). E_R is the energy required to receive data, E_T is the energy required to send data, X is the number of member nodes within the cluster, and c is the data fusion rate. Data transmission will only occur if the remaining energy of the CH is greater than that of the CH_{BS}; otherwise, the clustering process will restart.

4. ANALYSIS OF SIMULATION RESULTS

In this chapter, we conducted experimental simulations of RLEACH and LEACH, followed by an analysis and discussion of the simulation results. We assume that there are 100 sensor nodes randomly distributed within a 200m × 200m area, with the Base Station (BS) located at (100, 250). Apart from their differing positions, all other parameters of the nodes are the same. The specific simulation parameters are shown in Table 1.

Table 1 Simulation parameters

Parameter	Value
Number of nodes	100
Area	200m * 200m
Initial energy (E_0)	1 J
BS location (x, y)	(100,250)
E_{elec}	50 nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{mp}	0.0013 pJ/bit/m^4
EDA	5 nJ/bit
Packet size	2000 bits
Control size	100 bits

4.1 Simulation Design

We randomly generated 100 sensor nodes within a 200m × 200m area, as shown in Figure 2, with the Base Station (BS) located at (100, 250).

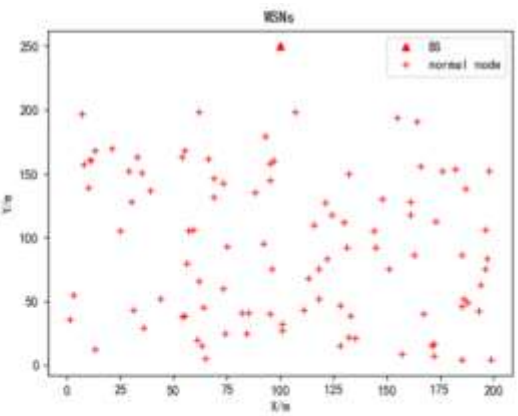

Figure 2 Sensor Node Distribution

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4.2 Network Life

We conducted a comprehensive comparison between LEACH and RLEACH. In this context, FND refers to the round in which the first node dies, HND is the round in which 50% of the nodes, specifically the 50th node, die, and LND is defined as the round in which 85% of the nodes in the network die, corresponding to the 85th node's death.

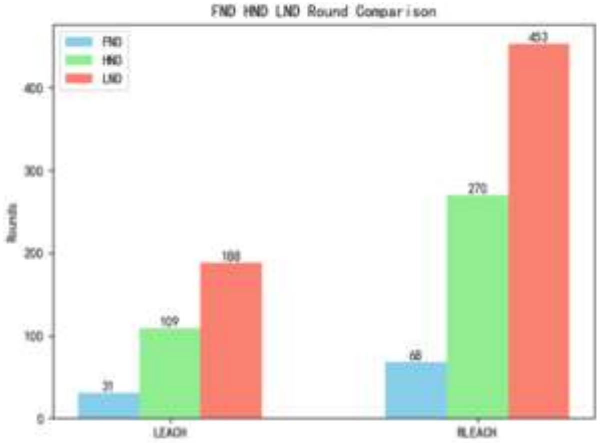

Figure 3 FND HND LND Compare

As shown in Figure 3, our proposed RLEACH demonstrates improvements of 119%, 148%, and 141% in FND, HND, and LND, respectively, compared to LEACH. This indicates that our proposed RLEACH is effective and represents a significant advancement.

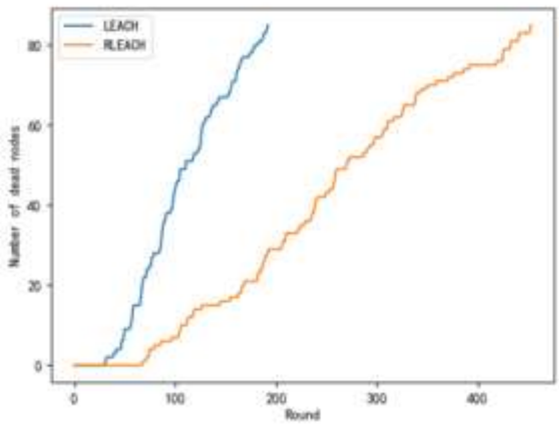

Figure 4 Comparison of node death rounds

Figure 4 clearly illustrates that RLEACH significantly enhances network longevity compared to LEACH.

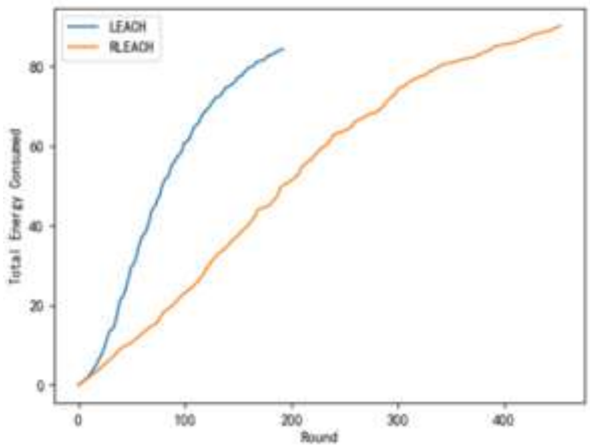

Figure 5 Comparison of total energy consumption for rounds

From Figure 5, it can be observed that RLEACH shows a significant improvement in balancing energy consumption compared to LEACH.

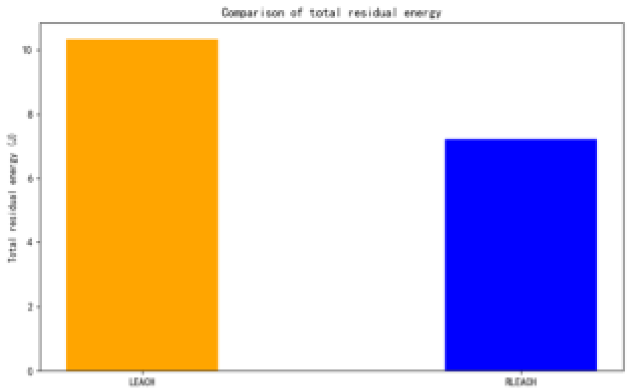

Figure 6 Comparison of total network energy surplus

Figure 6 illustrates the total remaining energy of all nodes after the network ceases to operate. It is evident that the remaining energy of RLEACH is significantly lower than that of LEACH.

5. CONCLUSION

The RLEACH protocol, based on energy-adaptive cluster head management and flexible transmission rounds, effectively addresses the issues of network failure and data loss caused by cluster head energy depletion in the LEACH protocol by incorporating an energy-aware mechanism into the data transmission rounds. The RLEACH protocol dynamically adjusts the transmission rounds based on the remaining energy of the cluster heads, thus avoiding unnecessary re-clustering and extending the lifespan of wireless sensor networks. Experimental results indicate that, compared to the traditional LEACH protocol, RLEACH achieves improvements of 119%, 148%, and 141% in the metrics of first node death (FND), half node death (HND), and last node death (LND), respectively. Additionally, RLEACH demonstrates significant advantages in energy consumption balance and network remaining energy, proving its effectiveness in prolonging network lifespan and enhancing energy efficiency.

6. ACKNOWLEDGMENTS

This paper and research were supported by Undergraduate Education and Teaching Research and Reform Project of Chengdu University of Information Technology (No. JYJG2023169, JYJG2023046), and Industry-school Cooperative Education Project of Ministry of Education (No. 202002230010 , 202101014067, 202101291013 , 220500643270506). We also would like to thank the sponsors of Sichuan Province Science and Technology Department, Sichuan Province Major Science and Technology Project (No. 24JBGS0050), Sci. and Tech. Pro. for Overseas Students in Sichuan Province (No. 2022-30), Sichuan Province Philosophy and Social Science Research Project, (No. SC23TJ006), and Network and Data Security Key Laboratory of Sichuan Province, UESTC (No. NDS2024-3).

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