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Enhancing Parameters of LEACH Protocol for Efficient Routing In Wireless Sensor Networks

Chandra Prakash Verma*

In Time Tech, RIICO Industrial Area, Sirsi Road, Kanakpura, Jaipur, Rajasthan, India 302034

Abstract

The increasing popularity of wireless sensor networks can be attributed to their unique characteristics, which include high density, low power consumption, software programmability, and long-term accuracy. This paper thoroughly analyzes key parameters for sensor network applications, including network lifetime, packet delivery ratio, energy-efficient transmission, and dead node ratio. This paper examines the effectiveness of clustering in wireless sensor networks for achieving efficiency. The research focuses on the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol and proposes an enhanced algorithm that improves network lifetime, throughput, and the number of alive nodes. This paper evaluates the performance of the improved LEACH protocol and compares it to other protocols currently in use. The results indicate that the proposed method significantly improves the protocol's performance, making it a promising method for efficient routing in wireless sensor networks. This study is an important contribution to wireless sensor networks and can aid in creating more efficient and effective protocols for various sensor network applications.

Keywords: Wireless Sensor Networks; LEACH Protocol; Clustering; Network Lifetime; Energy-Efficient Transmission

1 Introduction

Wireless networks have revolutionized communication, and wireless sensor networks (WSNs) have brought about significant advancements in ubiquitous computing, smart systems, and the Internet of Things [1]. WSNs comprise several tiny sensor nodes that are densely deployed inside or near the phenomenon to be sensed. These nodes consist of sensing, data processing, and communication components, allowing for random deployment in inaccessible terrains or disaster relief operations. One unique feature of WSNs is the self-organizing capabilities of their protocols and algorithms. This feature is necessary because the position of sensor nodes does not need to be engineered or predetermined. Furthermore, WSNs use cooperative effort, as each sensor node is fitted with an onboard processor that carries out simple computations and transmits only required and partially processed data rather than sending raw data to nodes responsible for fusion [2]. WSNs are highly distributed and self-aware networks that face resource problems, such as power consumption, processing speed, communication range, and available bandwidth [1]. A general form of a WSN architecture is shown in Figure 1.

*Corresponding author: chandra.rbs@gmail.com

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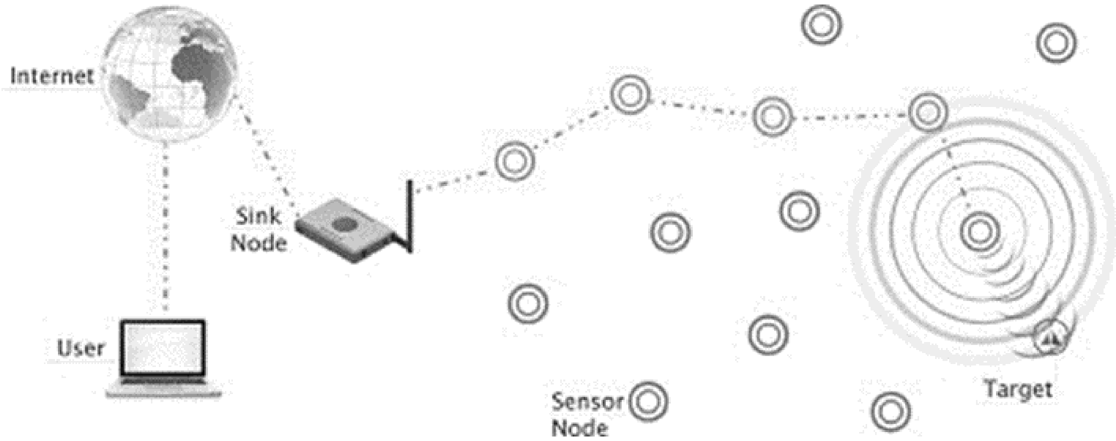

Figure 1: General representation of a wireless sensor network architecture [3].

However, WSNs provide an indispensable sensing and actuation platform in various cyber-physical infrastructure and systems, including smart metering of electric grids, distance and speed monitoring of vehicles in transportation systems, environment and health monitoring, security and surveillance, early warning systems, disaster management. WSNs and auxiliary computation facilities such as clouds can integrate sensing, communication, computation, and control functionalities. These networks facilitate several applications that promote a comfortable and smart-economic life, including energy saving by minimizing rare energy sources, noise and atmospheric monitoring, reducing pollution, and healthcare monitoring promoting health [4]. Wireless sensor networks also make significant strides in enabling distributed sensing functions inside buildings. Concepts such as smart meters and smart appliances rely on wireless sensor networks, highlighting the potential for wireless networks to revolutionize our lives and work. As such, WSNs are an emerging technology expected to impact various aspects of our lives significantly [4, 5].

It is crucial to consider critical parameters such as network lifetime, packet delivery ratio, energy-efficient transmission, and dead node ratio to address the battery constraint issue in WSNs. Energy-efficient routing techniques play a vital role in increasing the network lifetime. The current routing protocols for WSNs are classified into two categories based on their orientation towards either homogeneous or heterogeneous WSNs, further divided into static and mobile protocols. This paper summarizes the characteristics, limitations, and applications of these protocols. Routing in WSNs is a challenging area of research, and packets are forwarded through multiple nodes to the base station. Therefore, sharing the packets in an energy-efficient manner while considering the battery's residual power is crucial to prolong the network lifetime. Energy consumption is a fundamental issue that needs to be addressed to improve energy efficiency. However, it has not been adequately addressed by researchers and practitioners. Despite the efforts to improve energy efficiency in WSNs, some open issues in energy-efficient routing protocol design still need to be addressed [6–8]. Several energy-efficient routing protocols are available, such as low energy adaptive clustering hierarchy (LEACH), Hybrid Energy Efficiency Protocol (HEEP), threshold-sensitive energy-efficient network protocol (TEEN), and power-efficient Gathering in sensor information systems (PEGASIS). Notably, LEACH is considered the father of clustering protocols. It operates in rounds, each consisting of two phases: a setup phase where clusters are formed and a steady-state phase where member nodes send their data to their corresponding cluster heads, which then transfer it to the base station. During setup, nodes exchange messages to form clusters, including cluster head announcements, member node join query messages, and cluster head Time Division Multiple Access (TDMA) schedules. LEACH is a hierarchical routing protocol that is self-adaptive and self-organized, reducing unnecessary energy costs. The steady-state phase is typically much longer than the setup phase. However, the setup phase is more important as it allows sensor nodes to randomly elect themselves as cluster heads and divide themselves into clusters. Each cluster head creates a TDMA schedule for the sensor nodes within the cluster, allowing the radio components of each non-cluster head node to be turned off at all times except during their transmit time [6, 9, 10].

However, LEACH has several limitations, such as uneven distribution of energy among the nodes, premature death of the cluster heads, and a lack of scalability. Therefore, this paper presents a comprehensive analysis of critical parameters for sensor network applications and proposes an improved algorithm that enhances network lifetime, throughput, and the number of alive nodes. The proposed approach is based on the LEACH protocol and addresses its limitations. The research objectives of this paper are to evaluate the performance of the enhanced LEACH protocol, compare it with existing protocols, and demonstrate its effectiveness in improving the critical parameters of WSNs. The contributions of this research are expected to aid in developing more efficient and effective protocols for various sensor network applications. By optimizing energy consumption and reducing the number of dead nodes, the proposed protocol can help extend the network lifetime, increase the packet delivery ratio, and improve energy-efficient transmission.

Furthermore, the proposed algorithm can overcome the limitations of the traditional LEACH protocol by improving the uniformity of energy distribution among nodes, reducing the number of dead nodes, and increasing scalability. In summary, this paper contributes to developing energy-efficient routing protocols for WSNs by proposing an improved version of the LEACH protocol. The proposed protocol addresses the shortcomings of the traditional LEACH protocol, and its effectiveness is demonstrated through simulation experiments. This research provides valuable insights for researchers and practitioners in the field of WSNs and can help in the design of more efficient and effective routing protocols for various WSN applications.

2 Related Works

Wireless Sensor Networks (WSNs) require a decisive feature of an expected lifetime, as the nodes are spread out in the field for months or years without proper post-maintenance [11, 12]. The energy supply is the main limiting factor for the lifetime of a sensor network. Each node must be designed to improve battery utilization for maximum network lifetime. Sensor nodes are densely deployed in a field of interest. The primary advantage of WSNs is their ease of deployment. Coverage and speed are essential characteristics for WSNs, and it is beneficial for the sensor network to cover a larger physical area to increase the network area for sensing.

However, Ad-Hoc communication networks can prolong the network coverage beyond the range of the radio technology alone. Still, Ad-Hoc networking protocols usually increase energy consumption, decreasing the overall network lifetime [4]. A study proposed directed diffusion, a data-centric protocol for wireless sensor networks, which diffuses data based on their communication interest [13]. The protocol establishes paths between the Base Station (BS) and the source node by utilizing interested nodes, and several paths can be established between the sender and receiver. The most efficient path with less power consumption is selected. If the path breaks anywhere between the source and sink, the alternative path is used for transmission. However, the overhead is increased when making alternatives among paths, so the multipath concept may not be applied to larger, complex networks. Hierarchical routing protocols are clustering-based routing techniques that aim to efficiently utilize the energy resources of sensor nodes by usually operating in an Ad-Hoc network fashion. In this type of routing, sensor nodes are organized into clusters, and for each cluster, a responsible node is selected as the cluster head (CH). The CH collects data from its member nodes, and the aggregated data is transmitted to the sink by the CH [14, 15]. The non-CH members are put in sleep mode, preserving energy.

LEACH was the first energy-efficient protocol and inspired other hierarchical routing protocols, including the TEEN one. Clustering Topology uses two threshold values, one sensed from attribute and the other small change in that value, both hard and soft thresholds simultaneously, with the sensed value being the absolute value [16, 17]. HEED is a hybrid protocol that uses residual energy and network topology characteristics (like node degree) to achieve energy balancing in communication networks. The cluster selection of nodes is done by minimizing the network cost, and the CH selection of data is done randomly, but only particular clusters are joined. HEED uses efficient Ad-Hoc networking topology by using adaptive and proactive transmission energy in the cluster-to-cluster transmission. However, the HEED protocol has disadvantages, including creating more cluster heads than expected due to tentative cluster heads that do not become final cluster heads and some uncovered nodes left behind. This protocol also creates more iterations due to the broadcasting and multicasting of packets, resulting in high overhead. Additionally, some nodes may die early because of more energy consumption, mainly the cluster heads near the sink [18–20].

3 Methodology

This research investigates the energy efficiency of wireless sensor networks (WSNs) using a descriptive research methodology. The study assumes that each sensor node is a self-organizing device that is uniformly distributed, stationary, and capable of performing computations and storing information about neighboring nodes. To address the research question of conserving energy in WSNs and the challenge brought by the heterogeneity of nodes, an established routing algorithm based on an existing protocol, the heterogeneous low energy adaptive clustering hierarchy (H-LEACH), is used. The stated algorithm introduces modifications aimed at prolonging the network lifetime and increasing the throughput of the whole network. The key features of the proposed algorithm include adaptive cluster formation, dynamic selection of cluster heads, and energy-efficient data transmission. Simulations were conducted using the NS-3 network simulator to evaluate the performance of the proposed routing algorithm. The simulation environment consisted of 100 sensor nodes deployed randomly in a 100 x 100 m area, each equipped with a 2.4 GHz radio and a battery with an initial energy of 1 J. The simulation ran for 1000 sec, and the parameters used with their respective values are presented in Table 1. The performance of the proposed algorithm was evaluated using four key performance metrics: network lifetime, energy efficiency, packet delivery ratio, and the number of dead nodes. Energy efficiency was measured as the total energy consumption divided by the total data packets transmitted, while the packet delivery ratio was defined as the ratio of the number of data packets received by the base station to the total number of data packets generated.

Table 1: Parameters and the respective values for H-LEACH simulation

Network Parameters for H-LEACH simulation	Values
Field coordinates	$a_{\text{max}} = 100$, $b_{\text{max}} = 100$
Coordinates of the Base Station (BS)	base.x $= 0.5a_{\text{m}}$, base.y $= 0.5b_{\text{m}}$
Number of nodes in the WSN field (m)	100
Probability of a node becoming a cluster head (P)	0.1
Heterogeneity value	$Q = 0.1 \times (10\%)$, $\alpha = 1$
Model for energy in heterogeneous nodes	$E_{\text{o}} = 0.5$ joules, $E_{\text{elect}} = E_{\text{txy}} = E_{\text{rxy}} = 10 \times 1 \times 10^{-9}$ joules, $E_{\text{rxy}} = 10 \times 1 \times 10^{-9}$ joules
Transmission amplifier types	$E_{\text{fx}} = 2 \times 1 \times 10^{-12}$, $E_{\text{mp}} = 0.0013 \times 1 \times 10^{-12}$
Data aggregation energy	$E_{\text{DAG}} = 5 \times 1 \times 10^{-9}$
Maximum number of rounds	$R_{\text{max}} = 2000$

The number of dead nodes was defined as those nodes whose energy was depleted during the simulation. The simulation was designed to measure the network lifetime, which was defined as the time until the last node in the network died. This metric is commonly used to measure the energy efficiency of wireless sensor networks. The evaluation criteria included these performance metrics to compare the performance of the proposed algorithm with that of existing protocols.

4 Results and Discussion

Figures 2(a) and 2(b) represent the simulation results obtained for the performance of the wireless sensor network, considering all alive and dead nodes, respectively. The H-LEACH protocol, based on the existing E3PSC protocol, uses dynamic clustering to prolong the network lifetime and reduce energy consumption. The simulation results show that the H-LEACH protocol outperforms existing routing protocols in terms of network lifetime and energy consumption. One of the key advantages of H-LEACH is its dynamic clustering approach, which optimizes the number of clusters based on the initial specification by the sink node. The simulation results demonstrate that this approach leads to better energy consumption and network lifetime performance compared to the static clustering approach used by E3PSC.

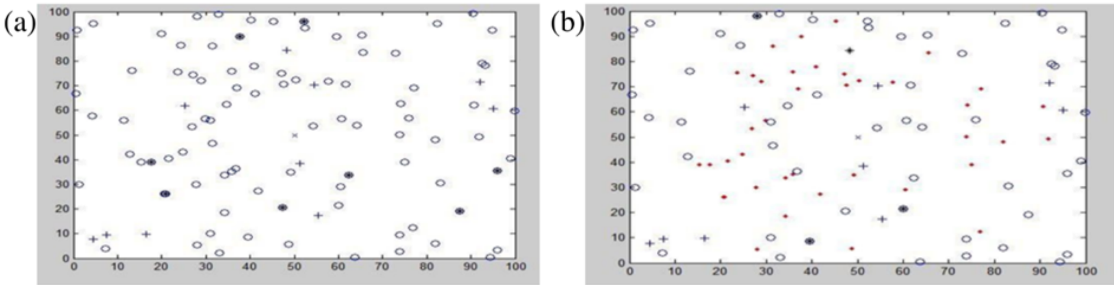

Figure 2: Wireless Sensor Network: **(a)** with alive nodes; **(b)** with dead nodes.

However, the H-LEACH protocol has its limitations. The simulations were conducted for a network with only 100 nodes, and the results may not be generalizable to larger or smaller networks. Additionally, the simulation parameters and assumptions may not accurately reflect real-world scenarios, and further research is needed to validate the protocol's performance in real-world settings. Furthermore, although the protocol was compared with existing routing protocols, it was not compared with all possible protocols, and further research is necessary to compare its performance with other protocols. Moreover, while H-LEACH prolongs the network lifetime, there is room for improvement in terms of energy conservation. Incorporating energy harvesting techniques into the protocol could further prolong the network lifetime while optimizing the network's throughput. Therefore, further research is needed to validate the protocol's performance in real-world scenarios and optimize its energy conservation techniques.

5 Conclusion

The proposed H-LEACH protocol for wireless sensor networks is based on dynamic clustering and the selection of cluster heads using the highest energy of nodes and minimum distance from the average node distribution in each cluster. The simulation results demonstrate that the H-LEACH protocol outperforms existing routing protocols regarding network lifetime and energy consumption reduction. Moreover, the study suggests incorporating energy harvesting techniques could further prolong the network lifetime and optimize network throughput. The H-LEACH protocol was simulated using network parameters such as field coordinates, number of nodes, probability of cluster head election, heterogeneous energy model, transmission amplifier types, and data aggregation energy. The simulation results were based on network lifetime, defined as the time until the last node failed. The H-LEACH protocol shows potential for improving wireless sensor networks' performance and energy efficiency, particularly in applications where network lifetime and energy conservation are critical. Further research can explore integrating energy harvesting techniques and other advanced technologies to optimize the performance of wireless sensor networks.

Declaration of Competing Interests

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Chandra Prakash Verma: Conceptualization, Visualization, Investigation, Methodology, Data curation, Software, Writing- Original draft preparation, Writing- Reviewing. The author has read and approved the submitted version.

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