Scalability and Applicability of IoT-WSN-Based Energy Efficiency Protocols: Extending the Lifespan of Large-Scale Networks

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Abstract: **This study's major objective is to investigate how IoT-based energy efficiency strategies for WSNs might be used to extend their useful lives. The analysis of these papers revealed that the use of IoT-WSN-based energy efficiency protocols has significant potential in extending the lifetime of WSNs. The study identified machine learning techniques as one of the key enablers of energy-efficient protocols. The incorporation of machine learning in the development and execution of energy-efficient protocols enables the creation of intelligent systems that can make informed decisions on how to optimize energy consumption. The application of machine learning methods likes decision trees, clustering, and neural networks was found to be effective in optimizing energy consumption in WSNs. In order to extend the lifespan of WSNs, it is essential to employ energy-efficient routing protocols. this study shows that IoT-WSN-based energy efficiency protocols have significant potential in enhancing the lifespan of WSNs. The incorporation of machine learning techniques and the use of energy-efficient routing protocols are critical in achieving this. However, there is a need for further research to explore the scalability and applicability of these protocols in large-scale WSNs.**

Keywords: Sensor Network, lifetime enhancement, Machine Learning, Clustering Methods, IoT applications.

I. Introduction

Each area of our daily life has seen a significant transformation as a result of the growth of wireless networking technologies. The Internet of Things (IoT) is one of the innovations whose development is expected to accelerate in the next years. IoT allows for the association of several gadgets with physical objects, effectively altering our daily lives. Hence, there is a swiftly expanding requirement for communications everywhere and at all times, especially in industries with increased activity [1]. Communication between machines through a network is the general definition of the Internet of Things (IoT). In addition, Cloud data collection, management, and monitoring is the main objective of the Internet of Things. A wireless network called a WSN links numerous nodes. In the WSN, these nodes are used for communication and information [2]. For a number of uses, such as monitoring the weather, tracking wildlife, managing disasters, using bio-medical applications, and using the Internet of Things (IoT), WSNs are made up of huge sensor nodes that are dispersed over an extensive area in order to detect and gather information about the environment and systems. [3]. These sensor nodes are a favourite in every sphere of human existence due to their minimal maintenance requirements, self-configurability, and wide range of applications in which they perform a key role. If the aforementioned parameters are satisfied, a WSN enables us to use applications in numerous fields, such as in farming, the military, surveillance of health, and environmental monitoring. Figure 1 illustrates the fundamental architecture of IoT-WSN. [4].

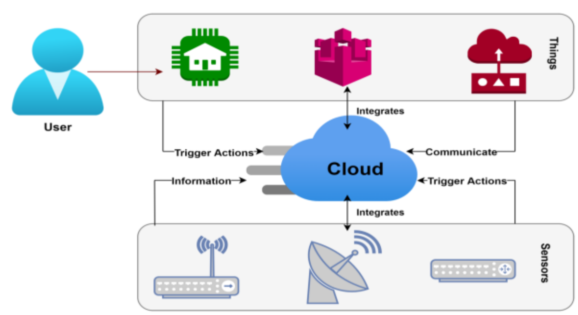

Figure 1 shows a WSN design based on IoT.

- In the Internet of Things (IoT), WSNs are a crucial element. The development of wireless sensor nodes with rapid CPUs and low-power radio connectivity enables WSNs and applications for the IoT. The IoT-based WSN (Wireless Sensor Network) is a groundbreaking smart monitoring system that has brought about a significant revolution. One of the key communication protocols within this system is ZigBee, which plays a vital role in WSN and IoT applications. Its importance lies in its ability to facilitate low-power and cost-effective IoT solutions while supporting various network configurations. This study included a general review of the energy-efficient and routing structures of the ZigBee WSN, uses for IoT-enabled WSN, and security concerns about IoT WSN.

- The Internet of Things (IoT) refers to a network that enables seamless communication and interaction between machines, sensors, and physical objects, eliminating the need for human intervention. WSNs play a vital role as a fundamental element within the Internet of Things, which has experienced remarkable growth and diversification in its applications. Presently, IoT and WSNs have a significant impact on numerous aspects of our daily lives, encompassing both essential and non-critical domains. WSN nodes are commonly small devices powered by batteries. Additionally, the implementation of energy-efficient data aggregation methods becomes crucial to prolong the lifespan of the network. The presentation of several strategies and methods for IoT-WSN systems' energy-efficient data aggregation. The components of wireless networking for energy efficiency and data aggregation are the main topics of this research review.

Although sensor nodes in WSNs are often only supplied by batteries and must operate for extended periods of time, energy efficiency is always given priority. In addition, replacing sensor nodes after deployment is impractical and costly. The truth is that, according to earlier studies, energy is mostly employed for transfer of data, and the routing design has a significant impact on how effectively data is transmitted. Developing an energy-efficient routing protocol is of utmost importance to significantly reduce energy consumption and extend the operational lifespan of the network. Numerous routing protocols have been employed in Wireless Sensor Networks (WSNs). RPL-based routing has grown in acceptance for WSNs. The clustering approach is a different kind of effective strategy for extending the life of WSN networks, and it does so in two ways. Firstly, Managing the node's energy. According to the node energy circumstances, these schemes follow a strategy that allows the nodes to become cluster heads and construct clusters of varying sizes, which lowers node mortality and increases network longevity. Second, enhancing the cluster heads' equilibrium distribution. By using several auxiliary factors and various cluster head selection techniques, the authors are able to connect the clusters and spread the network's cluster heads uniformly, It employs cluster heads to lower the energy required for the transfer of data.[5]

Machine learning (ML), one of the most popular uses of artificial intelligence, is the process by which computers build a mathematical framework from a portion of data called "training data" with the goal to formulate forecasts or judgements without being explicitly instructed to do so. [6]. Recent ML innovations have been used to address a variety of WSN-related problems. Recent technological developments have made it possible to use machine learning to a variety of problems to enhance network performance while requiring less human programming and interaction. In addition, Modern technological and application developments are crucial For accomplishing machine-to-machine connectivity, the Internet of Things, and physical structure collaboration, and the cloud to suit user expectations [7]. Utilizing ML reduces the need for human intervention or reprogramming while also enhancing WSN efficiency. It is challenging to access the massive volumes of data that sensors have collected and to retrieve the relevant information from the data without machine learning (ML). Additionally, it integrates machine-to-machine (M2M), cyber-physical systems, and the Internet of Things (IoT) [8]. The resources and computing capabilities of nodes, as well as the requirement for sizable data sets for learning, provide the two key obstacles to ML in WSNs. Moreover, the difficulty of using ML algorithms to meet the confidentiality and integrity of security criteria is one of the biggest problems ML algorithms confront in terms of the safety of WSN networks. As a consequence, machine learning algorithms can lower all types of congestion issues while also enhancing wireless network security [9]. The development of routing protocols that consider the topology, traffic patterns, and energy limitations of the nodes of the network can be accomplished using machine learning techniques.

Machine learning can enhance network longevity in a number of ways, including:

- Predicting node failure: The likelihood of a node failing or running out of power can be predicted using machine learning methods. Utilizing nodes that are likely to fail soon can be prevented by employing the data to dynamically modify the routing protocol.
- Energy-efficient routing: The development of routing protocols that account for the nodes' energy usage can be facilitated by machine learning. The network's overall energy consumption can be decreased by choosing less energy-intensive pathways, which can increase the lifespan of the nodes.
- Dynamic adjustment: When network conditions change, such as when traffic patterns change or nodes are added or removed, machine learning can be used to dynamically modify the routing protocol. The network will run more effectively and last longer if it can adjust to changing circumstances.
- Optimization: The placement of nodes, the scheduling of tasks, or the distribution of resources are just a few of the network features that can be optimized using machine learning. The network's energy consumption can be decreased through

the optimization of these factors, resulting in a longer node lifespan.

The current work in the domain of machine learning has made significant advancements in recent years; However, it still has several problems that require to be solved. The difficulty in interpreting the data is among the biggest problems. and transparency in the decision-making processes of machine learning models, which can make it difficult to trust and understand their outputs. To overcome these challenges, there is a need for the growth of new technologies and techniques that can improve the performance and reliability of machine learning models. Despite the challenges, the future of machine learning is bright, and it holds tremendous potential for transforming various industries and sectors. With the increasing amount of data being generated every day, machine learning can help us make better decisions, solve complex problems, and improve our overall quality of life.

II. Related Work

Xu, Chuan, et al. [10], offered a brand-new energy-efficient region source routing protocol, or ER-SR, to enhance the network lifespan of the WSN. An energy region distributed approach was proposed in ER-SR for dynamically choosing the network nodes with the largest residual energy as source route nodes. Additionally, they offered a potent distance-based ant colony optimization method to locate each node's worldwide optimal transmission channel in an effort to lower the energy required for the transfer of data. According to the simulation outcomes, the ER-SR routing protocol showcased superior performance compared to rival routing protocols in WSNs in terms of network longevity, packet delivery ratio, and delivery latency, all while exhibiting enhanced energy efficiency. **Sharma, H.; Haque, et al. [11],** For conventional WSN-IoT nodes used in applications for smart cities, the authors of this research suggested machine learning techniques as an optimization tool. The author acknowledges that this comprehensive examination represents the inaugural investigation of all machine learning algorithms within the realm of low power consumption Wireless Sensor Networks (WSN) and Internet of Things (IoT) for smart urban areas. Additionally, based on the outcomes of this original surveying research, supervised learning algorithms were used for applications related to smart cities the most commonly (61%) compared to unsupervised learning (12%), reinforcement learning (27%) and unsupervised learning methods. **Dogra, R.; Rani, et al. [12],** suggested an improved smart-energy-efficient routing protocol (ESEERP) method. It increased the lifespan of network and strengthens its connectivity. Based on an effective optimization technique drawn from many reasons, it chooses the Cluster Head (CH). After selecting the CH, a Sail Fish Optimizer (SFO) was used to choose the best course to take for data transmission to the sink node. In addition, the suggested method was mathematically studied, and the outcomes have been contrasted with similar existing approaches like a Genetic algorithm (GA), Ant Lion optimization (ALO), and Particle Swarm Optimisation (PSO). The outcomes have been examined in terms of bandwidth, packet delivery proportion, energy consumption, and network durability. Furthermore, The model demonstrated that there were 3500 rounds in the suggested strategy for the network's longevity, a maximum energy utilization of 0.5 Joules, a bandwidth transmitting data rate of 0.52 MBPS, and a packet delivery ratio (PDR) of 96% for 500 nodes, correspondingly. **Rani, S.; Talwar, et al. [13],** The proposal put forth a pioneering deployment strategy aimed at tackling the challenges related to energy efficiency. It introduced innovative concepts such as a hierarchical network architecture, an energy-efficient approach for the IoT, and a transmission technique that minimizes energy consumption. These novel ideas pave the way for efficient resource utilization and contribute to optimizing energy usage in the context of IoT and WSNs. The simulation findings demonstrated that the novel scheme was greater flexible and energy efficient than conventional WSN schemes, and as a result, it may be used to perform effective communication in the IoT. **Behera, Trupti Mayee, et al. [14],** the low-energy adaptive clustering hierarchy (LEACH) clustering technique underwent modifications by presenting a threshold limit for selecting the cluster head and adjusting power distribution among the nodes. The suggested modified LEACH protocol exhibited superior performance compared to the existing LEACH protocol. It demonstrated a remarkable 67% improvement in throughput and extended the lifetime of the Wireless Sensor Network (WSN) by enabling the sustenance of a larger number of nodes for up to 1750 rounds. Notably, the proposed approach outperformed other energy-efficient protocols in terms of stability duration and network lifetime across various node densities, energy consumption levels, and area conditions. **Gopika, D., et al. [15],** IoT-driven networks have a number of difficulties, but the biggest one was the transmission of the massive amounts of data that sensor devices produced, which puts the node's durability in danger owing to excessive communication power consumption. As a result, it has grown of utmost relevance to provide answers to network-based problems regarding quality of service, safety, conserving energy, trustworthy routing, and avoiding overload. In order to extend the life of sensors, recent studies have mostly concentrated on how the sensor node uses energy. This study offered a thorough overview of numerous energy-efficient protocols and processes, including Energy Harvesting, Bio-Inspired Routing, Fuzzy Logic-based Methodologies, and Sustainable Computing. **Gulati, Kamal, et al. [16],** these days, the Internet of Things and wireless sensor networks (WSNs) have a number of important and non-critical technologies that touch practically every aspect of our everyday life. Small, battery-powered devices called WSN nodes were typical. The use of energy-efficient data aggregation algorithms to lengthen network longevity was therefore crucial. In IoT-WSN systems, a variety of strategies and methods for data aggregation that uses less energy were offered. . This literature review also highlighted the importance of wireless networking for data collection and energy efficiency. **Kulin, M.; Kazaz, et al. [17],** gave a methodical and extensive study of recent research initiatives targeted at ML-based enhancements to the efficiency of wireless networks, taking into consideration entire protocol stack, including all levels, comprising PHY, MAC, and network. In order to make the presented techniques understandable to those who were not machine learning experts, The needed basic knowledge of data-driven methodologies and machine learning was presented after a description of the pertinent work and publication contributions. The research investigations utilizing ML-based techniques to improve wireless communication configurations for enhanced network quality-of-service (QoS) and quality-of-experience (QoE) were also carefully examined. Radio analysis, MAC analysis, and network forecasting methods were the first divisions made for these studies, each of which was further divided into subcategories. Open issues and wider views were then discussed. **Sapkta, Tirtharaj, et al. [18],** Since the sensors have limited energy, the WSN must ensure that the least amount of energy was used while carrying out various functions and that the network's lifespan was extended. One of the major design difficulties for WSN was lowering the amount of energy that sensors use. In order to effectively use the sensor nodes' restricted energy capacity, a number of routing approaches were documented in the literature. Additionally, the quantity of information that the sensor nodes must acquire, process, and distribute, however, climbs significantly as the WSN gets bigger. Due to the sensors' low energy capacity, processing and transmitting such a vast volume of data was impossible. As a result, machine learning (ML) methods must be used in WSNs. Moreover, The machine learning approaches used to optimize the efficiency of WSN were the topic of this research review, as well as the routing protocols utilized in WSN. **Tripti Sharma, Archana Balyan, et al. [19],** an upgraded clustering-based strategy was presented in this research that was based on reinforcement learning. Energy-efficient methods have been developed using a lot of clustering-based strategies. A group of methods called reinforcement learning was affected by the animal behavioural principle of operant conditioning. In addition to this, the nodes could be scheduled and planned out according to the suggested approach, ensuring a longer network lifetime. The aim of this effort was to evaluate power usage, improve its efficiency, and lessen energy loss at sensor nodes. Moreover, the simulation's findings demonstrated demonstrating the proposed approach successfully lowers the energy consumption of sensor nodes and guarantees an extended lifespan for the network of sensors. **Liu, Y.; Wu, et al. [20],** developed a novel modified routing technique to improve the WSN's energy efficiency. Both the average energy of the networks and the residual node energy are taken into consideration by the recently established IEE-LEACH protocol, which was more energy-efficient than LEACH. Furthermore, the proposed IEE-LEACH protocol addresses the optimal number of cluster heads (CHs) and prevents nodes in close proximity to the base station (BS) from participating in cluster formation. This approach aims to achieve significant efficiency gains by reducing sensor energy consumption. The IEE-LEACH protocol incorporates single hop, multi-hop, and hybrid communication techniques, along with a novel threshold for selecting CHs from among the sensor nodes. These advancements are implemented to enhance energy utilization within the networks, further optimizing their overall performance. Moreover, The outcomes of the simulation showed that, in comparison to some current routing methods, the suggested protocol significantly lowers the energy usage of WSNs. **Ghosh, Ahona & Ho, et al. [21],** As per the latest research, enhancing the quality of service in wireless sensor networks (WSNs) during data transfer primarily revolves around addressing two critical challenges: security and energy efficiency. Machine learning has emerged as a successful approach for devising efficient solutions to tackle complex issues in various aspects of network operations. Routing, which involves determining the optimal path for transmitting information among different sensor nodes, is a crucial aspect of WSNs. In order to create energy-efficient routing protocols, machine learning has been employed extensively. This chapter covered the efforts that have already been done in the field and serves as a guide for those interested in learning more. **Nayak, Padmalaya, et al. [22],** In this work, an effort has been made to give contemporary "researchers" a broad perspective on machine learning techniques that were used to address a variety of difficulties in WSNs, with a focus on routing challenges. **Behera, T.M.; et al. [23],** provided an overview of changes to the network's CH selection threshold value since CH selection has historically been a crucial requirement for clustered networks. The CH selection was improved by taking the network's behaviour into account as bio-inspired algorithms have progressed. In addition, this article briefly discussed the advantages and disadvantages of LEACH-based and bio-inspired protocols, as well as the underlying presuppositions and selection criteria for CHs. Ultimately, the performance characteristics of different protocols were compared and mentioned, including their durability, scalability, and packet delivery ratio. **Sebastin Suresh, et al. [24],** suggested the opportunistic energy-efficient routing protocol (OEERP) technique. It offered precise target position identification, improved energy economy, and longer network longevity. Additionally, Its goal was to optimize network energy usage by scheduling idle nodes into a sleep state. Sleep was dynamically altered using the network's flow rate (FR) and residual energy (RE). Additionally, the sleep nodes were informed to get up after a specified period of time. The results of the simulation show that in terms of accuracy, energy efficiency, and longevity of network extension, the suggested OEERP algorithm has superior performance to the most recent state-of-the-art approaches.

Table 1. Analysis for different research with finding

Sr. No.	Author Name	Reference No.	Findings
1.	Xu, Chuan, et al.	[10]	Introduced ER-SR, a revolutionary region source routing system for WSNs that employs an ant colony optimization method and a distributed energy region technique to maximize energy efficiency and reduce data transmission energy usage.
2.	Sharma, H.; Haque, et al.	[11]	a suggestion was made to leverage WSN-IoT nodes that are now in use as optimization tools for machine learning projects involving smart cities.
3.	Dogra, R.; Rani, et al.	[12]	Introduces an improved smart-energy-efficient routing protocol (ESEERP) method that utilizes a Sail Fish Optimizer (SFO) for selecting a Cluster Head (CH) and choosing the best route to take for data transfer to the sink node.
4.	Rani, S.; Talwar, et al.	[13]	provides an innovative method for attaining energy efficiency in the Internet of Things (IoT) using a hierarchical network architecture, an energy-efficient IoT approach, and a transmission method with the lowest possible energy usage.
5.	Behera, Trupti Mayee, et al.	[14]	introduces a threshold limit and changes the power distributed to suggest improvements to the low-energy adaptive clustering hierarchy (LEACH) clustering method.
6.	Gopika, D., et al.	[15]	focuses on a variety of energy-efficient protocols and techniques for smart IoT networks, covering major issues like energy conservation, dependable routing, congestion escape, network variation, safety, and quality of performance. .
7.	Gulati, Kamal, et al.	[16]	Emphasizes the significance of energy-efficient data aggregation algorithms for prolonging the lifespan of WSNs in the context of Internet of Things systems.
8.	Kulin, M.; Kazaz, et al.	[17]	Examined recent research initiatives focused on using machine learning to improve the efficiency of wireless networks across the entire protocol stack.
9.	Sapkta, Tirtharaj, et al.	[18]	emphasizes the value of machine learning methods in enhancing the efficiency of WSNs while taking energy restrictions into account.
10.	Tripti Sharma, Archana Balyan, et al.	[19]	Introduces an upgraded clustering-based strategy for wireless sensor networks (WSNs) using reinforcement learning. This approach effectively reduces energy consumption, prolongs the network's lifespan, and improves efficiency.
11.	Liu, Y.; Wu, et al.	[20]	Introduces IEE-LEACH, a modified routing protocol for WSNs, which incorporates residual node energy and average network energy considerations.
12.	Ghosh, Ahona & Ho, et al.	[21]	Highlights the importance of addressing security and energy efficiency challenges in WSNs to enhance the quality of service during data transfer.
13.	Nayak, Padmalaya, et al.	[22]	Provides a comprehensive overview of machine learning techniques applied to handle different issues in Wireless Sensor Networks (WSNs), particularly in routing.
14.	Behera, T.M.; et al.	[23]	Highlights the significance of Cluster Head (CH) selection in clustered networks and provides an overview of the changes in CH selection thresholds.

15.	Sebastin Suresh, et al.	[24]	Suggested Opportunistic Energy-Efficient Routing Protocol (OEERP) technique aims to improve energy economy and network longevity through precise target position identification and dynamic sleep scheduling of idle nodes based on flow rate and residual energy.

III. Conclusion

Energy efficiency is a critical challenge in the field of wireless sensor networks (WSNs), and the integration of the Internet of Things (IoT) further complicates this challenge. Several studies have focused on developing routing protocols that increase network lifetime by minimizing energy consumption. The use of machine learning (ML) techniques in these protocols has been shown to improve energy efficiency significantly. For example, the use of a decision tree-based approach for routing in IoT-WSNs can lead to a 30% reduction in energy consumption compared to traditional routing algorithms. Additionally, several studies have proposed using clustering techniques in IoT-WSNs to improve energy efficiency. By clustering the sensors, the network can reduce communication overhead and decrease energy consumption. The use of artificial intelligence (AI) algorithms, such as k-means clustering, has been shown to improve network lifetime by up to 50%. Furthermore, researchers have proposed using sleep scheduling to reduce energy consumption in IoT-WSNs. By allowing sensors to periodically enter sleep mode, the network can conserve energy and prolong network lifetime. The use of machine learning algorithms, such as the support vector machine (SVM), for sleep scheduling can reduce energy consumption by up to 40%.

In conclusion, the use of IoT-based WSNs in energy-constrained environments necessitates the development of energy-efficient protocols. The studies summarized above demonstrate that the use of ML and AI techniques in energy efficiency protocols can significantly improve network lifetime and reduce energy consumption. Therefore, future research should continue to explore the use of these techniques to further enhance the energy efficiency of IoT-WSNs.

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