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Advancements in Clustering Protocols for Wireless Sensor Networks-Assisted Internet of Things – A Comprehensive Review

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ABSTRACT

According to the current study, there will be a large number of Internet-connected systems, including not just mobile phones but also devices capable of performing a range of duties such as data collection and operation under outdoor circumstances. Accordingly, WSNs are essential to the Internet of Things (IoT) paradigm to provide several advantages, including intelligence, adaptability, and dependability. Typically, a collection of sensors with constrained power and memory resources is used to build the WSN. However, the biggest challenge in these systems is the high energy consumption during data transfer from the origin node to the destination nodes, which affects the node's lifetime. Energy consumption has become a crucial design concern in WSN-IoT systems, as it is very impossible to replace or recharge the batteries in those nodes. Therefore, in WSN-IoT systems, the clustering protocol is crucial to improving network lifetime and energy efficiency. Numerous academics have developed many clustering techniques to help WSN-IoT devices save energy. By grouping the nodes according to various parameters, such as the node's residual energy, the distance between other nodes, etc., these protocols primarily aim to maximize energy productivity. This paper provides a thorough analysis of several clustering techniques for WSN-IoT systems. Additionally, it presents those protocols' advantages, drawbacks, and simulation effectiveness in tabular form. To evaluate certain protocols in terms of network lifetime, residual energy, throughput, Packet Delivery Ratio (PDR), and stability, some of them have also been simulated. Lastly, certain possible modifications are suggested to reduce the energy consumption of WSN-IoT systems and extend their lifespan.

Keywords: *WSN, IoT, Clustering, Energy efficiency, Data transfer, Network lifespan*

1. INTRODUCTION

The IoT represents one of the most significant technological advancements of this century, establishing a foundation for innovative services and technological progress. Numerous applications of IoT can be categorized into sectors such as healthcare, sustainable infrastructure, agriculture, and distributed energy resources, among others [1]. At present, the communication framework is characterized by interconnected devices, commonly referred to as ubiquitous connectivity. This framework facilitates the distribution of smart devices through a decentralized network utilizing wireless communication [2]. As an increasing number of individuals migrate to urban areas in search of improved quality of life, there has been a significant surge in the adoption of intelligent systems, including sensors, mobile devices, and home automation technologies. This trend supports the aims of the IoT by facilitating connectivity among various devices and enabling seamless information exchange over the Internet [3].

The conventional design of the IoT, as illustrated in Figure 1, features a perception layer that includes sensing devices, controllers, and mobile phones. These interconnected devices serve as the terminal for an IoT platform. The network layer, often referred to as the connectivity or edge computing layer, facilitates the exchange of information among the connected devices. The collected data is subsequently transmitted to a cloud system for processing, which involves extraction, computer vision, and analysis. Ultimately, the application layer interprets the data and presents it visually to end users, aiding them in business operations, strategic planning, and collaboration based on the insights obtained through IoT technology [4]. Numerous IoT solutions are built upon WSNs as their foundational platform. Currently, significant research and development efforts are being directed towards this domain of WSNs [5]. A key aspect that requires attention is energy efficiency. The longevity of the network is directly linked to the energy available at the nodes. The primary function of these nodes is to gather data regarding environmental conditions and convert it into signals for subsequent processing and analysis. Various operations, including transmission, sleep mode, passive monitoring, congestion management, and collision avoidance, all consume energy. Among these functions, data transmission is the most energy-intensive. WSN-IoT systems are extensive and diverse, facilitating improvements in daily human activities. Generally, these activities can be categorized into three types: societal activities, environmental activities, and business activities.

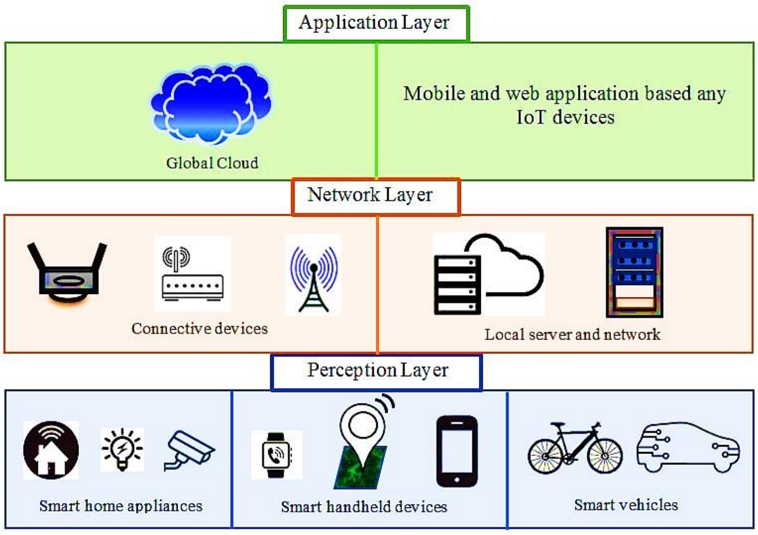

Figure 1. Conventional Design of IoT System

A standard configuration of WSN integrated with the IoT, comprising numerous distributed and autonomous devices, such as sensors. These devices possess the capability to detect, process, and transmit data to other devices or Base Stations (BS) via wireless communication networks [6]. Due to their compact size, these devices often have limited power resources, primarily relying on batteries. The maintenance or replacement of batteries in most WSN deployments within IoT systems can be challenging and costly, particularly when the devices are situated in remote or harsh environments. In addition to the constraints on power supply, these devices also have limited computational and memory capabilities, which must be taken into account when developing protocols for such networks. Extended network lifespan is recognized as a significant challenge in WSN-IoT. Consequently, the clustering protocol can be utilized within WSNs to enhance their longevity and reduce energy consumption [7]. These protocols effectively organize devices into smaller clusters, which serves as a strategic approach to decrease energy expenditure and extend the overall system lifespan by minimizing long-distance transmissions (refer to Figure 3). Within each cluster, a designated device is appointed as the Cluster Head (CH), assuming greater responsibilities compared to the Member Nodes (MNs). In practice, all MNs within the cluster relay the collected data to their CH, who then transmits the information to the BS using either a one-hop or multi-hop communication method.

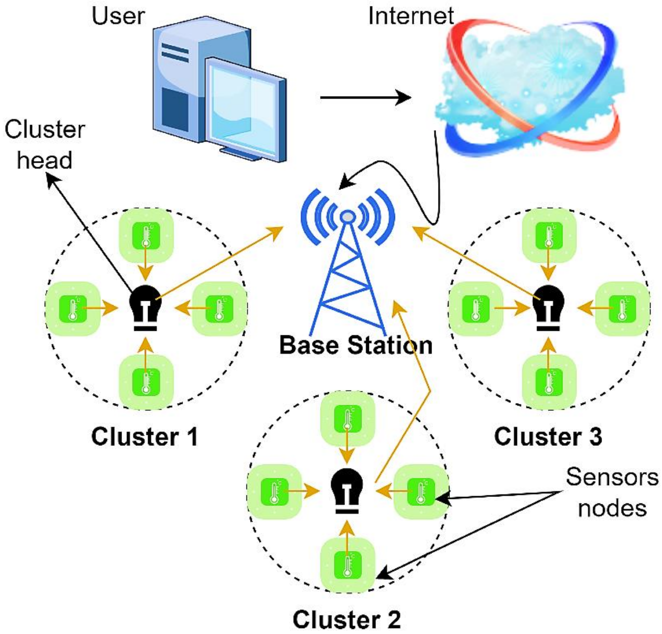

Figure 3. Typical Scenario of Clustering in WSN-IoT System

The clustering procedure is recognized as a vital method for conserving energy among nodes in WSNs. However, the architecture of clustering remains a significant challenge that can diminish the network's lifespan due to inefficient energy consumption by nodes. Furthermore, an inadequate clustering topology within the WSN can adversely affect subsequent processes such as information fusion and path identification, which are critical for optimizing system performance. Consequently, the reliability of the clustering topology plays a crucial role in determining the lifespan of the WSN. One of the primary issues arises from the selection of a suboptimal number of clusters, whether it be too few or too many, leading to increased energy consumption by nodes. Existing theoretical approaches often result in the formation of overlapping clusters that do not accurately estimate the ideal number of clusters, primarily because the distance to the CH is not assessed correctly. Additionally, the process of cluster generation can significantly influence the longevity of the WSN.

The third concern pertains to energy efficiency. As node density increases, the volume of information processed escalates, leading to higher power consumption and premature node failure. Consequently, numerous energy-efficient clustering protocols have been developed to minimize energy expenditure during data collection and transmission, thereby enhancing the network's lifespan. One of the most recognized clustering protocols is the Low-Energy Adaptive Clustering Hierarchical (LEACH) protocol, which is straightforward to implement and effectively balances system requirements. The foundational concept of the LEACH protocol has inspired many subsequent clustering protocols. The primary objective of this protocol is to rotate devices into CHs, thereby distributing energy consumption across all devices connected to the network while maintaining communication with the BS [8]. The operation of LEACH is divided into rounds, each consisting of two phases: setup and steady-state. During the setup phase, clusters are formed, and data is relayed to the BS in the steady-state phase. In the setup phase, all nodes determine whether to become a CH for the current round based on the anticipated ratio of CHs and their previous participation as CHs. This decision is made by each node selecting a random value between 0 and 1. Once a node is designated as a CH, it transmits a notification signal to other nodes. These nodes can then decide which cluster to join for the current round based on the strength of the received signal and subsequently send their participation information to their CH. Additionally, CH rotation occurs in every round to evenly distribute energy demands among nodes through a novel advertising mechanism. During the steady-state phase, nodes gather data and relay it to the CH, which then consolidates the information from the respective cluster and transmits an aggregated packet directly to the BS. To mitigate collisions both between and within clusters, this protocol utilizes a Multiple Access Time-Division (TDMA) scheme.

This manuscript offers an extensive review of different clustering protocols utilized in WSN-IoT networks. It also briefly examines their advantages, disadvantages, and performance metrics. Furthermore, several clustering protocols are simulated to evaluate their effectiveness in terms of system longevity, stability, residual energy, throughput, and PDR. Additionally, it outlines several promising avenues for improving clustering process in WSN-IoT networks.

This manuscript includes several sections that address different aspects of clustering protocols tailored for WSN-IoT systems. Section 2 elaborates on the various clustering protocols developed for these systems. Also, it discusses their merits, limitations, and findings. Section 3 summarizes the survey and suggests potential areas for further improvement.

2. SURVEY ON CLUSTERING PROTOCOLS FOR WSN-IOT NETWORKS

2.1 Clustering Protocols Based on Different General Strategies and Criteria

Shah et al. [9] formulated a routing protocol that is both power-efficient and interoperable, aimed at optimizing throughput in clustered IoT-WSNs. The protocol focuses on the fundamental phases of clustering protocol to enhance throughput by minimizing End-to-End Delay (E2D), reducing data loss, and improving the overall longevity of the system. Aranzazu-Suescun and Cardei [10] introduced an improved version of the reactive Anchor-based Routing scheme for Event Reporting (ARER), incorporating limited flooding and adaptive clustering within IoT-WSNs. The approach began with an adaptive anchor strategy, which adjusted the group of anchors over time in response to the mobility of the sink. Subsequently, an event-based clustering strategy was devised to facilitate data collection concerning mobility events. This method effectively reduces the volume of event-reporting data transmitted to the BS.

Asad et al. [11] developed a novel IoT-assisted Multi-Adaptive Clustering (MAC) algorithm aimed at minimizing energy consumption and enhancing system efficiency. This protocol employs a hybrid approach to cluster formation, dividing the network topology into two distinct zones: a centralized initial zone and a decentralized secondary zone. Furthermore, the protocol encompasses three key processes: (i) facilitating resource allocation to nodes through IoT, (ii) establishing a hybrid cluster to evenly distribute system traffic across nodes, and (iii) formulating an innovative strategy to decrease power consumption during long-range data transmission. Behera et al. [12] developed an effective method for selecting CHs, referred to as R-LEACH, which strategically varies the location of the CH among devices with higher power levels. The selection process for the subsequent set of CHs, suitable for IoT systems, considered the initial energy, remaining power, and the most optimal CHs. Throughout each cycle, the remaining power of non-CH nodes was assessed, and the node with the highest power was designated as the CH for the following cycle.

Bouaziz et al. [13] introduced an innovative Energy-efficient and Mobility-Aware Routing Protocol (EMA-RPL) designed for low-energy and lossy systems. This protocol enhances the maintenance of node connectivity and energy harvesting capabilities. EMA-RPL incorporates energy and mobility identification strategies through the ongoing assessment of the distance between nodes and their interactions. Additionally, it features a novel method for estimating points of interaction based on the devices' new locations, along with an efficient replacement mechanism aimed at conserving node energy.

Chithaluru et al. [14] developed an Improved-Adaptive Ranking-based Energy-efficient Opportunistic Routing (I-AREOR) protocol that takes into account neighborhood density, relative distance, and remaining power to prolong the duration until the first node experiences failure. This approach aims to achieve a balance between power consumption and the overall lifespan of the network. Additionally, it evaluates the residual power of nodes, adaptive thresholds, relative distances, and regional density to select CHs and reduce power usage. Manchanda and Sharma [15] created an Energy-efficient Compression Sensing-based Clustering Framework (ECSCF) specifically for WSN-IoT. Initially, the selection of CH was conducted based on factors such as energy levels, distance, device count, and average power consumption. Subsequently, data collection was optimized and compressed at the CH nodes to regulate the quantity of compressed samples.

Alharbi et al. [16] suggested an Improved Clustering and Routing (ICR) protocol based on fixed areas of clusters for resolving hot-spot issues in IoT-based WSNs. It applied the CH selection task that chooses the CH based on the cumulative weights of the remaining energy and node connectivity. Also, a routing scheme was adopted that handles fail-over scenarios by providing alternate routes to any chosen CH. Sehrawat and Goyal [17] suggested a Neighborhood-aware Improved Stable Election Protocol (NaISEP) for WSN-IoT. In this protocol, the optimal CH was chosen based on the neighborhood of the node.

Tumula et al. [18] developed an Opportunistic Energy-efficient Dynamic Self-configuration Routing (OEDSR) protocol for WSN-IoT. First, the mobility and energy factors of the sensor nodes were calculated to choose an optimal path to the BS. After that, the number of connections was reduced by creating a cluster using a hierarchical tree design, which minimizes energy depletion in the WSN. The graph theory scheme done node clustering via the Steiner tree algorithm and the central node of a cluster was selected as the CH.

2.2 Clustering Protocols Based on Metaheuristic Algorithms

Janakiraman [19] introduced a Hybrid Ant Colony Optimization and Artificial Bee Colony scheme for Cluster Head Selection (HACO-ABC-CHS) aimed at identifying an effective CH for the IoT. This protocol addresses the inertia encountered in the reinforcement process of ACO by utilizing employee bee agents for the search function. Additionally, it mitigates the slow convergence issue present during the onlooker bee phase of the ABC by dividing the development task into two distinct stages, thereby incorporating the employee bee phase in the initial search stage.

Preeth et al. [20] developed a dynamic Fuzzy rule-based Energy-Efficient Clustering and Immune-Inspired Routing (FEEC-IIR) framework. The selection of the optimal CH was facilitated by the Adaptive Fuzzy Multi-Criteria Decision-Making (AF-MCDM) approach, which combines the fuzzy Analytic Hierarchy Process (AHP) with the TOPSIS method. This selection process was based on several factors, including energy levels, Quality-of-Service (QoS) considerations, and the positions of devices. Additionally, an immune-inspired optimization strategy was employed for routing, enhancing the reliability of packet delivery while reducing energy consumption. Thangaramya et al. [21] introduced a novel Neuro-Fuzzy rule-Based Cluster Formation Protocol (FBCFP) aimed at enhancing transmission efficiency in IoT-WSNs. This protocol employs energy formulation to establish clusters that facilitate effective data transfer, utilizing a convolutional neural network with fuzzy rules to adjust weights for prolonging system longevity. Consequently, the residual power of the CH, the distance from the CH to the BS, the distance from the sensor to the CH, and the rank of the CH were all evaluated. Bensaid et al. [22] introduced a novel Fuzzy C-Means (FCM)-based communication protocol for WSN-IoT systems. This protocol employs a fuzzy logic clustering approach to form clusters and select the optimal CH during each communication cycle, thereby minimizing the overall power consumption across all clusters.

Karunanithy and Velusamy [23] introduced a Cluster Tree-based Energy Efficient Data Gathering (CTEEDG) protocol aimed at improving both the longevity and throughput of the system. This protocol employs fuzzy logic to select the CH based on locally gathered information. During the inter-group transfer phase, a tree structure is established among the groups leading to the BS, ensuring a congestion-free route. Seyyedabbasi and Kiani [24] developed an innovative routing protocol based on ACO for multi-agent systems, effectively managing system resources in practical applications. This protocol leverages key characteristics of ants to identify subsequent nodes and determine the most efficient route, taking into account factors such as residual energy, queue length, traffic rate, and distance.

Yousefi et al. [25] introduced an innovative strategy for selecting and clustering CH in the IoT, which consists of two primary phases. First, the ABC algorithm was employed to identify the most suitable nearby CHs, taking into account factors such as the remaining energy of the nodes, the number of neighboring nodes, the Euclidean distance from each node to the BS, and the distances between all devices and their respective neighbors. Subsequently, the nodes were organized into clusters based on the Euclidean distances from all CHs to their MNs and the volume of information generated by each group.

Hassan et al. [26] introduced an Enhanced Energy-Efficient Clustering Protocol (IEECP) aimed at prolonging the operational lifespan of WSN-IoT. The primary objective of the IEECP was to extend the longevity of the WSN-IoT, which is significantly influenced by the battery life of the devices, thereby broadening the application scope of the WSN-IoT. Initially, a revised mathematical framework was proposed, focusing on the assessment of energy consumption during multi-hop transmissions and overlapping groups to determine the optimal number of clusters. Subsequently, balanced-static clusters were established using the Modified FCM (M-FCM) approach, which was integrated with a strategy aimed at reducing and compensating for the energy consumption of the nodes. Additionally, a new methodology known as the CH Selection and Rotation Algorithm (CHSRA) was developed, which incorporates a back-off timer strategy for the election of CHs, along with an innovative alternation strategy for the rotation of CHs among other mobile nodes.

Ahmad et al. [27] designed WSN clustering based on the Memetic Algorithm (MemA) to decrease the probability of early convergence by utilizing local exploration schemes. This algorithm chose the optimal clusters and CH set in WSN-IoT to dynamically balance the load among clusters. The nodes with high weight values were chosen instead of new inhabitants in the subsequent generation. A crossover strategy was used to create new-fangled chromosomes as soon as the two maternities had been nominated. The local search method was initiated to enhance the worth of individuals. Jaiswal and Anand [28] presented a Grey Wolf Optimization (GWO)-based hierarchical clustering protocol for WSN-IoT, that selects CH based on factors like energy level of the node, node degree, sink distance, intracluster distance, and priority factor. Once the CH was chosen, the routing challenge was resolved by the cost function to select a QoS-aware relay node for effective and reliable inter-cluster routing from CHs to BS.

Srivastava and Paulus [29] investigated the multi-objective optimization for joint Energy and Lifetime aware Cluster-based Routing (ELR-C) for WSN-IoT. It employed a Multi-objective Chaotic Slime Mold (MCSM) algorithm for optimal clustering. After that, various factors based on trust degree were optimized by the Improved Butterfy Optimization (IBO) to choose CH across several nodes. Moreover, Cat Hunting with a Feed-Forward Neural Network (CH-FFNN) was applied for multi-hop routing between CHs and sink nodes. Pravin et al. [30] presented a Stochastic CH Selection Model (SCHSM) for energy balancing in heterogeneous WSN-IoT. This model utilized the Genetic Algorithm (GA) for optimal CH selection based on parameters such as distance, node energy, density, and capacity of nodes. Rekha and Garg [31] developed a hybrid K-means ant Lion optimization for Energy-efficient clustering-based Routing (K-LionER) protocol for WSN-IoT. The clusters were formed by K-means and each CH was elected by the ant lion optimization. The CH selection was based on the residual energy, the distance between the CHs and BS, and the intra-cluster transmission cost. Table 1 summarizes the strengths and weaknesses of the above-studied clustering protocols for WSN-IoT networks.

Table 1. Comparison of Different Clustering Protocols for WSN-IoT Networks

Ref. No.	Protocols	Benefits	Shortcomings	Performance metrics considered
[9]	Energy and interoperable-aware routing protocol	It can maximize the throughput compared to the LEACH protocol.	It needs to enhance cluster creation to further increase the overall network efficiency.	No. of data dropped, the No. of data received, energy utilized per node, death of initial node. and the No. of dead nodes
[10]	ARER	Good efficiency about power usage and complex actions identified via the BS.	Other QoS parameters like network lifespan, throughput, etc., were not analyzed.	Mean remaining energy and mean number of clusters
[11]	MAC energy-efficient routing protocol	It achieves significant enhancement in network lifespan, stability and PDR.	It was only appropriate for a network having the 1-hop transmission and wherein the BS was fixed and situated in the network centroid.	No. of alive nodes, the No. of dead nodes, the No. of received data by CHs, the No. of data accepted by BS, the No. of CHs created, and PDR
[12]	R-LEACH protocol	It enhances routing in homogeneous networks by limiting power consumption.	It needs additional factors to choose the CH.	No. of dead nodes, the No. of data sent to BS, mean remaining energy, and throughput

[13]	EMA-RPL	It minimizes power utilization and increases the PDR.	The network lifespan and throughput were not evaluated.	Consumed power, PDR, signaling cost, and handover delay
[14]	I-AREOR protocol	It can expand the period of the initial node die so that the network longevity is increased.	The number of data transfers to the CHs was not reduced, which led to high energy usage.	No. of alive nodes and residual energy
[15]	ECSCF	It improves the CH selection in the setup stage along with increasing the signal-to-noise ratio of the network.	The number of dead nodes was still high while increasing the number of rounds.	No. of dead nodes, the No. of alive nodes, remaining power, throughput, and stability interval
[16]	ICR	It prolongs network lifetime and increases throughput efficiently.	Energy consumed for clustering was high.	Throughput, network lifetime, energy consumption, and mean hop count to sink node
[17]	NaISEP	It achieves high network lifetime and throughput.	E2D and energy consumption were not evaluated.	Network lifetime and throughput
[18]	OEDSR	It provides reliable transmission in the presence of link failures.	The network lifetime was not satisfactory.	Network lifetime, energy efficiency, energy consumption, E2D, throughput, PDR, and residual energy
[19]	HACO-ABC-CHS-based protocol	It lessens the number of dead nodes and prolongs system longevity.	Its efficiency was less while increasing the number of rounds significantly.	No. of alive nodes, remaining energy, the No. of dead nodes, and throughput
[20]	FEEC-IIR	It improves the PDR, and network lifespan, as well as reduces the packet loss ratio, and jitter efficiently.	It needs to find the best path with maximum remaining energy for multi-hop inter-cluster transfer and to reduce the traffic on CHs nearer to the single BS for increasing overall network longevity.	Network lifespan, E2D, throughput, bit error rate, packet loss rate, channel load, buffer occupancy, and jitter
[21]	FBCFP	It enhances the network longevity and reduces power depletion efficiently.	It was assumed that every node was trusted, which was not probable.	No. of alive nodes, network lifespan, residual power, and mean power consumed
[22]	FCM-based clustering	It improves the total residual energy.	The network lifespan was less than the LEACH protocol.	No. of alive nodes and total residual energy
[23]	CTEEDG protocol	It provides better data gathering efficacy and ensures the congestion-less route.	It needs to determine the proper fuzzy membership values for effective CH selection.	Energy utilization, E2D, control overhead, the No. of alive nodes, and throughput
[24]	ACO-based routing protocol	Better efficiency in simultaneous and real-time information exchange on a large-scale WSN/IoT	It needs to enhance the objective function for further improving the network longevity.	Remaining energy and energy utilization of route

		network.		
[25]	ABC-based Device Clustering (ABC-DC)	It increases energy efficiency, and lifespan.	It needs to develop a delay and energy-aware protocol to transmit collective information from CHs to the sink, to further increase longevity.	Energy utilization, the No. of live nodes, and data transfer delay
[26]	IEECP	It has the highest number of messages received by BS and the maximum lifetime.	The CH selection was impacted by the random initial selection of the FCM algorithm.	Number of messages received by BS, energy consumption, and network lifetime
[27]	MemA	It prevents early convergence and reduces control overhead.	Its computational complexity was high.	Cluster lifetime and control overhead
[28]	GWO-based hierarchical clustering	It increases the lifespan and stability of the network in the presence of heterogeneous nodes.	Computational complexity was high.	Residual energy, stability period, throughput, network lifetime, and data delivery delay
[29]	ELR-C	It enhances energy efficiency and network lifetime.	Coverage efficiency was low.	Energy consumption, network lifetime, number of coverage and connectivity nodes, coverage rate, coverage efficiency, and connection cost.
[30]	SCHSM	It extends the network lifespan and scalability.	The transmission delay was slightly high.	Residual energy, transmission delay, cluster lifetime, scheduling overhead, and PDR
[31]	K-LionER	It prolongs the network lifespan and improves energy efficiency.	It did not consider node degree, mobility factors, etc., for CH selection.	Alive nodes, stability period, dead nodes, and network lifetime

Inferences & Challenges

Clustering network nodes is crucial for reducing power consumption and prolonging system longevity during data transfer. Numerous studies have focused on this topic, with various reviews evaluating CHs for WSN-IoT networks from different angles. The clustering process should consider four key factors: determining the optimal number of clusters, creating stable and predefined clusters, evenly distributing elected CHs in the forecasted area with minimal decision-making overhead, and implementing a CH rotation process based on a threshold. To further enhance the longevity of WSN-IoT systems, several sub-questions have been identified: (i) How to determine the ideal number of clusters in the presence of overlapping stable clusters? (ii) How to form stable clusters with minimal intra-cluster distance in a randomly distributed node scenario? (iii) How to maintain stable power usage among CHs? (iv) How to balance energy consumption among consecutive CHs in the cluster? Addressing these challenges requires innovative solutions that improve clustering efficiency while adhering to energy constraints.

3. CONCLUSION

The advancements in IoT technology have had a significant impact on our daily lives. Despite the variety of research in this field, challenges persist in WSN-IoT systems, particularly related to sensor longevity and energy efficiency. This paper provides an overview of clustering protocols for WSN-IoT systems, discussing innovative strategies, performance measures, benefits, and shortcomings of emerging protocols. It highlights the need for researchers to focus on designing protocols that address energy efficiency and sensor lifespan. Challenges such as scalability, load balancing, and security issues remain, requiring the integration of AI-driven clustering, hybrid approaches, and mobility-aware algorithms. Future research should explore blockchain-based security, cross-layer optimization, and energy harvesting techniques to enhance network sustainability. Leveraging 5G and edge computing can enable real-time processing and energy-efficient communication. By embracing these advancements, WSN-IoT clustering protocols can evolve to support large-scale, secure, and energy-efficient deployments.

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