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RESEARCH INTO AND ASSESSMENT OF CLUSTERING-BASED ROUTING TECHNIQUES FOR MANETS

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Abstract: Wireless Sensor Network (WSN) plays a crucial role in the current infrastructure of the Internet of Things (IoT) by enabling the continuous collection of data across various applications. One of the primary challenges in WSNs is effectively managing energy to prolong its lifespan while maintaining optimal performance. Therefore, there is a need for the synthesis of clustering and routing protocol as a method to achieve energy balance and enhance the lifespan of WSNs. By aggregating and processing data from a large number of sensor nodes, clustering techniques can significantly cut down on energy use. It intentionally selects Cluster Heads (CHs) to facilitate internal cluster communication and deliver consolidated information to the base station. Simultaneously, routing protocols optimize the paths through which data flows by considering factors such as energy levels of nodes in a network, network's topology and traffic demands of users. By implementing hierarchical communication structures WSNs can effectively address energy imbalances, prolong the network's lifespan and optimize the overall system's efficiency. This survey provides instances from various studies where clustering and routing protocols have been implemented to address energy balancing and extend network life in WSN. In addition, a comparative analysis of these studies demonstrates the advantage and disadvantages of various protocols. Possible future research topics are recommended to expand the capabilities of WSNs that include enhancing the durability of protocols, addressing security concerns

Keywords: WSN, Clustering, Routing, Energy management, Network Longevity, CH.

I. INTRODUCTION

A WSN is a system of interconnected, autonomous sensors placed in various locations around an area. These sensors collect data about various physical and environmental factors such as sound, vibration, pressure, motion and pollutants and then send that information to a central hub. [1] It consists of sensor nodes each with its own set of sensors, microprocessor and communication module, a Base Station (BS) or "Sink" that acts as a data collector, processor and a gateway that links WSN to external networks [2].

Figure 1 depicts the fundamental structure of WSN. WSNs integrate ideas and frameworks from the fields of wireless communications, networking, and systems & control theory [3,4]. Data transmission without physical connections is the essence of wireless communications. Devices' interconnections and interactions are the main points of networking. The study, analysis and management of systems in motion is the focus of systems & control theory. By fusing these domains, WSNs are able to efficiently gather data, process it and communicate it across the network. However, WSNs face several challenges in terms of energy management, network life and so on.

Since many sensor nodes run on batteries, minimization of power consumption is the most important priority. Solar or kinetic energy harvesting can help keep the network running [5,6,7] but they make managing variable energy sources more complicated. The reliability and efficiency of each sensor node determine the lifespan of WSN. Consequently, maintaining a network over time requires energy conservation measures, trustworthy communication, and data integrity. Implementing efficient protocols is crucial for improving energy stability and extending the lifecycle of networks.

Clustering and routing protocols were the two strategies that could help to solve the existing issues. Assembling sets of related sensor nodes into larger groupings is known as clustering. Each cluster has a CH who coordinates communication within the cluster and with other clusters. By enabling CHs to aggregate data from member nodes and reduce the quantity of data provided to the base station, this system of hierarchy reduces the use of energy and network traffic [8]. In order to prevent any node from overloading, CHs are recycled among nodes to help distribute the energy load evenly which increases the overall lifespan of the network. Meanwhile, routing protocols are essential for network-wide data transmission path optimization. They intelligently choose the most energy-efficient paths for data packets to travel from source nodes to the BS by considering node energy levels, network topology, and traffic conditions [9]. Adaptive routing protocols further increase efficiency by dynamically altering routes in response to changes in the network in real time. When combined, these routing and clustering techniques reduce energy usage, enhance network efficiency, and support the long-term viability of WSNs.

A. Data transmission

In WSNs, data transmission typically follows a hierarchical approach where normal sensor nodes communicate with CHs, and then CHs relay aggregated data to the sink or base station. Here's a detailed explanation of this approach and how it works:

1. Member Nodes to CHs

The normal sensor nodes in WSNs are usually low in resource capability and are powered by limited batteries. Thus, by sending data to neighboring CH instead of to the base station, nodes can save energy. The chosen CHs are located closer to each other in the network such that data transmission between them consumes minimal energy per hop. Moreover, it is high traffic congestion and energy-consuming process to directly transmit all the acquired data from the sensor nodes to the base station. Clustering incidence also provides an option to reduce this overhead since the information collected by the nodes are centralized at CHs before forwarding them to the base station. This aggregation results in minimizing the number of individual broadcasts and the efficient use of the network's bandwidth.

2. CHs to Sink (Base Station)

CHs receive samples from normal nodes that are inside their clusters and then collect data from all of them. This aggregation minimizes the volume of data conveyed over long distances to the base station a feature that is very helpful especially in large-scale network where the base station might be situated far from nodes in the network. CHs are likely to contain more energy resources than normal nodes because of their central functionality and energy collection equipment. It will be noted that the aggregated data transmission from CHs to the base station consumes less energy as compared to the individual transmission from all the sensor nodes. As seen in Figure 2, the sensor nodes feed data into the BS through a clustering process [10].

B. Process of data transmission

1. Normal Nodes to CHs

In reality, sensor nodes are often grouped together using clustering protocols like Hybrid Energy-Efficient Distributed (HEED) or Low-Energy Adaptive Clustering Hierarchy (LEACH). Distance, residual energy, or node traffic are the usual criteria for selecting a CH from among the nodes in a cluster. The normal nodes of a cluster gather information from their environment in consonance with the node's capabilities (temperature, humidity, etc.). Once data is collected, nodes integrate and sometimes clean it locally to remove and reduce irrelevant data. The normal nodes then forward their collected information to the CH using wireless communication standards (IEEE 802.15.4, ZigBee). After that, the CH is in charge of the cluster and all of the communication between the nodes in the cluster, whether that's receiving data returned from any of the nodes or doing additional processing or aggregation.

2. CHs to sink

Different routing algorithms (data centric, hierarchal or multi-path routing) are used in order to find efficient routes from the CHs to the sink. These protocols analyse aspects like topology, energy status, and priority levels associated with data to help in choosing the best route. Often the data can be exchanged by several CHs or through other nodes on its way to the sink if the routing protocol used allows it. This kind of communication makes the transmission distance per hop to be small and distributes the energy load in many nodes to make the network more reliable and durable. Using developed communication channels (GPRS, cellular, satellite or other wireless connection) CHs transmit the collected and processed information to the BS to make decision and further action about the received signal. [11].

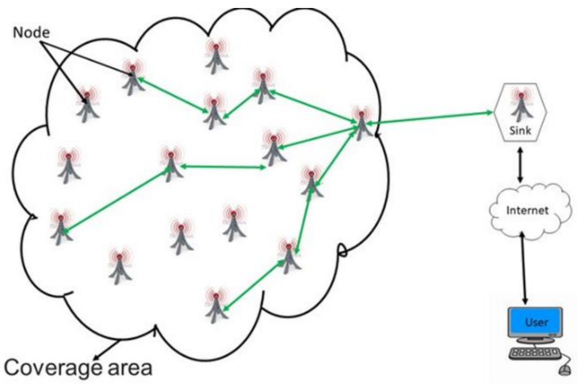

Figure 1. General architecture of a WSN [2]

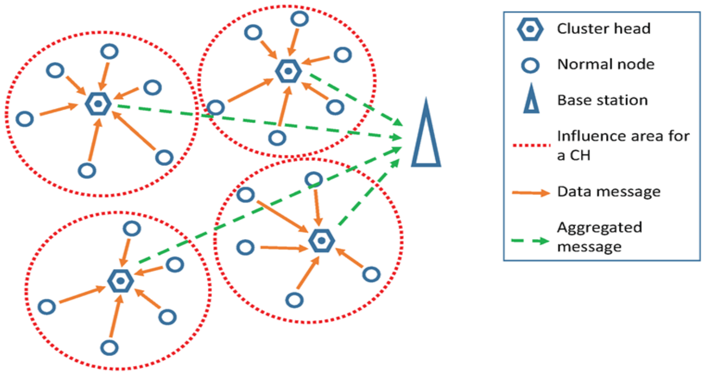

Figure 2. Clustering process in a WSN [11]

II. LITERATURE SURVEY

In WSNs, the CHs can adversely affect energy efficiency and effective transmission distance thereby reducing the overall network lifetime. To mitigate these issues, clustering based Routing protocols have been developed to select best CHs and optimize transmission paths. These protocols enhance network reliability and longevity by minimizing energy consumption and ensuring efficient data transmission over shorter distances. This section reviews several clustering based Routing protocols in WSNs.

Al-Otaibi et al. [12] introduced a novel approach known as the Hybrid Metaheuristics-Based Cluster-Based Routing (HMBCR) technique for WSN. This method employed two main algorithms: Brainstorm Optimization with Levy Distribution (BSO-LD) and Water Wave Optimization with Hill-Climbing (WWO-HC). The first step was to deploy and initialize the nodes. After that, the best CHs in the network were found using the BSO-LD method. When choosing CHs, this algorithm made use of a Fitness Function (FF) that took into account things like energy levels, distances to nearby nodes, some distance to the BS and network stress. Data transmission was carried out using inter-cluster pathways that were constructed by the WWO-HC algorithm once CHs were found.

Reddy et al. [13] established a hybrid algorithm Ant Colony Optimization (ACO) integrated Glow-worm Swarm Optimization (GSO) approach (ACI-GSO) to elect optimal CH across WSN. In this method, distance, delay, and energy consumption were the considering factors for selecting appropriate CH. The process begins with the initialization of nodes, where luciferin intensity and decision domains are set. Nodes then update their luciferin intensity based on the fitness of their positions and move towards neighbors with higher luciferin levels. The neighbourhood range is adjusted according to node density. During the position updates, the Ant Colony Optimization (ACO) model's pheromone updating process is integrated, optimizing movements and helping to find the optimal solution.

Sadrishojaei et al [14] introduced a Clustering and Location Prediction Routing method based on Multiple Mobile Sinks (CLRP-MMS) to improve routing in the Mobile Internet of Things (MIoT). Setup and communication were the two parts of the model. Deploying nodes and creating clusters were part of the setup process, which also included calculating the CH Candidate Factor (CHCF). Each node joined the cluster, and the one having the largest CHCF was named CH. Throughout the communication phase, data was aggregated inside clusters, and mobile sinks collected data from all CHs along specified pathways.

Abbad et al. [15] illustrated the Weighted Markov Clustering (MCL) Based Clustering Routing Protocol (WMCL-BCRP), which enhances energy stability and network longevity. The protocol workflow began with a configuration phase led by the BS comprising network matrix representation using GPS data, MCL for cluster formation and configuration broadcast to set energy thresholds and assign cluster-heads and queried sensors based on abundance. The communication phase then utilized intra-cluster TDMA for sensor data transmission and inter-cluster CDMA for aggregated data to the BS in fixed rounds which aimed to optimize network performance and resource utilization.

Gamal et al. [16] introduced a novel approach that combined Fuzzy Logic (FL) with LEACH and Particle Swarm Optimization (PSO). This hybrid model used PSO alongside the K-Means Clustering algorithm to cluster WSNs effectively. Initially, K-means divided data into clusters, while PSO optimized their locations. After considering the available energy, the distance to the cluster centres, and the proximity to the base station, FL made a smart selection of principal CH (PCH). Secondary CH (SCH) were chosen similarly. Once clusters were formed with designated PCH and SCH nodes, the BS sent out message packets containing PCH and SCH identifiers, along with cluster membership (CM) details. The CM nodes used TDMA slots to coordinate the delivery of data.. Upon receiving data, SCH nodes aggregated sensor data before passing it to PCH nodes, which then relayed it to the BS. Experimental results confirmed that this integrated protocol effectively optimized energy consumption while maximizing network throughput.

An energy-minimization technique for multi-hop WSNs was devised by Shah et al. [17] using bimodal Inter-Cluster and Intra-Cluster (ICIC) parameters. The method relied on two types of communication: intra-cluster communication, which used a distance-based dynamic duty cycle allocation, and inter-cluster communication, which found the best route for packets to go to the BS. Efficient energy conservation was the goal of this two-pronged strategy. Further improving energy efficiency, the method drastically cut down on the number of hops needed for packet transmission.

Subha et al. [18] introduced an Improved Emperor Penguin Optimization Algorithm-based Clustering Protocol (IEPOACP) for identifying the optimal routing paths and determining the most suitable CHs within WSN. Modelled after the huddling habits of emperor penguins, this method uses techniques like determining the length of distance among search agents, establishing and assessing the huddle boundary, and selecting CHs using a successful mover relocation mechanism. The results showed that this protocol greatly increased the network's lifetime by distributing energy more efficiently and transmitting data at a higher rate.

Yalçın et al. [19] proposed the Mobile Clustering Routing Protocol based on Thermal Exchange Optimization (TEO-MCRP) for heterogeneous WSNs. The TEO algorithm was inspired by Newton’s cooling law which modelled node communication similarly to the temperature exchange process where node positions represented cooling objects, sensor nodes as objects and neighbouring nodes as environmental temperatures. They established FFs aimed at enhancing network longevity and conserving energy which is crucial for selecting optimal CHs. The results demonstrated that the TEO-MCRP significantly improved the performance of heterogeneous WSNs by enhancing metrics such as network lifespan, energy consumption, packet reception rate at the base station, packet delivery rate, and end-to-end delay.

Bourebia et al. [20] formulated a fusion technique by integrating Raccoon optimization algorithm (ROA) with Multi Objective Clustering Technique (MOCT) (ROA-MOCT) to enhance the clustering quality in WSN. ROA algorithm was inspired by food seeking characteristics of raccoons and this algorithm imitates the searching pattern in two distinct operations at a time thereby ensuring time efficient exploration process. This method consisted of rounds and each round has two phases: Clustering phase where ROA helped BS for electing CHs and MOCT for grouping with their cluster members: Step one of data collecting and routing involves sending sensed data to CHs and then back to the BS. When compared to the current protocols, the results showed that the network residual energy, number of packets received by the BS, and network lifetime were all significantly improved.

Hosseinzadeh et al. [21] developed the Cluster Tree-based Trusted Routing Method using the Grasshopper Optimization Algorithm (GOA) (CTTRG) for WSNs. This method integrated Time-Variant Trust (TVT) model to assess node trust dynamically and the GOA-based Trusted inter-cluster Routing Tree (GTRT) to establish reliable connections between CHs and the BS. The TVT model incorporated Time-Variant Direct Trust (TVDT), Recommended Trust (RT) and Time-Variant Final Trust (TVFT) by leveraging direct interactions and recommendations from shared nodes to estimate trust in decentralized networks. The BS utilized the GOA algorithm to construct optimal GTRT trees by iteratively adjusting CH positions based on attributes such as distance to the BS, trust levels, and energy levels ensuring efficient routing in the network.

Santhosh et al. [22] developed an Energy Optimization Routing system using an improved Artificial Bee Colony (EOR-iABC) for large-scale cluster-based WSN to improve energy efficiency and prolong network lifespan. The iABC algorithm incorporated various techniques for CH selection. It integrated unique search strategies like the Grenade Explosion Method (GEM) and Cauchy operator allowing for dynamic extension of the search process across different regions of the WSN to optimize the selection of energy-efficient CHs. The FF metric was computed to assess the likelihood of a cluster being chosen as a CH.

Sikarwar et al. [23] developed a novel hybrid clustering protocol named Modified Fuzzy C-Means with PSO (MFCM-PSO) to group nodes with their respective CHs based on location and to optimize the selection of CHs. This protocol introduced a Tree-Based Multi-Hop Routing Algorithm aimed at minimizing energy consumption in WSNs, thereby extending the network's lifespan. In this approach, each sensor node within the tree structure acted as a relay, transmitting data to the sink node by forwarding information to its parent node until it reached the root node through a series of multi-hop broadcasts. PSO was utilized to identify the optimal CHs, maximizing overall efficiency. Additionally, a FF was calculated using Direct CH (DCH) and Parent CH (PCH) to improve communication between CHs. The results indicated that this adaptive and hybrid multi-level method was both efficient and effective.

Babu et al. [24] developed a Trust Index Optimized CH Routing (TIOCHR) technique to select the optimal CH and path for WSN. In this algorithm, the trust index influenced CH selection, guiding the protocol to identify the most suitable node. The trust index was determined by trust metrics such as packet delivery rate, the number of consistent packets, and remaining energy. Consequently, calculating the trust index and selecting CHs were the most critical steps. The CH nodes were chosen randomly and recycled at specified intervals.

Gangal et al. [25] introduced a decentralized approach using Analytic Hierarchy Process (AHP) technique integrated with LEACH algorithm to discover the optimal CH automatically thereby conserving energy and expanding packet transmission to the sink. In this method AHP method determined the threshold values for choosing the desired CH. Then, after selecting the CH, normal nodes close to them transmit their data to CH and CH transmitted it to the sink which ensures the energy efficiency.

Patil et al. [26] investigated a Clustering-based Genetic Routing Protocol (CGRP) to improve the scalability and to minimize the latency of time-sensitive WSNs. This method initialized by randomly distributing sensor nodes across the target area and then grouping them into clusters, each with a chosen CH to optimize energy use and minimize data transmission delays. After forming clusters, a Genetic Routing algorithm was used to find the best routes for data, using evolutionary principles like selection, crossover & mutation and considering factors like distance, latency, and energy consumption. The system adapted to network changes by quickly establishing new links to keep data flowing smoothly. Finally, yet importantly, these optimized routes were used to send data from the originating node to the recipient node, guaranteeing efficient and rapid delivery.

Roberts et al. [27] devised an enhanced two-tier optimization mechanism that combined Sail Fish Optimization (SFO) with Spotted Hyena Optimization (SHO) for both exploration and exploitation in WSN. In order to achieve optimal routing and effective energy management in WSN, SFO was chosen for its fast exploration capabilities and SHO for its enhanced exploitation abilities. Initialization of parameters, dynamic speed adaptation, intelligent cluster creation, SHO-based clustering and routing refinement, memory components, and latency- and energy-focused criterion formulation were all part of the procedure.

Yuan et al. [28] developed a fusion algorithm that combined the improved Beluga Whale Optimization (BWO) algorithm with improved Prim algorithm (DPR) technique (tCBWO-DPR) for WSNs to optimize the selection of CHs, thereby conserving energy and enhancing system efficiency. The tCBWO algorithm operated in three phases, global exploration, local exploitation and whale fallen phase each serving distinct purposes. The global exploration phase introduced a cosine dynamic boundary strategy to facilitate broader exploration of the search space. For optimal CH selection, the proposed algorithm computed the FF based on the nodes' locations and capacities. The integration of the DPR algorithm significantly enhanced energy efficiency in WSNs.

Guo et al. [29] developed a fusion of Sine-Cosine Algorithm (SCA) and Levy mutation for WSN clustering routing protocol to enhance the search step and optimize the selection of CHs which in turn minimizes energy consumption. In this algorithm, the Base Station (BS) executed SCA and Levy mutation to elect optimal CH where random heads were selected to form initial population. Then, the FF was calculated to find the CH with small intra-cluster distances and make it evenly distributes which ensures minimum energy consumption across the networks. Finally, the CH sent information to the BS either directly or through relay nodes.

In this study, the notable evaluated performance metrics are Alive Nodes, Average Residual Energy (ARE), Delay, Throughput, Energy Consumption, Network Lifetime, Packets Received by the Base Station (PBS), Dead Nodes, Packet Delivery Ratio (PDR), Packet Loss Rate (PLR) First Node Dies (FND), Half of the Nodes Die (HND), Last Node Dies (LND) and Latency. These metrics are critical for assessing the efficiency and effectiveness of the network under various conditions and scenarios. Table 1 compares all the above-studied Cluster based Routing protocols in WSNs in terms of their advantages, limitations and performance metrics. From Table 1, it is inferred that the implementation of Clustering and Routing Protocols in WSNs effectively addresses energy management challenges and facilitates optimal path selection, contributing to enhanced network longevity. Nevertheless, there remains an opportunity to further optimize these protocols to minimize energy dissipation and latency in WSN operations.

Table I. Comparison of Cluster based Routing protocols in WSNs

Ref No.	Protocols	Advantages	Limitations	Environment	Major performance metrics
[12]	HMBCR	Maximum average Residual energy	Hot spot issue in WSN is not addressed	MATLAB	For 1000 nodes, ARE = 0.9755 J and Alive nodes = 851 for 3000 rounds; Delay = 154.5 ms, PLR= 0.1710, PDR =0.8657 and Network lifetime = 4865 rounds
[13]	ACI-GSO	Persistent level of network energy	Hybrid algorithm has high time complexity	NS-2 Simulator	All results here for 100 nodes. Alive nodes = 45 in 80 rounds and 63 at 80 ms, ARE= 0.92J in 80 rounds and 0.92J at 80s ; Throughput = 420 kbps in 80 rounds and 220 kbps at 80s
[14]	CLRP-MMS	Avoid frequent reclustering	Delay is high	NS-2 version 2.35 and MATLAB R2017a	For 300 nodes. Alive nodes = 300 for 400 rounds, Throughput is 82% in 600 rounds and 60% in 1200 rounds, Delay = 0.1 ms Dead nodes =70 for 1500 rounds ARE = 47 J in 1200 rounds
[15]	WMCL-BCRP	Low overheads which leads to efficient energy management	Because the sensors with the lowest weight factors were chosen, the first sensor expiration performance was poor.	MATLAB	For 100 nodes; ARE= 0.0159J, Expired nodes = 8 for 1000 rounds
[16]	FL-LEACH based PSO	More accurate membership functions are used	Delay is high	MATLAB	Number of nodes in a network = 1000, For 10000 rounds, ARE = 10 J, FND = 1551, HND = 1866, LND = 970 rounds, Throughput = 260000 packets
[17]	ICIC	Dynamic duty cycle allocation allows shorter distant child nodes to send more packets while using less energy.	Relay energy conservation failed	MATLAB	For 300 nodes and 3000 rounds, PBS = 306923, Network energy utilization= 41.97%, Network energy for relaying = 25.85%, Dead nodes = 51.56
[18]	IEPOACP	Improves local optimality of basic EPOA algorithm leads to reduced delay	Need to improve energy saving	MATLAB	For 500 nodes; Energy Consumption= 75J,Delay=61ms, Throughput = 0.84 Mbps, PDR= 81%
[19]	TEO-MCRP	Reduced memory requirement	Has complexity of applicability in real-time	MATLAB 2019b	For 500 nodes, PBS = 658546, Network lifetime = 53589 rounds, Energy consumption = 80 % for 21254 round
[20]	ROA-MOCT	Enhanced clustering quality	Delay is high	OMNET++ simulator and INET 4.0 platform	For 100 nodes, ARE= 25% for 625 round, Network lifetime = 1060 rounds
[21]	SCA, Levy	Avoids premature node death	Short Network lifecycle if area is large	MATLAB	For 200 nodes, PBS = 188619 in 1000 rounds, Energy consumption = 0.1 J for 900 rounds
[22]	CTTRG	Independent of recommendation node which can affect the trust value	Delay and jitter to be improved	NS-2 Simulator	For 100 nodes, Energy consumption = 4.1 J for 500 round, For 8 malicious nodes, PLR = 3%, Delay = 15 ms
[23]	EOR-iABC	Frequent selection of CH is avoided due to global optimization	Energy saving needs to be improved	Discrete Event Simulation tool	For 100 nodes and 50 rounds, Alive nodes= 30, Delay=0.1ms, PBS = 921, Energy consumption = 17 J

[24]	MFCM-PSO	Offers better network coverage	Implementation of this technique is complex	MATLAB	For 100 nodes, FND= 63, HND= 966, LND= 1681 rounds, Energy consumption = 4% per round
[25]	TIOCHR	Usage of trust index and measurement makes it trustworthy	Works only for static nodes	NS3 Simulator	For 500 nodes, Energy consumption = 0.35 J for 500s, , PDR = 60%, Latency = 18 s
[26]	CGRP	Ideal for networks that are both widely dispersed and growing at a rapid pace	Delay is high	MATLAB7	For 1000 nodes, latency=1000ms, Scalability=49%, Energy Consumption = 50%
[27]	SFO-SHO	Outperforms single-algorithm methods in terms of both novelty and value	Inadaptable to dynamic environments	MATLAB R2021a	For 1000 nodes, Network lifetime = 650s, ARE = 0.65 J in 1500 rounds
[28]	tCBWO-DPR	Maintain relatively low hops under different network conditions	Planning of node data transmission paths is challenging in larger networks	PyCharm 2021.3	For 200 nodes ; Alive Node = 80, ARE = 0.08J, Throughput = 1000kbps in 200 rounds
[29]	LEACH- AHP	Adopts decentralized architecture	Determining threshold values can be challenging	MATLAB	For 100 nodes, PBS=136264.65, Network lifetime = 4504 rounds, ARE = 7.5J for 1500 rounds

III. PERFORMANCE EVALUATION

Here we go over how to measure how well WSN models' Clustering and Routing models work. This evaluation was conducted using network lifetime and packets received by the Base Station (BS) as the key metrics. The protocols were tested under various simulation environments to determine their efficiency in real-world applications.

It is important to note that, to facilitate a meaningful comparison and standardization of the performance metric values, they are normalised by dividing each value by the corresponding number of rounds and no of packets with number of nodes. This approach ensured that all values were expressed in a common unit, which enables a more accurate analysis of the parameters. The computed common values only utilized in Figure.3 and Figure 4.

Figure 3 demonstrated Performance analysis of clustering and routing protocols based on their network lifetime. It shows that [19] outperformed other protocols with an exceptional increase in network lifetime extending the operational period. However, it struggled with packet delivery, achieving a comparatively lower success rate because of its complexity and limited capability in larger networks. But [29] excels in network lifetime as it overcomes the limitations. Figure 4 demonstrated Performance analysis of clustering and routing protocols based on the packets received by BS. On the other hand, [17, 19, 21, 23] focused on maximizing packet delivery, achieving high success rates.

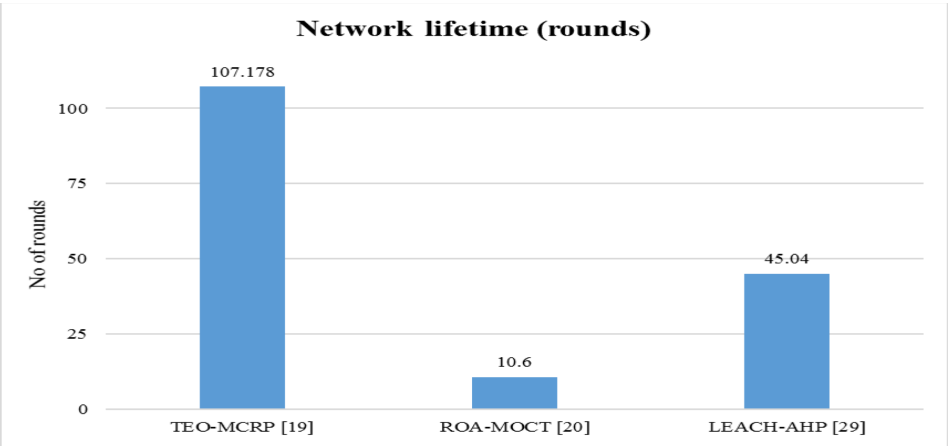

Figure 3. Performance analysis of Protocols based on their network lifetime

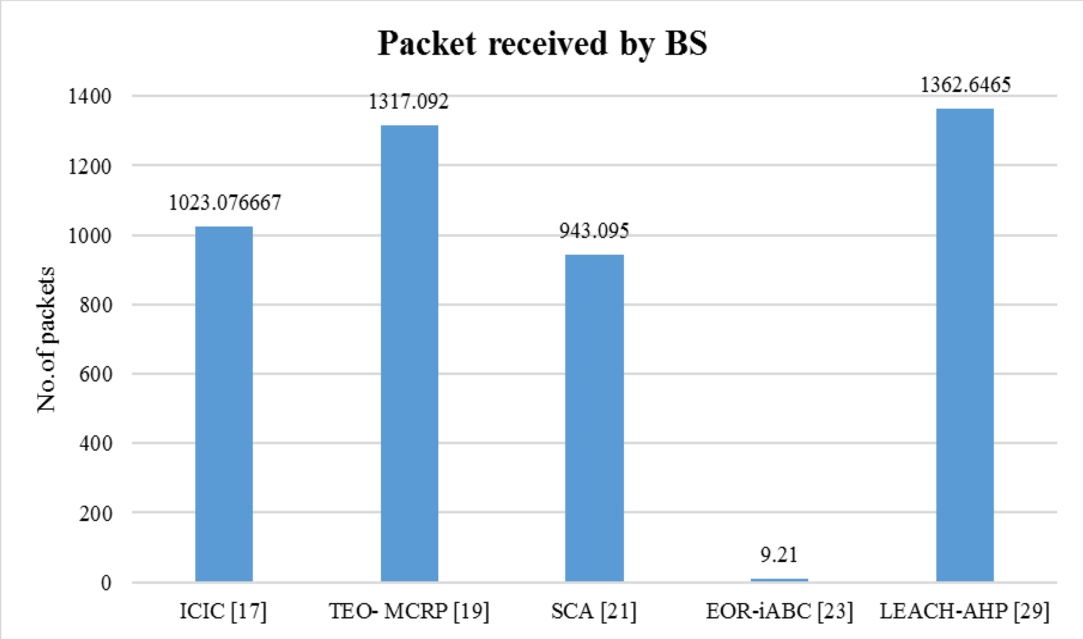

Figure 4. Performance analysis of Protocols based on their Packet transmission

However, this emphasis on packet delivery often resulted in increased energy consumption and reduced network lifetime, as the protocols prioritized reliable data transmission over energy efficiency. Meanwhile [29] outperformed than other methods by showing relatively higher packets transferred to the BS.

So, the model presented in [29] significantly outperformed the other protocols across both metrics. It extended the network lifetime which is crucial for the sustained operation of WSNs in long-term deployments. Moreover, it achieved a highest packet delivery rate by ensuring that the data collected by the sensors reliably reached the BS. The superior performance of [29] can be attributed to its innovative energy-balancing mechanism and efficient routing strategy which dynamically adapts to network conditions and optimizes resource usage.

This comprehensive evaluation indicates that [29] is the most effective protocol which offers a well-rounded solution that maximizes both network longevity and data transmission reliability, making it the best choice for WSN applications.

IV. CONCLUSION

In this paper, a comprehensive review has been presented to evaluate various clustering and routing protocols in WSN aimed at achieving energy balancing and extending network lifespan. Each protocol's efficiency has been assessed based on its advantages, limitations, simulation environments, and performance metrics achieved in diverse WSN applications. Through this scrutiny, it has been highlighted that clustering and routing protocols play a crucial role in optimizing energy consumption, improving network scalability, and ensuring reliable data transmission in WSNs. Future research directions will focus on exploring advanced routing strategies, optimizing network topology management, and integrating adaptive mechanisms to handle dynamic network conditions and diverse application requirements.

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