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Clustering Algorithms and Optimization Strategies in WSNs: A State-of-the-Art Review

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***Abstract*— Wireless Sensor Networks (WSNs) have emerged as a groundbreaking technology for collecting data on various physical phenomena, offering the potential to revolutionize infrastructure systems. The paper provides an exhaustive exploration of the existing literature on clustering algorithms within WSNs and the diverse optimization techniques proposed for cluster head selection. A comprehensive analysis of various routing protocols, mobility-based solutions, and energy conservation strategies is presented, shedding light on their respective strengths and limitations. The examination encompasses a wide spectrum of approaches, including hierarchical cluster-based routing, mobile sensor integration, and energy-efficient techniques inspired by industry standards like ZigBee. The paper further explores ecological monitoring applications, redundancy reduction mechanisms, and power-efficient hierarchical routing protocols, offering valuable insights into their contributions to the field. This review paper aims to consolidate and synthesize the wealth of knowledge in the domain of clustering algorithms and optimization techniques for WSNs. By assessing the strengths and weaknesses of these methodologies, it seeks to provide a comprehensive resource for researchers and practitioners in the field, ultimately contributing to the advancement of energy-efficient and reliable wireless sensor networks.**

***Keywords*— APTEEN, EARP, ECCP, GPS, HEED, LEACH, PEGASIS, TEEN, WSN.**

I. INTRODUCTION

WSN is a network formed by a large number of sensor nodes where each node is equipped with a sensor to detect physical phenomena such as light, heat, pressure, etc. WSNs are considered a revolutionary method of gathering information to build the information and communication system that will greatly improve the reliability and efficiency of infrastructure systems [1].

Each node in a wireless sensor network (WSN) is resource constrained: node have limited power, speed of processing, capacity to store data, and communication bandwidth. After their deployment in the target area they are responsible for self-organizing an appropriate network infrastructure. Global Positioning System (GPS) and local positioning algorithms are used to obtain location of the sensor nodes [1].

Wireless Sensor Network nodes are densely deployed in the target area and the power is provided to them via battery which is the only source of energy for most of the sensor nodes. Sometimes this target area is not reachable by the humans so it is impractical to replace a battery therefore once energy or computational resources are consumed, immediate recovery of these resources is a complex task. This is the reason why a large part of the research in WSN focuses on the development of energy efficient or economical method for WSN [2] [3].

This paper aims to provide an overview of the existing literature related to the use of clustering algorithms in WSNs and the different optimization techniques proposed for cluster head selection.

II. LITERATURE REVIEW

Wankhade et al. [4] surveyed hierarchical cluster-based routing protocols for reliability and power requirements. The prime concern of this paper was to highlight the routing problem of WSNs. This paper reviews the recent routing protocols which are designed for energy consumption.

You-Chiun et al. [5] presented a hybrid wireless sensor that coordinates with static and dynamic nodes. Events happening in the interested region are sensed by Static sensors. The general lifetime of the network is amplified by using mobile sensors to collect data. The path of the mobile sensor is scheduled in an energy balance way so that the network lifetime is maximized. They also proposed centralized and distributed heuristics to schedule mobile senor's path keeping in mind optimized energy consumption.

Gerard Chalhoub et al. [6] proved that ZigBee and IEEE802.15.4 standards fail to provide concurrent behavior to achieve QoS and energy efficiency at the same time. They also proposed an energy conservation technique to improve QoS based on time segmentation. This technique improves the overall performance of the system using a tree-based beacon diffusion inspired by the ZigBee protocol.

Rathna R. et al. [7], proposed an ecological monitoring use of wireless sensor networks. The more consideration is given to the two zones i.e. routing and clustering. Their work is an endeavor to lessen the power utilization of the sensor nodes, by focusing on the radio. The Cluster-based sleep/wake-up booking strategy is turning out to be productive when tested on NS2. The scheduling algorithm proposed in it depends on TDMA totally. They considered routing and clustering at the same time.

M. Soleimani et al. [8], considered the fact that sometimes the sensor's area of sensing overlaps each other. They proposed that the nodes which are near produced redundant information and cause misuse of energy since they sense similar information. In this protocol, a specific number of nodes are indicated in each round; the nodes which have at least one neighboring node at minimum distance limit. Then the node which has less energy and more coverage is chosen to go to sleep mode. Likewise, by incorporating the separation of nodes from the base station the energy unevenness among sensor nodes is diminished. This technique increases the lifetime of the system.

S. Waware et al. [9] introduced a brief overview of the power-efficient hierarchical routing protocols for wireless sensor networks. They compared LEACH, PEGASIS, HEED, TEEN, APTEEN, and EARP protocol based on different attributes considered while developing above said protocols

S. Rani et al. [10] proposed improvement in PEGASIS protocol for selecting the next neighboring node reliably using the combination of distance, residual energy and response time parameters. Their improved PEGASIS outperforms the LEACH by eliminating the overhead of dynamic cluster formation, minimizing the distance non-leader-nodes must transmit, limiting the number of transmissions and receives among all nodes, and using only one transmission to the BS per round.

Samia A. et al. [11], proposed a new protocol called CCBRP (Chain-Chain based routing protocol). It accomplishes both reductions in energy utilization and delay. This protocol separates a WSN in various chains and operates in two stages. In the primary stage, the Greedy algorithm selects the chain leader node where the data is transmitted by each chain from the sensor node. The second stage built a chain from all chain leader nodes by the Greedy algorithm.

Lathies Bhasker et al. [12], presented a genetically optimized cluster head election in WSN which initially, in light of the node availability the CHs were chosen, which goes about as an information aggregator. At that point, utilizing the GA the clustering procedure was executed. An encryption strategy is utilized that offers authenticity, confidentiality, and integrity when a cluster needs to transmit the information to the aggregator or a cluster head. The proposed method minimizes the energy utilization, guaranteed information security and decreased the transmission overhead.

Stephanie L. et al. [13], presented three new protocols for wireless sensor networks. PEGASIS is one of these protocols it is a greedy chain protocol that is near-optimal for sensor networks having data-gathering problems. By minimizing the distance, eliminating the overhead of dynamic cluster formation, limiting the number of transmissions and receptions among all the nodes and using the only single transmission to the BS per round PEGASIS out-performs LEACH. The simulation shows that when 1%, 25%, 50%, and 100% of nodes die for different topologies and network sizes the PEGASIS performs better than LEACH by about 100% to 200%. Compared to LEACH-C, which doesn't have the cluster formation over-head in each round, the improvements will be slightly lesser. As the size of the network increases PEGASIS shows even further improvements.

O. Zytoune et al. [14], presented a new algorithm in WSN for data gathering. This is based on chain formation using the greedy algorithm. Its primary focus is to distribute the energy load equally over the whole network nodes. To improve node lifetime, the role of a leader node is better distributed over nodes based on their energies required to transmit to the sink. Thus, all the network nodes would have the same lifetime and then as a result, the lifetime of the network will increase. In the proposed algorithm the transmission energy over the whole network nodes is balanced correctly which increases the network lifetime. The result of simulation shows that as compared to the well-known protocol for chaining in wireless sensor network this technique provides improvement

R. Sheikhpour et al. [15], Presents an Energy Efficient Cluster-Chain based Protocol (ECCP) for wireless sensor networks that aim at maximizing stability period, network lifetime, and balancing the energy consumption among sensor nodes. ECCP chain based data transmission mechanism is also used to send data packets to the base station from the cluster heads. ECCP offers an advantage of small transmit distance by chaining the nodes in each cluster and by conserving their energy ECCP helps them to be operational for a longer time period. The result of simulation shows that in terms of network lifetime, stability and instability period and balancing the energy consumption among the sensor nodes ECCP is more efficient as compared to CBRP, LEACH, and PEGASIS.

C. Wang et al. [16], proposed a concentric data aggregation model. The main purpose of this model is to consider the base station location and divide the whole WSN into several hierarchical and concentric zones refer to the base station's location, each zone is also divided into some areas and nodes are organized as PEGASIS in every area. Sensor nodes collect the data which goes through proper areas belong to different level zones towards the base station and in each hop that data is aggregated. The aggregated data is transmitted to the base station by the head on the last area which is the nearest node of the base station. The simulation results show that in transmission delay and energy efficiency it performs better it also avoids data, gathering latency and reduce energy consumption.

Hui Li et al. [17], proposed a developed routing protocol named DL-LEACH. The name is given DL-LEACH since it uses a double cluster-based routing protocol. This protocol aids in prolonging the network lifetime by using the double cluster head node for data transmission that reduces the energy of the individual nodes. The simulation results show that DL-LEACH enhances the network lifetime by 75 % than LEACH.

M. Elshrkawey et al. [18] presented an energy balancing technique to reduce energy consumption and increase the network lifetime. Two amendments are done in this approach. Initially, the selection of a cluster head is improved for consistent cluster head formation among all sensor nodes in the network. The second modification is done in the TDMA schedule to elude the energy consumption.

H. Ouchitachen et al. [19] proposed an Improved Multi-Objective Weighted Clustering Algorithm (IMOWCA) using extra constraints to choose cluster heads in WSN. This approach separates the network into various clusters and chooses the best performing sensors based on residual energy to communicate with BS. A base station genetic algorithm is also developed to maintain energy consumption.

Conventional methods such as Direct Transmission (DT) and Minimum Transmission Energy (MTE) [20] are not successful in ensuring that the energy load is evenly distributed among the WSN nodes. When DT is used, since the sensor node data is transmitted directly to the base station, the energy of the nodes far from the base station is depleted beforehand [21]. When MTE is used, data is transmitted in minimum cost ways, the transmission power consumed here reveals the cost. When MTE is used, nodes closer to the base station are more likely to act as message senders than nodes far from the base station. Therefore, nodes closer to the base station tend to run out of energy faster. When both DT and MTE are used, a portion of the sensor network cannot be monitored for a significant portion of the network's lifetime, meaning that the detection operation will be biased [22].

The method proposed in [23], called the LEACH protocol, ensures that the energy load is appropriately allocated by the dynamically generated clusters and the cluster heads are dynamically selected based on the precomputed optimal probability. The data detected by the cluster members is collected by the cluster heads and then transmitted to the base station. Over time, each sensor node tends to consume the same amount of energy, rotating the cluster head role equally among all sensor nodes. In the LEACH protocol, clusters are regenerated each round. In each round, new cluster heads are selected and as a result, the network load is evenly and evenly distributed among the nodes of the WSN. Additionally, each sensor node transmits data per nearest cluster to reduce communication cost with base station. It is reported to the base station only by the cluster heads, which tend to consume large amounts of energy, but this happens at regular intervals for each node. The original version of the LEACH protocol does not take into account the heterogeneity of nodes with respect to their initial energies. Consequently, when the sensor network is energy heterogeneous, the consumption of energy resources of the WSN is not optimized. In the LEACH protocol, only the spatial density of the sensor network is taken into account [22].

The first study to question the behavior of clustering protocols in the case of heterogeneity in clustered wireless sensor networks was done by Heinzelman [24]. Heinzelman explored a method to select cluster heads based on the remaining energy of each node. He proposed a selection method that assumes that the total energy of the network is known by each node and that each node adapts its cluster head selection probability according to its remaining energy. The disadvantage of this method is that this decision is made per round and it is assumed that the remaining total energy of the network is known. The method is difficult to implement as it is based on the assumption that the remaining energy of the entire network is known.

In SEP [22], which depends on the initial energy of the nodes, the effect of heterogeneity with respect to the node energy was investigated. SEP was developed to extend the time (stability period) before the first node de-energizes. This is of great importance for multi-applications where the response from the sensor network must be reliable. SEP has developed the stable region of the clustering hierarchy process using typical heterogeneity factors such as the ratio of advanced nodes (m) and the additional energy factor (α) between advanced and normal nodes [22].

Probabilistic heterogeneous-aware cluster head selection method proposed by Mary et al. [25]; It has improved the network lifetime compared to the fuzzy logic-based ZSEP-E (Zone-based Stable Election Protocol- Enhanced) protocol for cluster head selection, taking into account the energy of the remaining node, its density, and its distance from the base station.

Barani et al. [26] improved the average delay and transmission rate of the LEACH-FL (LEACH-Fuzzy Logic) protocol by considering the node density, battery level and distance of the node to the nearest hop.

A new dynamic, distributive and self-organizing, entropy-based clustering scheme that takes advantage of the local knowledge of the sensor nodes and uses it as criteria for cluster head selection and cluster formation has been proposed by Osamy et al. [27]. It has been revealed that the proposed method outperforms existing basic algorithms in terms of energy consumption, stability period and network lifetime.

Preethiya et al. [28] proposed the Mobile Dual Cluster-Particle Swarm Optimization (MDCH-PSO) algorithm, which outperforms the standard LEACH-C, LEACH-M algorithm in improving network lifetime to improve network lifetime and load balancing in hybrid WSN.

In [29], a fuzzy logic based cluster head selection method was developed by Batra et al. The proposed Fuzzy Logic based Cluster Selection (FLCHS) method helped balance the node load and saved energy. The FLCHS protocol outperformed the SEP [22] protocol in terms of network lifetime, energy consumption, and efficiency.

Dutt et al. [30] proposed a method in the form of Cluster Headed Constrained Energy Efficient Protocol (CREEP) to further improve network lifetime by changing cluster head selection thresholds in a two-level heterogeneous WSN. The simulation results showed that the proposed solution provides improvement in network lifetime in fixed and mobile SSA scenarios.

Based on dynamically changing cluster head selection probability, it selects cluster heads based on the remaining energy level of nodes and the minimum number of clusters per round, outperforming SEP [22] and Threshold Sensitive Stable Selection protocol (TSEP) in terms of stability and network lifetime. The Stable Selection Protocol (ETSSEP) was proposed by Kumar et al. [31].

The Virtual Cluster Selection Method, which balances the distribution of cluster heads, selects nodes with relatively higher energy as cluster heads, and has been shown to improve network lifetime, is proposed in [32].

An adaptive cluster head selection methodology based on dynamically selected parameter coefficients for cluster-based WSN architectures is proposed in [33].

In heterogeneous wireless sensor networks, the cluster selection criteria of different clustering protocols were reviewed in [34] and the performance of these protocols;

clustering technique, cluster head selection criteria, node lifetime, energy efficiency in two- and three-level heterogeneous networks are compared using various parameters. The comparison has shown that TDEEC (Threshold Distributed Energy Efficient Clustering) has very effective results compared to other two- and three-level heterogeneous wireless sensor network protocols and significantly expands the unstable region. The simulation results showed that adding node heterogeneity can significantly increase the network lifetime.

In the Sleep-Awake Energy Efficient Distributed (SEED) clustering method, which is a heterogeneous clustering where the remaining energy of the nodes and the network average energy are added to the threshold value in the cluster head selection, the SEED protocol, which is a heterogeneous clustering method in wireless sensor networks has been improved. In [35], EEMCE (Energy Efficient Multi-Hop Cluster-Head Election Strategy), which is a two-stage cluster head selection method offering high energy efficiency, long stability time and scalability, is proposed. DARE-SEP (Distance Aware Residual Energy-Efficient Stable Election Protocol) recommended in [36]; It is a hybrid approach that combines the features of REE-SEP (Residual Energy Efficient Stable Election Protocol) with Direct Transmission (DT) and DP (Distance-Based) protocol, and it has been shown to provide 10% increase in energy efficiency.

In [37], a weighted threshold-based probabilities formula, which takes into account the different energy types of the networks and the node density in the detection range, was proposed for the effective selection of cluster heads, and the network lifetime could be extended by 115.4% compared to SEP.

Based on multi-level heterogeneity [38], SEP inspired by NEECP (Novel Energy-Efficient clustering protocol), ICACO (Inter Cluster Ant Colony optimization) and DCHSM (Dynamic Cluster Head Selection Method) to extend network lifetime and increase efficiency in heterogeneous wireless sensor networks) methods were found to give better results.

In recent studies, successful results have also been obtained by using genetic algorithm and fuzzy logic-based cluster selection methods. The Genetic Algorithm-based Optimized Clustering protocol [39] offers optimized cluster head selection by integrating the remaining energy, distance to base station and node density parameters in the formulated fitness function.

Nandan et al. [40] determined the performance criteria of the remaining energy of the network, network lifetime, stability time, throughput and number of clusters per round with their proposed mobile base station strategy and an optimized genetic algorithm that shortens the distance between the base station and the cluster head and reduces the hot-spot problem. has improved.

HQCA-WSN [41], in which the optimal cluster head is selected using fuzzy logic, according to various criteria such as the remaining energy, the minimum and maximum energy in each cluster, and the minimum and maximum distances between the nodes in each cluster and the base station, high reliability, low error rate during clustering, more It provides good scalability and performance in networks with a high number of nodes.

In the Fuzzy Independent Circular Regions Protocol (FICZP) [42], the selection of cluster heads is based on two different metrics, one representing the number of neighboring nodes and the second representing the remaining energy by nodes, and these two metrics are combined with a fuzzy logic approach to define the lifetime cost values of the nodes.

III. CONCLUSION

In conclusion, this review paper has undertaken a comprehensive exploration of the multifaceted world of Wireless Sensor Networks (WSNs), focusing on the critical aspects of energy efficiency and clustering algorithms. WSNs have emerged as a transformative technology, offering immense potential for enhancing the reliability and efficiency of infrastructure systems. However, the inherent resource constraints and energy dependence of WSN nodes have presented formidable challenges that necessitate innovative solutions. The extensive literature review has unearthed a multitude of strategies and protocols designed to address these challenges. Hierarchical cluster-based routing protocols have been scrutinized for their reliability and energy efficiency. Mobility-based solutions, such as integrating mobile sensors with static ones, have shown promise in extending network lifetimes. Energy conservation techniques, inspired by industry standards like ZigBee, have been proposed to achieve a balance between quality of service and energy efficiency.

Furthermore, ecological monitoring applications, redundancy reduction mechanisms, and power-efficient hierarchical routing protocols have been explored in-depth, offering valuable insights into their potential applications and benefits. Notably, genetic algorithms, fuzzy logic, and optimization techniques have played a pivotal role in refining cluster head selection processes, improving energy distribution, and prolonging network lifetimes. This review paper serves as a comprehensive resource for researchers and practitioners in the field of WSNs, offering a holistic understanding of the existing literature on clustering algorithms and optimization techniques. By shedding light on the strengths and limitations of these methodologies, it provides a foundation for future research endeavors, ultimately driving the development of energy-efficient and robust Wireless Sensor Networks for diverse applications.

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REFERENCES

[1] M.A. Matin and M.M. Islam, "Overview of Wireless Sensor Network", *InTech*, pp. 03-24, 2018.

[2] Harshwinder Singh and Navpreet Kaur, "Energy Efficiency Techniques for Wireless Sensor Networks: A Review", *International Journal of Innovative Research in Computer and Communication Engineering,* Volume 2, Issue 5, pp. 4138-4142, May 2019.

[3] Rajesh Chaudhary and Sonia Vatta, "Review Paper on Energy-Efficient Protocols in Wireless Sensor Networks*", International organization of Scientific Research Journal of Engineering (IOSRJEN),* Volume 4, Issue 2, pp. 01-07, February 2020.

[4] N.R. Wankhade and D.N. Choudhari, "Advanced Energy Efficient Routing Protocol for Clustered Wireless Sensor Network: Survey", *International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS),* Volume 9, No. 3, pp. 237-242, June-August 2014.

[5] You-Chiun Wang, Wen-Chih Peng and Yu-Chee Tseng, "Energy-Balanced Dispatch of Mobile Sensors in a Hybrid Wireless Sensor Network", *IEEE Transactions on Parallel and Distributed Systems,* Volume 21, No. 12, December 2010.

[6] Gerard Chalhoub and Michel Misson, "Cluster-tree Based Energy Efficient Protocol for Wireless Sensor Networks", *International Conference on Networking, Sensing and Control (ICNSC) IEEE,* pp. 664-669, April 2010.

[7] Rathna R. and Sivasubramanian A., "Improving Energy Efficiency in Wireless Sensor Networks Through Scheduling and Routing", *International Journal Of Advanced Smart Sensor Network Systems (IJASSN),* Volume 2, No. 1, pp. 21- 27, January 2012.

[8] Mohammad Soleimani, Mohammad Ghasemzadeh and Mehdi Agha Sarram, "A New Cluster Based routing Protocol for Prolonging Network Lifetime in Wireless Sensor Networks", *Middle-East Journal of Scientific Research,* Volume 7, No. 6, pp. 884-890, 2011.

[9] Sanjay Waware, Nisha Sarwade and Pallavi Gangurde, "A Review of Power Efficient Hierarchical Routing Protocols in Wireless Sensor Networks", *International Journal of Engineering Research and Applications (IJERA),* Volume 2, Issue 2, pp.1096-1102, March-April 2012.

[10] Sunita Rani and Tarun Gulati, "An Improved PEGASIS Protocol to Enhance Energy Utilization in Wireless Sensor Network", *International Journal of Advanced Research in Computer Science and Software Engineering,* Volume 2, Issue 11, pp. 448-253, November 2012.

[11] Samia A. Ali and Shreen K. Refaay, "Chain-Chain Based Routing Protocol", *International Journal of Computer Science* Issues *(IJCSI),* Volume 8, Issue 3, No. 2, pp. 105-112, May 2011.

[12] Lathies Bhasker, "Genetically Derived Secure Cluster-Based Data Aggregation in Wireless Sensor Networks", *IET Information Security,* Volume 8, Issue 1, pp. 01–07, May 2013.

[13] Stephanie Lindsey, Cauligi Raghavendra and Krishna M. Sivalingam, "Data Gathering Algorithms in Sensor Networks Using Energy Metrics", *IEEE Transactions on Parallel and Distributed Systems,* Volume 13, No. 9, pp. 924- 935, September 2002.

[14] Ouadoudi Zytoune and Driss Aboutajdine, "A Lifetime Extension Protocol for Data Gathering in Wireless Sensor Networks", *International Journal of Innovation and Applied Studies,* Volume 4, No. 3, pp. 477-482, November 2013.

[15] Razieh Sheikhpour, Sam Jabbehdari and Ahmad khademzadeh, "A Cluster- Chain based Routing Protocol for Balancing Energy Consumption in Wireless Sensor Networks", *International Journal of Multimedia and Ubiquitous Engineering,* Volume 7, No. 2, pp. 01-16, April 2012.

[16] Cong Wang and Cuirong Wang, "A Concentric Data Aggregation Model in Wireless Sensor Network", *Progress In Electromagnetics Research Symposium*, Beijing, China, pp. 436-441, March 2009.

[17] Li, Hui, and Jing Liu. "Double cluster based energy efficient routing protocol for wireless sensor network." *International Journal of Wireless Information Networks* 23, no. 1 (2016): 40-48.

[18] Mohamed Elshrkawey, Samiha M. Elsherif, M. Elsayed Wahed in their paper "An Enhancement Approach for Reducing the Energy Consumption in Wireless Sensor Networks" Journal of King Saud University – Computer and Information Sciences 30 (2018) 259–267.

[19] Hicham Ouchitachen a, Abdellatif Hair, Najlae Idrissiin their paper "Improved multi-objective weighted clustering algorithm in Wireless Sensor Network" *Egyptian Informatics Journal* (2016).

[20] Alghamdi, T.A., 2020. Energy efficient protocol in wireless sensor network: optimized cluster head selection model. *Telecommunication Systems*, *74*(3), pp.331-345.

[21] Rodríguez, A., Del-Valle-Soto, C. and Velázquez, R., 2020. Energy-efficient clustering routing protocol for wireless sensor networks based on yellow saddle goatfish algorithm. *Mathematics*, *8*(9), p.1515.

[22] Smaragdakis, G., Matta, I. and Bestavros, A., 2004, August. SEP: A stable election protocol for clustered heterogeneous wireless sensor networks. In *Second international workshop on sensor and actor network protocols and applications (SANPA 2004)* (Vol. 3).

[23] Heinzelman, W.B., Chandrakasan, A.P. and Balakrishnan, H., 2002. An application-specific protocol architecture for wireless microsensor networks. *IEEE Transactions on wireless communications*, *1*(4), pp.660-670.

[24] Heinzelman, W.B., 2000. *Application-specific protocol architectures for wireless networks* (Doctoral dissertation, Massachusetts Institute of Technology).

[25] Sahaaya Arul Mary, S.A. and Gnanadurai, J.B., 2017. Enhanced zone stable election protocol based on fuzzy logic for cluster head election in wireless sensor networks. *International Journal of Fuzzy Systems*, *19*(3), pp.799-812.

[26] Barani, S. and Visalakshi, S., 2017. Super Cluster Head Selection and Energy Efficient Round Robin Load Balancing Technique in Wireless Sensor Networks. *International Journal of Engineering Science and Computing*, *7*(4), pp.10065-10072.

[27] Osamy, W., Salim, A. and Khedr, A.M., 2020. An information entropy based-clustering algorithm for heterogeneous wireless sensor networks. *Wireless networks*, *26*(3), pp.1869-1886.

[28] Preethiya, T., Muthukumar, A. and Durairaj, S., 2020. Double cluster head heterogeneous clustering for optimization in hybrid wireless sensor network. *Wireless Personal Communications*, *110*(4), pp.1751-1768.

[29] Batra, P.K. and Kushwah, R., 2019, November. Fuzzy Logic based Cluster Head Selection method for Heterogeneous Wireless Sensor Networks. In *2019 Fifth International Conference on Image Information Processing (ICIIP)* (pp. 86-90). IEEE.

[30] Dutt, S., Agrawal, S. and Vig, R., 2018. Cluster-head restricted energy efficient protocol (CREEP) for routing in heterogeneous wireless sensor networks. *Wireless Personal Communications*, *100*(4), pp.1477-1497.

[31] Kumar, S., Verma, S.K. and Kumar, A., 2015. Enhanced threshold sensitive stable election protocol for heterogeneous wireless sensor network. *wireless personal communications*, *85*(4), pp.2643-2656.

[32] Tsai, M.Y. and Chen, Y.C., 2015, August. A Virtual Cluster Head Election Scheme for energy-efficient routing in wireless sensor networks. In *2015 3rd International Conference on Future Internet of Things and Cloud* (pp. 341-348). IEEE.

[33] TURGUT, İ.A., 2020. Dynamic coefficient-based cluster head election in wireless sensor networks. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, *26*(5), pp.944-952.

[34] Hassan, S. and Ahmad, M., 2022. Energy heterogeneity analysis of heterogeneous clustering protocols. *Int. Arab J. Inf. Technol.*, *19*(1), pp.45-54.

[35] Zhao, L. and Guo, S., 2021. An energy efficient multi-hop cluster-head election strategy for wireless sensor networks. *Journal of Information Processing Systems*, *17*(1), pp.63-74.

[36] Naeem, A., Javed, A.R., Rizwan, M., Abbas, S., Lin, J.C.W. and Gadekallu, T.R., 2021. DARE-SEP: A hybrid approach of distance aware residual energy-efficient SEP for WSN. *IEEE transactions on green communications and networking*, *5*(2), pp.611-621.

[37] Singh, S., Malik, A. and Singh, P.K., 2021. A threshold-based energy efficient military surveillance system using heterogeneous wireless sensor networks. *Soft Computing*, pp.1-14.

[38] Kumar, H. and Singh, P.K., 2021. Enhancing Network lifetime and Throughput in Heterogeneous Wireless Sensor Networks. *Wireless Personal Communications*, *120*(4), pp.2971-2989.

[39] Verma, S., Sood, N. and Sharma, A.K., 2019. Genetic algorithm-based optimized cluster head selection for single and multiple data sinks in heterogeneous wireless sensor network. *Applied Soft Computing*, *85*, p.105788.

[40] Nandan, A.S., Singh, S., Kumar, R. and Kumar, N., 2021. An Optimized Genetic Algorithm for Cluster Head Election Based on Movable Sinks and Adjustable Sensing Ranges in IoT-Based HWSNs. *IEEE Internet of Things Journal*, *9*(7), pp.5027-5039.

[41] Baradaran, A.A. and Navi, K., 2020. HQCA-WSN: High-quality clustering algorithm and optimal cluster head selection using fuzzy logic in wireless sensor networks. *Fuzzy Sets and Systems*, *389*, pp.114-144.

[42] Djabour, D., Abidi, W. and Ezzedine, T., 2022. Fuzzy independent circular zones protocol for heterogeneous wireless sensor networks. *International Journal of Ad Hoc and Ubiquitous Computing*, *39*(3), pp.157-169.