Anusandhanvallari
Vol 2025, No.1
August 2025
ISSN 2229-3388

Advancements In Energy Optimization and Security in Wireless Sensor Networks a Comprehensive Survey

Sangeethapriya[1], Dr. S. Devaraju[2], Dr. Antony Cynthia[3]

[1]Computer science, Sri Krishna Arts and Science College, Bharathiar University, India

E-mail: sangeetha.cbe95@gmail.com

[2]Computer science, VIT Bhopal University, India.

E-mail: devamcet@gmail.com

[3]Computer science, Sri Krishna Arts and Science College, Bharathiar University, India

E-mail: antonycynthia@skasc.ac.in

Abstract: Wireless Sensor Networks (WSNs) have emerged as a crucial technology in various domains, including environmental monitoring, healthcare, industrial automation, and smart cities. However, the inherent constraints of WSNs, such as limited energy, computational capabilities, and communication range, pose significant challenges in ensuring their efficient operation and security. This comprehensive survey explores the recent advancements in energy optimization and security techniques tailored specifically for WSNs. The survey begins by examining energy-efficient protocols and algorithms designed to prolong the network lifetime by minimizing energy consumption during data transmission, aggregation, and routing. It discusses techniques such as data-centric routing, clustering, and duty cycling, along with advancements in energy harvesting and power management strategies. This article reviews 25 research papers for WSN and explores the potential of computer-assisted methods for efficient intrusion detection. Moreover, the survey delves into the critical aspect of security in WSNs, considering the vulnerabilities and threats unique to these networks, including node capture, tampering, eavesdropping, and denial of service attacks. It covers cryptographic techniques, key management schemes, intrusion detection systems, and secure routing protocols aimed at safeguarding data integrity, confidentiality, and availability in WSNs.

Keywords: Clustering, Energy Optimization, Energy-Aware Routing, security techniques, Wireless Sensor Networks

I. Introduction

Numerous domains find extensive use for wireless sensor networks (WSNs), including environmental and health monitoring, among many others. A good example of this is the widespread deployment of wireless sensors that are powered by solar or batteries in catastrophe warning systems. Sensors pick up on several occurrences in the vicinity [1-4]. The data is collected and processed by the sink after the sensors transmit it over many hops. Recharging the batteries is a pain since the monitoring location is frequently out of reach [5-6]. Therefore, conserving the finite energy is an essential concern for WSNs. The two primary processes that account for the majority of a sensor's total power consumption are transmission and reception [7-8]. The risk of data loss during transmission due to an unstable wireless connection necessitates the use of more energy for retransmission [9-10]. Designing a route that ensures effective and dependable data delivery is very desired. Furthermore, due to the presence of many source nodes, there could be a multitude of routing pathways. That is why the networks are obstructed. Indirectly contributing to energy savings, link scheduling can prevent node collisions [11, 12].

The individual nodes, or "sensors," that make up a wireless sensor network are tiny devices that can detect and record information about their immediate surroundings. They are able to exchange information with one other over a wireless media [13–14]. Using a multi-hop connection, the gathered data will be sent to a sink or sinks. Battery power is required by these sensor nodes. These sensor nodes are often placed in hazardous regions where humans are not welcome, such as on top of glaciers, in the middle of the ocean, or near volcanoes [15-16]. This makes routinely charging or replacing the SN's batteries a challenge. Since the sink node often has more power, researchers and developers in the area of Wireless Sensor Networks (WSN) have focused on finding ways to maximize energy efficiency in order to lengthen the SN's lifespan. Wireless, not bounded, is where the public's attention is now [17–18].

wired network because of the drawbacks of wired technology, such as its low coverage area and expensive setup cost, among others. Wireless communication and technology are the primary areas of study and funding [19]. If we want to communicate but don't have physical material on hand, we can use wireless technology. Among the many wireless technologies in use today, one can include wireless sensor networks (WSNs) [20]. In a wireless sensor network (WSN), each sensor node communicates with a central base station (BS). From what we can see, a sensor node is essentially a minicomputer with its own memory, antenna, CPU, and battery backup system [21–23]. One promising network technology for smart homes and factories is the wide area network (WSN), which offers a promising answer to the problem of wireless communication. One of the practical uses of wireless networks, WSN is expanding. A sensor node is one component of a WSN; a sink is another. Sensor nodes are groups of interconnected processing, sensing, and communication devices [24–27].

II. Background study

Abdulai, J. D. et al. (2023) In order to function for an extended amount of time, wireless sensor networks used for environmental monitoring must have a low power consumption rate and a long battery life. To maximize the wireless sensor network's lifespan and the nodes' and the network's performance, it was crucial that the nodes' energy consumption be maintained to a minimum.

Alazab, M. et al. (2021) Using factors from both WSN and IoT networks, including energy, latency, and distance, as well as temperature and load, this study presents a sophisticated model for Cluster Head (CH) selection. The primary goal of this CH selection model was to optimize normalized energy while minimizing device distance, delay, load, and temperature. The suggested FA-ROA paradigm served this objective by facilitating the CH selection procedure.

Alexopoulos, N. et al. (2018) The requirement for defenses to work together was growing as the number and complexity of cyber-attacks on vital infrastructure continue to rise. Building a trustworthy and responsible environment for the participating monitors was necessary for the practical improvement of collaborative intrusion detection. Using blockchain technology as an example, the author laid out a general architecture for building such a Composite Intrusion detection system (CIDS) in this article. The author also addressed the several potential future avenues of this field of study and identified the current obstacles to further research.

Alkadi, O. et al. (2020) The history of cloud computing, blockchain technology, and intrusion detection systems has been covered in this article. Additionally, the prior research on these systems has been detailed. The author have also looked at the difficulties of integrating intrusion detection systems with blockchain technology. While this study confirms that cloud computing was becoming more important for cyber defense, it also shows that a great deal of room remains for investigation in this area. In particular, businesses that rely on cloud services were vulnerable throughout the live transfer process.

Hu, W. et al. (2019) Future power sector research should focus on the UPIoT. In order for the UPIoT to function properly, wireless sensors were crucial. One way to speed up the rollout of the Internet of Things with ubiquitous electricity was to make wireless sensor networks more resilient and stable. Setting up CHs and dividing WSN sensors into many clusters improves energy efficiency, which was a frequent solution to the problem of wireless sensors draining their power during data transmission.

Huang, H., & Li, J. (2020) The author provide a system that combines quality-of-service routing with interference-avoidance link scheduling to increase the lifespan of WSN networks. In order to discover a quality of service routing that minimizes latency while maximizing network lifespan and link dependability, the author introduced a distributed method. After that, it was shown that the routing algorithm was proper. For the purpose of avoiding communication collisions, the author also developed a Time Division Multiple Access (TDMA) scheduling method that uses neighbor information exchange to determine the time frame length and timeslot assignment.

Khan, B. et al. (2018) These authors research study proposes an octagonal-trajectory-based Fuzzy-Technique for Preference by Similarity to Ideal Solution (TOPSIS) routing method for Cluster Head selection. The following five factors have been taken into account: remaining energy, rate of node energy consumption, number of surrounding nodes, average distance between neighboring nodes, and distance from the sink. Additionally, the author take into account threshold-based multi-hop communication both inside and across clusters. These authors suggested scheme's network lifespan was shown to be around 140% higher than Low Energy Adaptive Cluster Hierarchy (LEACH's) and 72% higher than earlier fuzzy-based schemes, according to simulation findings, even without an Additive White Gaussian Noise (AWGN) channel model.

Khan, F. et al. (2018) These authors proposed method for energy-efficient CH selection in this study uses the residual energies of nodes to choose CH, which significantly increases the network lifespan and reduces power consumption in WSNs. The author ran the simulation using NS-2. Both large-scale and small-scale networks were used for the simulation. These authors suggested method outperforms LEACH for small networks in terms of energy usage and network longevity based on these simulated findings.

Khan, T. et al. (2021) SNs transmit sensitive information, therefore ensuring their security was crucial for high throughput. By quantitatively analyzing the trust values of SNs during routing in WSNs, the author provide Well-Organized Trust Estimation Based Routing Scheme (ETERS), a realistic trust-based efficient and secure routing strategy, to identify and mitigate various internal assaults. An effective trust-aware routing framework for WSNs was developed by combining a routing mechanism with an efficient cluster head selection algorithm (ECHSA) and an attack detection algorithm (TADA).

Khonde, S. R., & Ulagamuthalvi, V. (2022) these authors research introduces IDSwBC, a unique intrusion detection system that uses the blockchain foundation. It was one of the first of its kind. This technology offers a one-of-a-kind way to safely exchange signatures over the internet. Anomaly detection and signature development and dissemination were the two stages of implementing and executing IDSwBC. When combined, the two steps provide a robust security mechanism. Processing time for transactions, throughput, average latency, and execution time were the metrics used to measure blockchain performance. The findings show that Hyperledger Fabric v2.0 was more performant than v1.0.

Kumar, R., & Gangwar, M. (2019) Two algorithms were used in these authors suggested work: (1) an algorithm for efficient cluster head selection and (2) an approach for data transfer called back propagation. The goal of these methods was to increase the wireless sensor network's lifetime and throughput. From among the nodes that were distributed at random, the cluster head was chosen using a cluster head selection method. An important factor in enhancing WSN performance was choosing a cluster head.

Liu, H. et al. (2021) The authors of this study suggested using federated learning and a blockchain to jointly identify intrusions in vehicle edge computing networks. By using multi-party aggregation training, the suggested technique was able to aggregate and share models with a better final accuracy. Distributed RSUs were incentivized to train high-accuracy models and provide safe storage and sharing using this work's proposed blockchain incentive system, which was based on trust and training model quality.

Narayan, V. et al. (2022) these authors research suggests an energy-harvesting-based routing system for continuous sensor network target coverage. The suggested Fuzzy based approach integrated with Grey Wolf Optimization (FGWOA) makes advantage of three essential property of energy optimization: average distance to sink, average distance within the cluster, and residual energy of node. When transmitting data, the FGWOA protocol chooses the best possible route and conducts a CH selection. By using the fuzzy approach with the given parameters, the author can find the best next hop. The simulation compared several protocols in terms of the total energy consumption of the network, the number of living nodes, and the total packets received at the base station.

Nayak, P. et al. (2019) these authors research presents these authors efforts to develop a cluster-based routing strategy for Wireless Sensor Networks with an emphasis on efficient Cluster Head selection. Genetic algorithms, which were derived from natural biological processes, provide optimum or near-optimal answers even when the search space was very large, and this concept was used to pick the cluster head. The Wireless Sensor Network incorporates GA's step-by-step techniques to choose a cluster head from the clustered nodes that can distribute network load uniformly.

Table 1: Comparative Analysis of Energy-Efficient Routing Protocols in Wireless Sensor Networks

Author	Year	Methodology	Advantage	Limitation
Alkadi, O. et al.	2020	Review of intrusion detection and blockchain applications	Comprehensive overview of techniques	Limited focus on specific algorithmic implementations, lack of empirical evaluations
Abdulai, J. D. et al.	2023	Modified distance-based energy-aware routing protocol	Improved energy efficiency through modified routing algorithm	Specific to energy optimization, cannot address broader security concerns
Khan, B. M. et al.	2018	Fuzzy-TOPSIS based cluster head selection	Incorporates fuzzy logic for more nuanced cluster head selection criteria	Complexity in implementation, can require additional computational resources
Sharma, D. & Bhondekar, A. P.	2018	Traffic and energy-aware routing for heterogeneous WSNs	Balances traffic load and energy consumption for improved network performance	Potential overhead in routing decisions, can require frequent updates based on network dynamics
Nezha, E. I. & Abdellah, N.	2021	Energy-aware clustering and efficient cluster head selection	Optimizes cluster head selection based on energy-awareness and efficiency	Can require tuning for different network topologies, scalability concerns for larger networks

Raslan, A. et al. (2021) The Internet of Things-WSN's primary challenge was the network longevity. The author presented a novel approach to pick the CHs in the IoT-WSN, an NP-hard problem, to address this issue. A better sun-ower optimization method was what the authors were proposing here (ISFO). A method that combines elements of both the lèvy flight operator and the conventional SFO algorithm was known as the ISFO algorithm.

Sarhan, M. et al. (2022) For ML-based intrusion detection systems, the author provide HBFL, a new CTI enabling framework. By sharing lessons gathered from various organizational settings, HBFL hopes to improve the organization's IoT security posture. With this architecture, the Internet of Things endpoints, combiners, and reducers were housed in the cloud, fog, and edges, in that order. By combining HFL with permission blockchains, a safe architecture was created. Furthermore, a smart contract has been created to guarantee that tasks were carried out in accordance with pre-established approval standards.

Sharma, D., & Bhondekar, A. P. (2018) In order to achieve best resource usage in real-world circumstances, WSN routing algorithms should take multi-heterogeneity into account. Nodes in WSNs that experience energy and traffic heterogeneities at random were the focus of this letter. An enhanced CH selection approach was used to create a traffic and energy aware routing (TEAR) methodology that takes into account the node's traffic in addition to its initial and residual energies. When it comes to stability period, TEAR outperforms historical algorithms like LEACH, SEP, and DEEC in the context of a multi-heterogeneous situation.

Shinde, A. S., & Bichkar, R. S. (2020) Ensuring that sensor nodes use energy efficiently and extending the lifespan of the network were two of the most difficult aspects of developing WSNs. Hence, the author have suggested an optimum cluster head selection method based on PSO for minimizing energy consumption and extending the lifespan of the network. This algorithm selects CHs according to residual energy, inter-cluster distance, and intra-cluster distance of the sensor nodes. The fitness function and efficient particle encoding approach enable the implementation of the suggested algorithm.

Tyagi, L. K. et al. (2022) To efficiently pick CH and NCH in the WSN based on the threshold value, the Energy Efficient Next Cluster Head Based Two-Tier Hierarchy Routing Protocol was suggested. For operations involving data transfer inside the network, the ideal quantity of CH and NCH was chosen. When deciding between CH and NCH, two factors were taken into account: the node's residual energy and its distance from the base station. The network lifespan was improved by using a multihop scheme between the CH. Alive node, packet delivery to BS, residual energy, and network stability were four areas where the suggested protocol outperforms the SEP protocol in simulations.

Yadav, R. N. et al. (2018) these authors research presents Energy Aware Cluster based Routing Protocol EACRP, a distributed and event-driven cluster-based routing method for energy-aware cluster based routing that aims to improve data delivery efficiency in Cognitive radio sensor network (CRSN). The first part of EACRP involves clustering CRSN nodes into an ideal number of groups and choosing an intra-cluster data channel based on the combined sensing results of each CR sensor node. The second part of EACRP involves delivering data to the sink node via the most efficient method possible.

III. Existing Methods

3.1 Popular methods

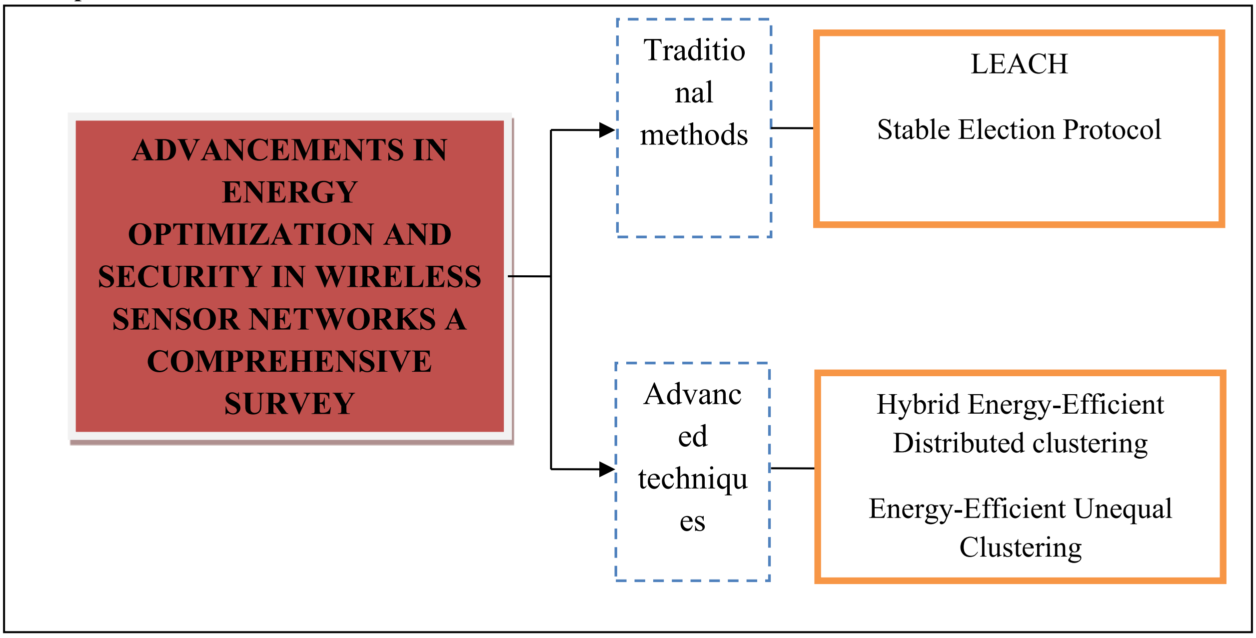

Figure 1: Traditional and Advanced techniques

Table 2: comparison table for existing methods

Algorithm	Merits	Demerits
LEACH-C	Because it takes energy levels and communication costs into account while selecting cluster heads, LEACH-C is more energy efficient than the original LEACH algorithm. This contributes to a more stable network lifespan by distributing power consumption evenly across nodes.	While there are certain algorithmic benefits to centralization, there is also some overhead when it comes to processing data and communicating with the entity in charge of cluster head selection. The complexity and scale of the network might cause this overhead to rise.
Power Efficient and Adaptive Clustering Hierarchy	By incorporating power control methods and dynamically altering clustering, PEACH enhances energy efficiency. As a result, the network lasts longer and uses less energy. .	The algorithm design and implementation becomes more sophisticated due to PEACH's adaptive and hierarchical structure. System overhead might rise if dynamic clustering and power control techniques are not well-coordinated.
Stable Election Protocol	By reducing the frequency of cluster head re-elections and minimizing energy usage, SEP greatly enhances network longevity by picking stable nodes as cluster heads.	Communication and computational overhead can be introduced by SEP's periodic re-election procedure and stability metrics. Larger network sizes or more frequent changes in network circumstances can cause this expense to grow.
Multi-Cluster LEACH	By enabling numerous cluster heads inside each cluster, MC-LEACH improves the scalability of the network. Because of this, the method outperforms classic LEACH when it comes to handling networks with more nodes and greater sizes.	Adding more than one cluster head to a cluster could raise coordination and communication costs. This cost could increase as the number of nodes in a cluster grows.
Multi-Granularity Energy Aware Routing	By taking into account several aspects including communication distances, data transmission speeds, and node energy levels, M-GEAR enhances energy efficiency. While routing data, the algorithm can then choose the most energy-efficient pathways.	There can be communication and processing overhead due to M-GEAR's energy-aware routing choices. Larger network sizes or more frequent changes in network circumstances can cause this expense to grow.

3.1 Power Efficient and Adaptive Clustering Hierarchy

With the goal of optimizing energy consumption and network efficiency, the Power-Efficient and Adaptive Clustering Hierarchy (PEACH) algorithm for Wireless Sensor Networks (WSNs) creates a hierarchical structure with sensor nodes organized into clusters, including base stations (BS), cluster heads (CHs), and member nodes. Adaptive clustering techniques are used by PEACH to dynamically construct and sustain clusters, taking into account energy levels, communication distances, and traffic patterns. To ensure effective data gathering, processing, and forwarding inside clusters, cluster heads are chosen based on criteria such as energy reserves, communication capabilities, and proximity to other nodes. Reduced power usage during data transmission, improved load balancing, and the elimination of network-wide energy hotspots are all results of using energy-aware routing algorithms. By allowing clusters and routing channels to be dynamically reconfigured in reaction to changing network circumstances, the method improves fault tolerance and resilience of the network. Adjusting factors like cluster size, communication thresholds, and routing metrics is crucial for efficient functioning. As a whole, PEACH offers a thorough framework for WSNs to use adaptive clustering in an energy-efficient manner, which in turn helps networks last longer and perform better.

3.2 Multi-Cluster LEACH

To improve the scalability, reliability, and energy efficiency of Wireless Sensor Networks (WSNs), Multi-Cluster LEACH (MC-LEACH) was developed as an extension of the Low Energy Adaptive Clustering Hierarchy (LEACH) method. Instead of using a single cluster head per cluster as in classic LEACH, MC-LEACH proposes using multiple cluster heads within each cluster. The goal of this strategy is to reduce energy consumption and increase the lifespan of the network by more fairly distributing the burden and duties of the cluster heads throughout the network. Sensor nodes in MC-LEACH are grouped into clusters, and there are many cluster chiefs in each cluster. Considerations including remaining energy, base station distance, and communication quality are usually used to choose cluster heads. The fault tolerance of MC-LEACH is enhanced by its numerous cluster heads. This allows for other cluster heads to take over in the event of node failures or energy exhaustion. As a result, the network's overall dependability is improved. In addition, MC-LEACH encourages load balancing by dividing up data aggregation and routing responsibilities across the cluster's many heads. As a result, energy hotspots are avoided and resources are used more efficiently. The technique also allows for adaptive clustering, which lets nodes change their responsibilities in response to changes in the network and energy levels in real time. Because of its flexibility, energy efficiency and network performance are both improved.

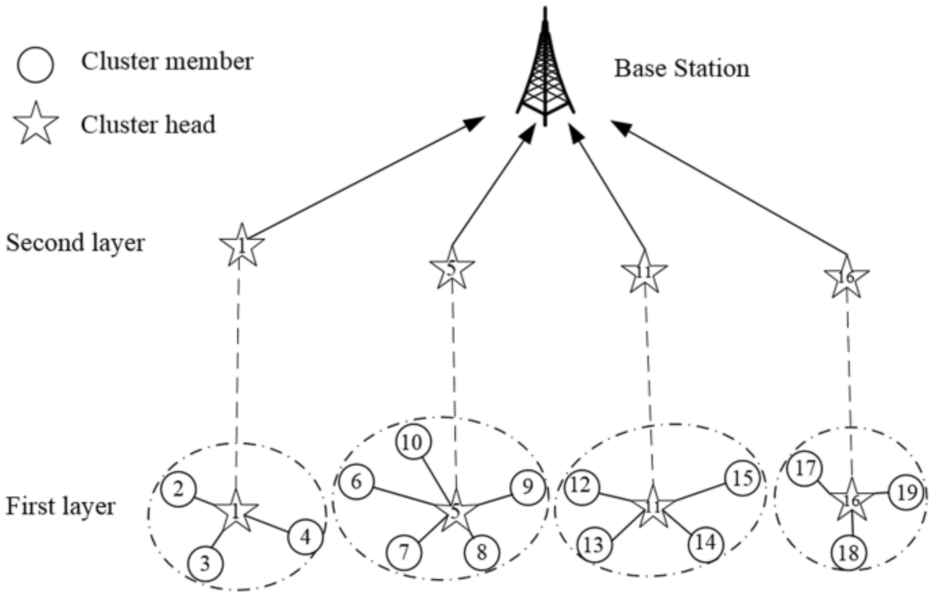

Figure 2: Multi-Cluster LEACH [Zhao, L. et al. (2018)**]**

3.3 Multi-Granularity Energy Aware Routing

By taking energy levels and communication distances into account, the Multi-Granularity Energy Aware Routing (M-GEAR) algorithm improves energy use in Wireless Sensor Networks (WSNs). To its granularity control mechanism, nodes can adapt their routing patterns on the fly to account for fluctuating energy levels and communication demands. To improve network efficiency and extend network lifespan, M-GEAR uses energy-aware decision-making algorithms to choose pathways that reduce energy usage while maintaining acceptable data transmission speeds. With its adaptive approach, M-GEAR becomes an ideal choice for dynamic WSN systems that prioritize energy efficiency and adaptation, to its increased fault tolerance and scalability.

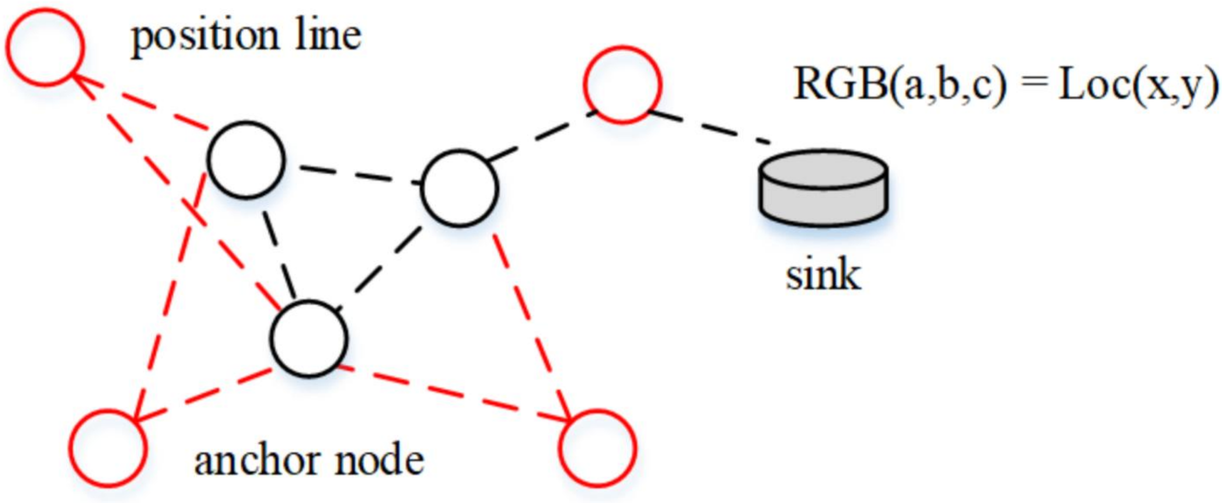

Figure 3: Multi-Granularity Energy Aware Routing [**Ding, Q. et al. (2021)**]

IV. Discussion

The advancements in energy optimization and security for Wireless Sensor Networks (WSNs) present a multifaceted landscape of challenges and opportunities. Energy-efficient protocols like data-centric routing and clustering, coupled with advancements in energy harvesting and power management, are extending network lifetimes and enabling sustainable deployments. However, integrating robust security measures is paramount given the unique vulnerabilities of WSNs, including node capture and denial of service attacks. The survey's exploration of cryptographic techniques, key management schemes, and intrusion detection systems underscores the critical need to safeguard data integrity and confidentiality. The ongoing convergence of energy optimization and security introduces complexities such as scalability, resilience to evolving threats, interoperability, and privacy concerns, necessitating collaborative efforts and innovative solutions to harness the full potential of WSNs across diverse domains while ensuring efficiency, reliability, and data security.

V. Conclusion

In conclusion, the advancements in energy optimization and security for Wireless Sensor Networks (WSNs) represent a pivotal step towards realizing their full potential across diverse domains. The survey has provided a comprehensive overview of cutting-edge techniques and methodologies aimed at addressing the inherent challenges of limited energy, computational capabilities, and security vulnerabilities in WSNs. Through the exploration of energy-efficient protocols such as data-centric routing, clustering, duty cycling, energy harvesting, and power management strategies, researchers and practitioners are empowered to extend the network lifetime and enhance operational efficiency. These advancements not only contribute to sustainability by reducing energy consumption but also enable WSNs to operate effectively in resource-constrained environments.

Furthermore, the survey's in-depth analysis of security mechanisms, including cryptographic techniques, key management schemes, intrusion detection systems, and secure routing protocols, underscores the critical importance of safeguarding data integrity, confidentiality, and availability in WSNs. By addressing threats such as node capture, tampering, eavesdropping, and denial of service attacks, these security measures bolster trust and reliability in WSN deployments.

VI. References

[1] Abdulai, J. D., Adu-Manu, K. S., Katsriku, F. A., & Engmann, F. (2023). A modified distance-based energy-aware (mDBEA) routing protocol in wireless sensor networks (WSNs). Journal of Ambient Intelligence and Humanized Computing, 14(8), 10195-10217.
[2] Alazab, M., Lakshmanna, K., G, T. R., Pham, Q.-V., & Reddy Maddikunta, P. K. (2021). Multi-objective cluster head selection using fitness averaged rider optimization algorithm for IoT networks in smart cities. Sustainable Energy Technologies and Assessments, 43, 100973. doi:10.1016/j.seta.2020.100973
[3] Alexopoulos, N., Vasilomanolakis, E., Ivánkó, N. R., & Mühlhäuser, M. (2018). Towards blockchain-based collaborative intrusion detection systems. In Critical Information Infrastructures Security: 12th International Conference, CRITIS 2017, Lucca, Italy, October 8-13, 2017, Revised Selected Papers 12 (pp. 107-118). Springer International Publishing.
[4] Alkadi, O., Moustafa, N., & Turnbull, B. (2020). A review of intrusion detection and blockchain applications in the cloud: approaches, challenges and solutions. IEEE Access, 8, 104893-104917.
[5] De, D., Mukherjee, A., Kumar Das, S., & Dey, N. (Eds.). (2020). Nature Inspired Computing for Wireless Sensor Networks. Springer Tracts in Nature-Inspired Computing. doi:10.1007/978-981-15-2125-6
[6] Hu, W., Yao, W., Hu, Y., & Li, H. (2019). Selection of cluster heads for wireless sensor network in ubiquitous power internet of things. International Journal of Computers Communications & Control, 14(3), 344-358.
[7] Huang, H., & Li, J. (2020). Distributed Energy-Aware Reliable Routing and TDMA Link Scheduling in Wireless Sensor Networks. 2020 29th International Conference on Computer Communications and Networks (ICCCN). doi:10.1109/icccn49398.2020.9209621
[8] Khan, B. M., Bilal, R., & Young, R. (2018). Fuzzy-TOPSIS based cluster head selection in mobile wireless sensor networks. Journal of Electrical Systems and Information Technology, 5(3), 928-943.
[9] Khan, F., Gul, T., Ali, S., Rashid, A., Shah, D., & Khan, S. (2018). Energy Aware Cluster-Head Selection for Improving Network Life Time in Wireless Sensor Network. Intelligent Computing, 581–593. doi:10.1007/978-3-030-01177-2_42
[10] Khan, T., Singh, K., Hasan, M. H., Ahmad, K., Reddy, G. T., Mohan, S., & Ahmadian, A. (2021). ETERS: A comprehensive energy aware trust-based efficient routing scheme for adversarial WSNs. Future Generation Computer Systems, 125, 921–943. doi:10.1016/j.future.2021.06.049
[11] Khonde, S. R., & Ulagamuthalvi, V. (2022). Blockchain: Secured Solution for Signature Transfer in Distributed Intrusion Detection System. Computer Systems Science & Engineering, 40(1).
[12] Kumar, R., & Gangwar, M. (2019). Improved BEST-MAC protocol for WSN using optimal cluster head selection. International Journal of Information Technology, 1-17.
[13] Liu, H., Zhang, S., Zhang, P., Zhou, X., Shao, X., Pu, G., & Zhang, Y. (2021). Blockchain and Federated Learning for Collaborative Intrusion Detection in Vehicular Edge Computing. IEEE Transactions on Vehicular Technology, 70(6), 6073–6084. doi:10.1109/tvt.2021.3076780
[14] NARAYAN, V., Daniel, A. K., & Chaturvedi, P. (2022). FGWOA: An efficient heuristic for cluster head selection in WSN using fuzzy based grey wolf optimization algorithm.
[15] Nayak, P., Kavitha, K., & Khan, N. (2019, October). Cluster head selection in wireless sensor network using bio-inspired algorithm. In TENCON 2019-2019 IEEE Region 10 Conference (TENCON) (pp. 1690-1696). IEEE.

[16] Nezha, E. I., & Abdellah, N. (2021). Energy-aware clustering and efficient cluster head selection. International Journal on Smart Sensing and Intelligent Systems, 14(1), 1-15.
[17] Rami Reddy, M., Ravi Chandra, M. L., Venkatramana, P., & Dilli, R. (2023). Energy-efficient cluster head selection in wireless sensor networks using an improved grey wolf optimization algorithm. Computers, 12(2), 35.
[18] Raslan, A. F., Ali, A. F., Darwish, A., & El-Sherbiny, H. M. (2021). An improved sunflower optimization algorithm for cluster head selection in the internet of things. IEEE Access, 9, 156171-156186.
[19] Sarhan, M., Lo, W. W., Layeghy, S., & Portmann, M. (2022). HBFL: A hierarchical blockchain-based federated learning framework for collaborative IoT intrusion detection. Computers and Electrical Engineering, 103, 108379.
[20] Sekaran, K., Rajakumar, R., Dinesh, K., Rajkumar, Y., Latchoumi, T. P., Kadry, S., & Lim, S. (2020). An energy-efficient cluster head selection in wireless sensor network using grey wolf optimization algorithm. TELKOMNIKA (Telecommunication Computing Electronics and Control), 18(6), 2822-2833.
[21] Sharma, D., & Bhondekar, A. P. (2018). Traffic and Energy Aware Routing for Heterogeneous Wireless Sensor Networks. IEEE Communications Letters, 22(8), 1608–1611. doi:10.1109/lcomm.2018.2841911
[22] Shinde, A. S., & Bichkar, R. S. (2020). Optimal cluster head selection and clustering for WSN using PSO. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 9(3).
[23] Tyagi, L. K., Kumar, A., Jha, C. K., Rai, A. K., & Narayan, V. (2022). Energy Efficient Routing Protocol Using Next Cluster Head Selection Process In Two-Level Hierarchy For Wireless Sensor Network. Journal of Pharmaceutical Negative Results, 4772-4783.
[24] Yadav, R. N., Misra, R., & Saini, D. (2018). Energy aware cluster based routing protocol over distributed cognitive radio sensor network. Computer Communications, 129, 54–66. doi:10.1016/j.comcom.2018.07.020
[25] Zakariayi, S., & Babaie, S. (2018). DEHCIC: A distributed energy-aware hexagon based clustering algorithm to improve coverage in wireless sensor networks. Peer-to-Peer Networking and Applications. doi:10.1007/s12083-018-0666-9
[26] Zhao, L., Qu, S., & Yi, Y. (2018). A modified cluster-head selection algorithm in wireless sensor networks based on LEACH. EURASIP Journal on Wireless Communications and Networking, 2018, 1-8.
[27] Ding, Q., Zhu, R., Liu, H., & Ma, M. (2021). An overview of machine learning-based energy-efficient routing algorithms in wireless sensor networks. Electronics, 10(13), 1539.