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A Wireless Sensor Networks for IoT and 6G: An Analysis of Intelligence and Energy Efficiency

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Abstract: Wireless Sensor Networks (WSNs) have emerged as a core technology for making intelligent environments available in healthcare monitoring, smart cities, industrial automation, and environmental monitoring applications. Increasing pressure for low-power, autonomous sensing systems and the explosive growth in Internet-of-Things (IoT) connected devices with corresponding pressure to improve the energy efficiency of WSNs make WSN architectures smarter and more energy-friendly. In addition, the development of next-generation paradigms of communication like 6G imposes new challenges as well as prospects for WSN integration. Intelligent and efficient WSN is the goal to be achieved while this survey takes into consideration innovation in system structure, communication, energy harvesting technology, and adoption of artificial intelligence and machine learning at the edge. The aim is to synthesize and critically review the state-of-the-art currently and determine gaps and possible areas of future work. Major challenges like energy limitations, secure data communication, interoperability, and scalability are examined in relation to contemporary application requirements. The originality of this work is that it has a holistic and futuristic approach, in which WSNs are studied not only in conventional applications but also in new areas motivated by smart decision-making and cross-layer optimization techniques. Moreover, this survey addresses the integration of WSNs with blockchain, edge computing, and green energy systems, providing insights into how these technologies together determine the future of autonomous sensor networks in the IoT and 6G era.
Keywords: Wireless Sensor Networks, Energy Efficiency, Intelligent Sensing, Internet of Things, Edge Computing, 6G Communication.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are the backbone of the development of the Internet of Things (IoT), with usage extending to healthcare, smart cities, agriculture, industrial automation, and environment monitoring [1]. With the IoT growing in depth, the demand for scalable, efficient, and robust sensor networks has ever been so intense. One of the most important challenges for WSNs is energy efficiency, since sensor nodes are usually equipped with batteries of limited capacity [2]. Therefore, the design of energy-efficient protocols, hardware, and energy harvesting solutions is essential to support long-term deployments in WSNs [3][4].

Current developments in WSNs focus on the incorporation of artificial intelligence (AI) and machine learning (ML) methods to minimize energy consumption and improve network performance [5][6]. AI-based models can dynamically adjust network behaviors and protocols according to environmental conditions to ensure improved resource usage and a lower energy overhead. In addition, the use of integrated 6G technologies provides novel possibilities for the creation of ultra-low latency, high-throughput networks that would greatly enhance the scalability and efficiency of WSNs for real-time applications [7].

To this end, this survey gives a summary of new advances in energy-efficient and intelligent WSNs with emphasis on innovation in system design, communication protocols, energy harvesting, and integration of AI/ML. Our goal is to emphasize trends, point out challenges, and propose future directions for research in the area, especially in relation to the new IoT and 6G world.

II. BACKGROUND AND MOTIVATION

Wireless Sensor Networks (WSNs) have made tremendous progress in the past twenty years, based on demands for intelligent, self-sustaining, and power-saving systems. A WSN is normally composed of many low-power sensor nodes that harvest and send data to some central processing node, e.g., a base station or sink. These sensor nodes tend to be installed in distant or hostile areas where power availability and network servicing cannot be done. This places energy efficiency at the forefront of WSN design [8].

Nodes in conventional WSNs use battery power to accomplish sensing, computation, and communication operations. Nevertheless, with limited energy resources being present on such devices, these devices' energy usage needs to be minimized in order to provide long network life. Different methods, such as energy-conscious routing protocols, data aggregation schemes, and power management algorithms, have been put forward for solving such issues [9].

One of the significant objectives of current WSNs is to reduce energy usage while supporting high performance and reliability. The objective becomes increasingly challenging with increasing network size and with the expansion of the IoT network to encompass billions of sensors [10]. Concurrently, the emergence of 6G networks opens up new possibilities for ultra-reliable, low-latency communication, which may also alleviate some of the energy problems of WSNs [11]. Nevertheless, the integration of 6G technologies with WSNs introduces new challenges with regard to scalability, data security, and interoperability.

III. ENERGY-EFFICIENT ROUTING IN WSNS

WSN routing is the most critical component for attaining energy efficiency and network lifetime. Energy-efficient routing protocols aim to reduce the energy consumed by sensor nodes during data transmission, thus maximizing the network lifetime. Several routing protocols have been proposed over the years, each with different methods of attaining energy consumption versus data delivery efficiency.

A. Reactive and Proactive Routing Protocols

Proactive protocols constantly update routing tables, while reactive protocols reserve route establishment to only when there is a need. Some of the proactive protocols include Destination-Sequenced Distance Vector (DSDV) and Optimized Link State Routing (OLSR), which have rapid delivery of data but lack power efficiency due to the fact that they store routes at all times [12]. Reactive protocols such as Ad Hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) save energy by establishing routes only when needed but introduce more latency.

New hybrid protocols have tried to integrate the best in proactive and reactive protocols, such as Hybrid Energy-Efficient Distributed Routing (HEED) [13]. These protocols will attempt to harmonize energy efficiency with network performance, sending data at low energy expenditure while being low-latency and high-throughput.

B. Clustering-Based Routing

Clustering-based routing protocols cluster the sensor nodes, with every node in a cluster acting as the cluster head. The cluster head collects data from cluster members and forwards it to the sink. Clustering reduces the overall communication overhead by decreasing the number of forwarding transmissions [14].

Leach (Low-Energy Adaptive Clustering Hierarchy) is one of the most widely used clustering-based protocols. Leach adjusts cluster heads such that energy load becomes distributed equally at all the nodes, thus preventing premature battery draining at any specific node [15]. LEACH also has some drawbacks, although having advantages, primarily related to scalability as well as overhead during cluster formation.

Recent advances in clustering-based routing have witnessed the introduction of multi-hop clustering and hierarchical clustering techniques that further reduce energy consumption by reducing the node-to-sink distance [16].

IV. ENERGY HARVESTING AND SUSTAINABILITY

Since WSNs are used in remote areas where it is not possible to replace batteries or recharge them, energy harvesting technologies are becoming increasingly popular in these networks. Energy harvesting is the technique of gathering energy from the environment around us, like solar, wind, or thermal energy, to supply the sensor nodes [17].

A. Solar Energy Harvesting

Solar energy harvesting is the most widely used method for powering WSNs. Solar-powered sensor nodes can recharge their batteries during both day and night and offer a permanent power supply to support long-duration deployments. Solar energy harvesting highly depends on environmental factors such as temperature, light, and humidity. Advances in the form of energy-efficient solar panels and energy storage units have helped improve the sustainability of solar-powered WSNs [18].

B. Thermal and Vibration Energy Harvesting

Other sources of energy harvesting, such as vibration and heat energy, are also being researched for WSNs, aside from solar energy. Thermoelectric generators (TEGs) and piezoelectric sensors can be utilized to generate electricity from mechanical vibrations and heat, respectively. These sources of energy are less efficient compared to solar energy but can be utilized to complement solar energy systems and enable continuous operation under changing environmental conditions [19].

V. ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN WSNS

Integration of Artificial Intelligence (AI) and Machine Learning (ML) with WSNs has provided new opportunities for the optimization of energy consumption, enhancement of security, and creation of the data processing capacity. AI algorithms can assist WSNs in making intelligent decisions based on environmental conditions, data insights, and network performance in real-time.

A. AI for Energy Optimization

Machine learning techniques, such as deep learning and evolutionary algorithms, are applied to optimize various aspects of WSNs, e.g., energy consumption, routing, and data aggregation. For example, reinforcement learning algorithms can be utilized to dynamically change transmission power levels based on network conditions and minimize energy consumption [20].

B. Machine Learning for Data Aggregation

ML algorithms are also employed to improve data aggregation in WSNs. Sensor nodes can perform smart data aggregation with the help of ML algorithms such as classification and clustering, reducing redundant data transmission across the network and saving energy. Additionally, ML algorithms can be utilized to forecast future network activity and perform proactive network parameter tuning [21].

VI. BLOCKCHAIN AND SECURITY IN WSNS

Security is also a critical concern in WSNs because they are vulnerable to various attacks, including eavesdropping, data forgery, and denial of service. Blockchain technology offers a secure and decentralized method of ensuring the privacy and integrity of data being exchanged in WSNs. Using blockchain, WSNs can offer secure data aggregation, authentication, and tamper-evident data storage [22][23].

VII. CONCLUSION AND FUTURE DIRECTIONS

The future uses are being combined with future technologies like 6G, edge computing, and IoT. With ultra-low latency and high speed enabled by 6G networks, they will be a perfect facilitator of high-performance massive-scale WSNs. The combination with edge computing will also facilitate near-data processing, hence minimizing communication overhead and energy efficiency [24].

In this survey of literature, we have presented the trends and development in energy-efficient Wireless Sensor Networks (WSNs) for IoT and 6G networks. The survey highlights some of the most important strategies including energy-efficient routing mechanisms, data aggregation mechanisms, and security communication mechanisms. Some major research pieces by Gopinath et al. [24], Zhang and Wang [29], and Kumari et al. [30] all pointed towards the importance of energy management in WSNs in maximizing the lifetime, reliability, and scalability. Different new techniques have been devised, including federated learning-based energy optimization [24], fault tolerance using reinforcement learning [33], and secure data aggregation with blockchain [29]. These techniques help address some of the current issues of data security, network lifespan, and rising complexity of IoT-based WSN.

Further, the blending of Artificial Intelligence (AI), machine learning, and metaheuristic algorithms has been remarkable in boosting the flexibility and performance of WSNs. Rajendran and Kumar's study [24], for example, looks into how much 6G-integrated WSNs can use such intelligent systems to get optimal performance in various applications. Aside from this, future developments in AI-based clustering, data gathering using UAVs [30], and AI-based intrusion detection [24] are yet to redefine the role of WSNs in complex environments like smart cities, health, and the military. Apart from this, there are some issues that are still pending to be solved with precise context to energy optimization, security in aggregation of data, and integration with emerging wireless technologies. With the onset of 6G and onward, WSNs are becoming much bigger, and therefore there is an urgent need to devise more efficient, scalable, and powerful methods able to manage the ginormous quantity of devices in the network. R&D has to continue to hone such methods, making them more energy efficient with hybrid protocols, and closing security loopholes through more sophisticated cryptography protocols like homomorphic encryption [24]. Moreover, fault-tolerant systems and secure data transfer are of top priority, especially for dynamic and heterogeneous networks such as disaster relief and military applications [32].

A. Future Directions

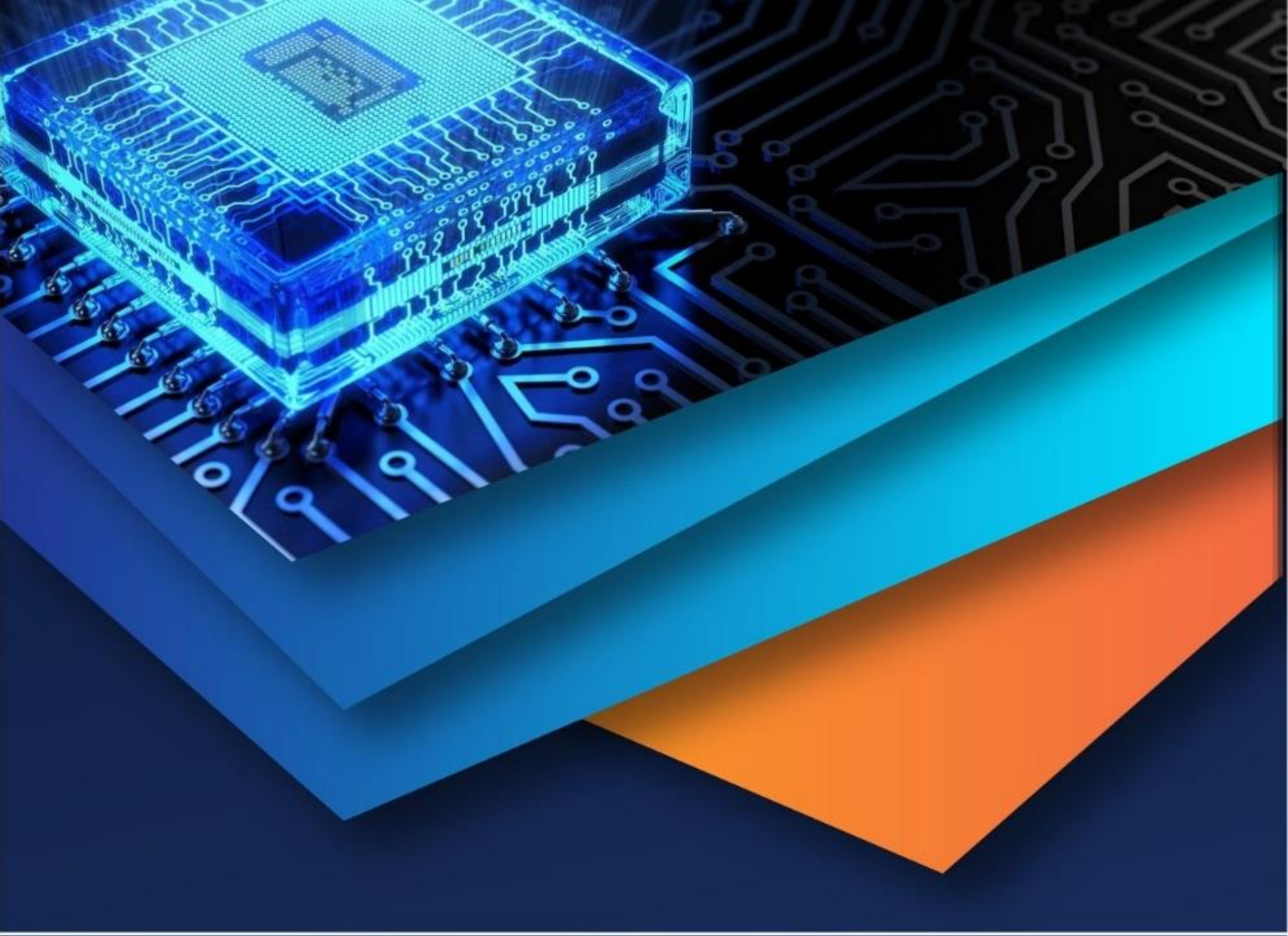
1) AI-Optimization: As the sophistication in AI and machine learning deepens, there are potential areas to enhance energy efficiency for WSN using this domain. Inclusion of deep models towards anticipating trends of energy consumption as well as real-time aggregation and routing optimization may be a field opened by potential future work. More study involving the implementation of clustering algorithms within AI to handle adaptability against change in the status of the network may be what enhances WSN's energy efficiency.

2) 6G and Beyond: With the world progressing towards 6G, WSNs will be faced with new challenges like connectivity, data rate, and interconnecting an unprecedented level of IoT devices. The work must be focused on the integrated integration of WSNs within 6G networks for ultra-low latency, high reliability, and low energy consumption. Literature [24] suggests that AI-based integration of 6G will be the driving force.
3) Advanced Security Mechanisms: As the need for data aggregation security grows, promising cryptographic techniques such as homomorphic encryption [24] have to ensure data privacy without being energy consumption. Future work can include using advanced cryptography protocols using blockchain to ensure security for data streams in large-scale sensor networks, especially for mission-sensitive applications such as the military and health care.
4) Energy Harvesting Technologies: Technology research would be focused more on the establishment of energy harvesting technologies that have the ability to power WSNs independently in remote and harsh environments. Power management strategies together with energy harvesting technologies would prolong sensor node lifetime to a high extent without recharge or maintenance. Fog and Edge Computing Convergence: Future research can investigate the convergence of edge computing and fog computing with WSNs to enhance data processing and decision-making capabilities at the network edge. It can alleviate communication overhead and WSN wastage by offloading computationally expensive tasks to local processing units to enable real-time data processing.

REFERENCES

[1] Sabrine Khriji, Dhouha El Houssaini, I. Kammoun, and Olfa Kanoun, "Energy-efficient techniques in wireless sensor networks," De Gruyter eBooks, pp. 287–304, Nov. 2018, doi: https://doi.org/10.1515/9783110445053-017
[2] L.-L. Hung, F.-Y. . Leu, K.-L. . Tsai, and C.-Y. . Ko, "Energy-Efficient Cooperative Routing Scheme for Heterogeneous Wireless Sensor Networks," IEEE Access, vol. 8, pp. 56321–56332, 2020, doi: https://doi.org/10.1109/access.2020.2980877
[3] A. Chugh and S. Panda, "Energy Efficient Techniques in Wireless Sensor Networks," Recent Patents on Engineering, vol. 13, no. 1, pp. 13–19, Feb. 2019, doi: https://doi.org/10.2174/1872212112666180731114046
[4] A. M. Zungeru, K. P. Seng, L.-M. Ang, and W. Chong Chia, "Energy Efficiency Performance Improvements for Ant-Based Routing Algorithm in Wireless Sensor Networks," Journal of Sensors, vol. 2013, pp. 1–17, 2013, doi: https://doi.org/10.1155/2013/759654
[5] S. Gopinath, E. Veera Boopathy, S. Pragadeswaran, S. Madhumitha, N. Sureshkumar5 "Location based Energy Efficient Routing Protocol for Improving Network Lifetime in WSN," International Journal of Electrical and Electronics Engineering, vol. 10, no. 2, pp. 84–91, Feb. 2023, doi: https://doi.org/10.14445/23488379/ijeee-v10i2p108
[6] S. Gayathri and D. Surendran, "Unified ensemble federated learning with cloud computing for online anomaly detection in energy-efficient wireless sensor networks," Journal of Cloud Computing, vol. 13, no. 1, Feb. 2024, doi: https://doi.org/10.1186/s13677-024-00595-y
[7] T. Liu et al., "6G Integrated Sensing and Communications Channel Modeling: Challenges and Opportunities," IEEE Vehicular Technology Magazine, vol. 19, no. 2, pp. 31–40, Apr. 2024, doi: https://doi.org/10.1109/mvt.2024.3373930
[8] K. Haseeb, F. F. Alruwaili, A. Khan, T. Alam, A. Wafa, and A. R. Khan, "AI Assisted Energy Optimized Sustainable Model for Secured Routing in Mobile Wireless Sensor Network," Mobile Networks and Applications, vol. 29, no. 3, pp. 867–875, Apr. 2024, doi: https://doi.org/10.1007/s11036-024-02327-7
[9] Mustafa Ozger, E. B. Pehlivanoglu, and O. B. Akan, "Energy-Efficient Transmission Range and Duration for Cognitive Radio Sensor Networks," IEEE Transactions on Cognitive Communications and Networking, vol. 8, no. 2, pp. 907–918, Nov. 2021, doi: https://doi.org/10.1109/tccn.2021.3130986
[10] B. Bougard, Francky Catthoor, D. Daly, A. P. Chandrakasan, and Wim Dehaene, "Energy Efficiency of the IEEE 802.15.4 Standard in Dense Wireless Microsensor Networks: Modeling and Improvement Perspectives," Design, Automation, and Test in Europe, Apr. 2005, doi: https://doi.org/10.1109/date.2005.136
[11] Hafsa Benaddi, K. Ibrahimi, Abderrahim Benslimane, and J. Qadir, "A Deep Reinforcement Learning Based Intrusion Detection System (DRL-IDS) for Securing Wireless Sensor Networks and Internet of Things," Springer eBooks, pp. 73–87, Jan. 2020, doi: https://doi.org/10.1007/978-3-030-52988-8_7
[12] Y. Liu, J. Wang, Z. Yan, Z. Wan, and R. Jantti, "A Survey on Blockchain-based Trust Management for Internet of Things," IEEE Internet of Things Journal, pp. 1–1, 2023, doi: https://doi.org/10.1109/jiot.2023.3237893
[13] M. Arulselvan, "Latency-Aware Packet Transmission Optimization in Duty-Cycled WSNs," Philpapers.org, 2024.
[14] S. Rajasoundaran et al., "Secure routing with multi-watchdog construction using deep particle convolutional model for IoT based 5G wireless sensor networks," Computer Communications, vol. 187, pp. 71–82, Apr. 2022, doi: https://doi.org/10.1016/j.comcom.2022.02.004
[15] N. Mittal, S. Singh, U. Singh, and R. Salgotra, "Trust-aware energy-efficient stable clustering approach using fuzzy type-2 Cuckoo search optimization algorithm for wireless sensor networks," Wireless Networks, Aug. 2020, doi: https://doi.org/10.1007/s11276-020-02438-5
[16] S. Pragadeswaran, "Security Analysis in Wireless Sensor Networks: Challenges, Threats and Security Issues," International Journal for Research in Applied Science and Engineering Technology, vol. 9, no. 4, pp. 683–690, Apr. 2021, doi: https://doi.org/10.22214/ijraset.2021.33693
[17] Rishabh Chanana, Amit Kumar Singh, Radhika Killa, S. Agarwal, and Pawan Singh Mehra, "Blockchain Based Secure Model for Sensor Data in Wireless Sensor Network," Mar. 2020, doi: https://doi.org/10.1109/icsc48311.2020.9182776
[18] C. Gherbi, Z. Aliouat, and M. Benmohammed, "A survey on clustering routing protocols in wireless sensor networks," Sensor Review, vol. 37, no. 1, pp. 12–25, Jan. 2017, doi: https://doi.org/10.1108/sr-06-2016-0104
[19] T. Mahmood et al., "An intelligent fault detection approach based on reinforcement learning system in wireless sensor network," The Journal of Supercomputing, vol. 78, no. 3, pp. 3646–3675, Aug. 2021, doi: https://doi.org/10.1007/s11227-021-04001-1
[20] Mr. S. Pragadeswaran, Ms. S. Madhumitha, and Dr. S. Gopinath, "Certain Investigations on Military Applications of Wireless Sensor Networks," International Journal of Advanced Research in Science, Communication and Technology, pp. 14–19, Mar. 2021, doi: https://doi.org/10.48175/ijarsct-819

[21] S. M. Kamruzzaman, X. Fernando, and M. Jaseemuddin, “Energy harvesting wireless sensors for smart cities,” 2017 IEEE Canada International Humanitarian Technology Conference (IHTC), pp. 218–222, Jul. 2017, doi: https://doi.org/10.1109/IHTC.2017.8058192
[22] S. Pragadeswaran, N. Suma, S. Madhumitha, and S. Gopinath, “Fuzzy based Fault Tolerant Routing Protocol for Node Reliability in MANET,” vol. 25, pp. 7223–7232, 2021.
[23] J. Zhang, P. Hu, F. Xie, J. Long, and A. He, “An Energy Efficient and Reliable In-Network Data Aggregation Scheme for WSN,” IEEE Access, vol. 6, pp. 71857–71870, 2018, doi: https://doi.org/10.1109/access.2018.2882210
[24] M. Dong, K. Ota, M. Lin, Z. Tang, S. Du, and H. Zhu, “UAV-assisted data gathering in wireless sensor networks,” The Journal of Supercomputing, vol. 70, no. 3, pp. 1142–1155, Apr. 2014, doi: https://doi.org/10.1007/s11227-014-1161-6
[25] R. Haji, A. Hasbi, M. Ghallali, and B. El Ouahidi, “Towards an adaptive QoS-oriented and secure framework for wireless sensor networks in emergency situations,” 2012 International Conference on Multimedia Computing and Systems, pp. 1007–1011, May 2012, doi: https://doi.org/10.1109/icmcs.2012.6320108
[26] S. Gopinath, N. Sureshkumar, S. Pragadeswaran, and S. Madhumitha, “Certain investigation on energy maximization in WSN using dynamic data availability method,” AIP conference proceedings, vol. 3266, pp. 020023–020023, Jan. 2025, doi: https://doi.org/10.1063/5.0263913
[27] Savita Lonare and Gayatri Wahane, “A survey on energy efficient routing protocols in wireless sensor network,” 2013 Fourth International Conference on Computing, Communications and Networking Technologies (ICCCNT), pp. 1–5, Jul. 2013, doi: https://doi.org/10.1109/icccnt.2013.6726591
[28] V. Tirth, A. H. Alghtani, and A. Algahtani, “Artificial intelligence enabled energy aware clustering technique for sustainable wireless communication systems,” Sustainable Energy Technologies and Assessments, vol. 56, p. 103028, Mar. 2023, doi: https://doi.org/10.1016/j.seta.2023.103028
[29] S. Pragadeswaran, S. Gayathri, S. Gopinath, and R. Felshiya Rajakumari, "Wireless Sensor Networks Security Issues, Security Needs and Different Types of Attacks Based on Layers: A Survey," Int. J. Adv. Eng. Sci. Inf. Technol., vol. 5, no. 5, pp. 60–67, May 2021.
[30] G. G. Gebremariam, J. Panda, and S. Indu, “Blockchain-Based Secure Localization against Malicious Nodes in IoT-Based Wireless Sensor Networks Using Federated Learning,” Wireless Communications and Mobile Computing, vol. 2023, pp. 1–27, Jan. 2023, doi: https://doi.org/10.1155/2023/8068038
[31] D. Srinivasan, A. Kiran, S. Parameswari, and J. Vellaichamy, “Energy efficient hierarchical clustering based dynamic data fusion algorithm for wireless sensor networks in smart agriculture,” Scientific Reports, vol. 15, no. 1, Feb. 2025, doi: https://doi.org/10.1038/s41598-024-85076-7
[32] S. Pragadeswaran et al., “Energy Efficient Routing Protocol for Security Analysis Scheme using Homomorphic Encryption,” Archives for Technical Sciences, vol. 31, no. 2, pp. 148–158, Oct. 2024, doi: https://doi.org/10.70102/afts.2024.1631.148
[33] H. Li, K. Li, W. Qu, and I. Stojmenovic, “Secure and energy-efficient data aggregation with malicious aggregator identification in wireless sensor networks,” Future Generation Computer Systems, vol. 37, pp. 108–116, Jul. 2014, doi: https://doi.org/10.1016/j.future.2013.12.021
[34] Dr. S. Gopinath and S. Pragadeswaran, "Reliable Energy Aware Multi-Hop Routing for WSN," Industrial People Management, vol. 4, pp. 25–32.
[35] D. He, S. Chan, and S. Tang, “A Novel and Lightweight System to Secure Wireless Medical Sensor Networks,” IEEE Journal of Biomedical and Health Informatics, vol. 18, no. 1, pp. 316–326, Jan. 2014, doi: https://doi.org/10.1109/JBHI.2013.2268897
[36] S. Pragadeswaran and M. Kamalanathan, “Disguised Characteristic Randomness From Routing Data In Mesh,” International Journal of Engineering Research & Technology, 2018.



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