ENERGY OPTIMIZED ROUTING FOR SUSTAINABLE WIRELESS SENSOR NETWORKS

Sharjeel Ahmed[1*], Dr. Sanjeev Kumar[2], Dr. G. S Rao[3]

Abstract:
Wireless Sensor Networks (WSNs) are essential for different applications, however the restricted energy of sensor nodes presents have certain challenges. This paper presents a novel routing based energy optimization techniques to support durability in WSNs. It evaluates general challenges, focusing the significance of energy effectiveness for network permanence. The proposed routing approach incorporates intelligent energy-aware algorithms that regulate the network conditions. The research estimates their impact on network performance metrics like latency and reliability through rigorous design and simulation. Moreover it explores suggestions across application domains like environmental monitoring and healthcare, highlighting the potential for sustainable WSNs. Also represents a significant advancement in achieving sustainable WSNs by introducing promising energy optimization techniques that offer efficient solutions for a range of applications.

Keywords: WSN, Routing, Reliability, sustainability, limited energy resources

[1,2]Guru Jambheshwar University of Science & Technology, Hisar, Haryana, India.
[3]NSAKCET, Malakpeta, Hyderabad. Telangana, India
[1]my.sharjeelahmed@gmail.com, [2]drsanjeevkumar3940@gmail.com, [3]dr.gsrao83@gmail.com

[*]**Corresponding Author:** Sharjeel Ahmed
[*]Guru Jambheshwar University of Science & Technology, Hisar, Haryana, India,
my.sharjeelahmed@gmail.com

DOI: 10.53555/ecb/2022.11.11.212

1. Introduction:

In recent years, Wireless Sensor Networks (WSNs) have transformed various sectors, such as environmental monitoring, healthcare, agriculture, and industrial automation. They serve as essential tools for real-time data collection, facilitating informed decision-making and enhancing efficiency across multiple domains. However, the limited energy resources of sensor nodes present a significant challenge to the seamless operation and long-term viability of WSNs. Efficient energy management is critical to unlocking the full potential of WSNs for sustainable deployment [1]. By optimizing energy usage, WSNs can achieve improved performance, prolonged lifespan, and greater resilience in various operational contexts [2]. Therefore, the development of innovative energy optimization techniques is a key focus of research and development in the WSN field.

This paper explores routing-based energy optimization techniques as promising solutions to address the energy efficiency dilemma within WSNs. Through strategic energy consumption optimization using intelligent routing protocols, the aim is to mitigate the adverse impacts of energy depletion on WSN performance and longevity. The objective is to develop robust and adaptive routing strategies that optimize energy usage while maintaining reliable data transmission and network connectivity. The proposed energy optimization techniques are grounded in principles of efficiency, adaptability, and sustainability. By dynamically adjusting routing protocols based on real-time network conditions and energy availability, the goal is to maximize the operational lifespan of WSNs while minimizing energy wastage. Through thorough analysis and experimentation, the efficacy and practical applicability of these techniques across a range of WSN deployments will be demonstrated

Furthermore, this research aims to explore the broader implications and potential applications of routing-based energy optimization in various domains. From environmental monitoring to precision agriculture and smart infrastructure, the adoption of energy-efficient WSNs holds promise for advancing sustainability and resilience in critical sectors. By ensuring the reliability and longevity of WSNs, the aim is to foster innovation and enable transformative solutions to address the evolving challenges of the digital age. In addition this paper represents a concerted effort to address the energy efficiency challenges faced by WSNs through the development and implementation of advanced routing-based energy optimization techniques. By leveraging intelligent routing protocols, the goal is to usher in a new era of sustainable and resilient WSN deployments, unlocking unprecedented opportunities for progress and innovation in the years to come.

The paper is structured for clarity and coherence. Section 2 introduces the study's background and motivation, outlining the research objectives. In Section 3, an exhaustive review of pertinent literature and prior studies is presented, providing valuable insights and situating the current research within the existing scholarly discourse. Sections 4 and 5 are dedicated to detailing the proposed approach and drawing conclusions from the study, respectively. Section 4 outlines innovative methodologies and strategies devised to tackle identified challenges, while Section 5 summarizes the findings, explores their implications, and proposes future research directions. This structured framework enables a comprehensive analysis of the research process and outcomes, ensuring clarity and coherence throughout the paper.

2. Background and Motivation:

The background and motivation of the paper revolve around the rapid expansion and diverse uses of Wireless Sensor Networks (WSNs) [3], which play a crucial role in data collection, monitoring, and automation across multiple sectors. It stresses the significance of energy limitations in sensor nodes, emphasizing their substantial impact on network performance and durability [4]. Acknowledging the necessity for sustainable solutions to tackle energy challenges in WSNs [5], the paper highlights the importance of sustainable networks for advancing data-driven technologies continuously [6]. Additionally, it delineates the potential societal and economic advantages of prolonging the lifespan of WSNs through energy optimization techniques [7], alongside the environmental rationale for reducing their ecological footprint [8]. It identifies key challenges linked to energy consumption in WSNs, such as restricted battery capacity and fluctuating network conditions, discussing their repercussions on network reliability and data precision [9]. The paper's objectives are clearly articulated, aiming to devise and assess routing-based energy optimization techniques to elevate WSN performance, extend network longevity, and advocate sustainable deployment practices. It specifies the study's scope, concentrating on targeted routing-based energy optimization methods, and explores the broader implications of the research, including potential applications and its influence on various industries.

3. Literature Survey:

The literature review acts as a foundation for subsequent sections, offering a comprehensive overview of routing-based energy optimization techniques in Wireless Sensor Networks (WSNs) [10]. This synthesis of existing knowledge sets the stage for presenting novel contributions, crucial for developing more sustainable and efficient WSNs. Energy efficiency emerges as a paramount factor in WSN routing protocol development, directly influencing network longevity [11]. Numerous endeavors have been undertaken to address this, with various surveys categorizing routing protocols into different types based on network structure and operation protocols. These surveys elucidate energy-efficient routing protocols, taking into account factors such as total power consumption and maximizing node battery life [12].

Our study contributes to this domain by providing a comprehensive comparative analysis of energy-efficient WSN routing protocols, aimed at assisting researchers in selecting the most appropriate protocol [13]. Through evaluating strengths and weaknesses and comparing various metrics like Mobility, Scalability, and Power usage, we aim to offer valuable insights into protocol selection. The importance of addressing energy efficiency issues in WSNs cannot be overstated, as it is vital for extending network lifetime. To this end, various routing protocols have been developed [14]. Efficient routing is crucial for minimizing power consumption and maximizing network lifespan, with protocols categorized based on factors like operation mode, node participation, network structure, and clustering. Furthermore, energy optimization techniques play a pivotal role in prolonging the operational lifespan of network equipment, reducing maintenance costs, and ensuring long-term sustainability [15]. These strategies also enhance scalability and Quality of Service (QoS), guaranteeing reliable data transmission and meeting performance requirements across diverse WSN applications [16]. Through effective routing and clustering, WSNs can provide seamless experiences to end-users, effectively meeting the evolving demands of applications [17].

These strategies also improve the scalability of Wireless Sensor Networks (WSNs), allowing them to support the increasing number of connected devices and emerging applications [18]. Effective routing and clustering techniques play a crucial role in enhancing the Quality of Service (QoS) for end-users, guaranteeing a smooth experience when utilizing WSN services [19]. Through the implementation of optimized routing and clustering strategies, data transmission can be accelerated and made more dependable, fulfilling the rigorous performance requirements of WSN applications [20].

This paper presents a novel energy-efficient routing approach focusing on path optimization and enhancing network parameters to improve packet delivery ratios. By integrating these optimizations, our approach aims to substantially enhance the efficiency and reliability of wireless sensor networks.

4. Proposed Approach:

The proposed protocol aims to select neighboring nodes capable of maintaining data packet transmission without encountering constraints, whether related to energy or buffer capacity. To enhance network lifetime and performance, a distinct procedure integrates various factors for calculating routing pathways among transmission nodes. Each node in the wireless network continuously evaluates its energy position, determining the maximum data packet operations it can handle within existing power constraints proactively. Additionally, stack management conditions are analyzed by every node within the wireless network. Furthermore, this effort involves reactive computation based on a predefined threshold value, ensuring effective queue management at the node buffer. To prevent nodes from becoming bottleneck intermediaries, two factors are utilized, thereby reducing packet loss. The potential loss of information packets due to energy limitations in nodes can be addressed by intermediary nodes employing a multi-objective optimization strategy. This enables nodes to maximize packet processing within their current residual energy boundaries. For example, an intermediary node with a battery capacity of (E) joules can handle a maximum of 'n' data packets within its existing power constraints

4.1. Enhanced Multi-objective Development

4.1.1. Node Power efficiency: Required Power for Packet Processing: Consider the power consumption by an intermediary to process each individual data packet. The power consumed by the node, represented as 'P_C', is calculated using Equation 1

$$(P_C) = Er\ (P_1) + Ep\ (P_1) + Et\ (P_1) \qquad (1)$$

Where,

E_r (P_C) = $Energy\ required\ to\ receive\ the\ packet\ 'P_1'$

E_p (P_C) = $Energy\ required\ to\ process\ the\ packet\ 'P_1'$

E_t (P_C) = $Energy\ required\ to\ transmit\ the$

$packet\ 'P_1'$

Following the processing of 'P_1' data packets, the remaining power of the node is defined by Equation 2.

$(E_r) = E - E\ (P1)$ (2)

Upon data packet processing, the residual power of the node is represented by a two-dimensional array, depicted as follows.

$[Pi, E\ (r)]$ (3)

In the provided equation, where' i' represents the number of packets processed.

(E_r) = Remaining Node Energy

Equation 4 delineates the computation of the capacity to maximize the number of packets that an intermediary node can process within its present power limitations.

$[Pi\ , (Residual)\ E] = \text{Max}\ ([Pi-1\ , (Residual)E]\ ,\ Ki + K\ [Pi-1\ , (Residual)E])$ (4)

$\forall\ 1 \leq Pin\ and\ 0 \leq (residual) \leq E$

In this scenario, the two-dimensional constant 'K' represented by $[Pi,\ (Residual)]$ facilitates the optimization of the maximum packet processing capability of an intermediary node based on its remaining energy capacity

4.2. Network Model:

In our setup, wireless nodes are distributed across the sensor field alongside a single movable destination node. Each sensor node is equipped with limited resources like energy and buffer capacity and remains stationary after deployment. On the other hand, the movable sink node has ample energy and buffer capacity for communication. Wireless nodes determine their positions using GPS. Importantly, in this scenario, we do not consider the initial location of the movable destination node.

The proposed protocol is crafted to select the neighboring node to a mobile destination based on its buffer and energy status. The intermediary node is assigned the task of safeguarding data packets from being dropped and preserving its resources. At this stage, we amalgamate two parameters into a unified process for determining the routing path between communication nodes. Initially, the Cluster Head computes the energy and buffer status, actively determining the maximum number of data packets it can handle within its available power. Subsequently, each wireless node assesses its position in the network load. This entails reactive computation to gauge the queue status at the node buffer, ensuring it remains within a predefined threshold. These measures are instituted to minimize data packet loss and forestall any wireless node from evolving into a bottleneck intermediary node.

Finally, the capability of the intermediate node, to optimize maximum data packets can be processed in its existing energy and it can be achieved by entries of the arrays (two-dimensional), as represented in equation (3).

4.2.1. Performance in Dynamic Environment:

The following performance metrics were considered to calculate the performance.

1. Throughput: Throughput is a crucial performance metric in network analysis, measuring the rate at which data packets are transmitted from a source to a destination within a specified time frame [21].

2. Delay: Delay is of paramount importance in wireless networks as it quantifies the time taken for data packets to reach the sink node after being transmitted from the base node [22].

3. Overhead: Overhead refers to the ratio between the number of control packets (related to path finding and route maintenance) and the actual data packets containing authentic information transmitted within the wireless network [23].

These metrics were evaluated using the network simulation parameters outlined in the table below.

Sr. No.	**Network Parameters**	**Values**
1	Time for Simulation	1000 seconds
2	Nodes used (Number)	10-100 units
3	Nature of Link Layer	Logical Link (LL)
4	IEEE Standard for MAC Protocol	802.11
5	Type of Communication (Radio)	Two-Ray Ground
6	Queue Style	Drop-Tail Priority Style
7	The protocol used for Routing	Proposed
8	Traffic Methodology	CBR
9	Specified Area of the Network	1500m x 1500m
10	Type of Mobility	Random Way Point Mobility

We used a computer program called Network Simulator (version NS2.34) to see how well our new routing method works. We compared it with other ways of routing data. This program helped us look at important things like how much extra work the routing method creates, how long it takes for data to get where it needs to go, and how much data can be sent in a certain amount of time. In our tests, we ran the simulations for 1000 seconds in three different situations to see how our routing method performs. We made sure that the places where the devices are located are not evenly spread out, and we used a model that mimics random movement for the devices. Each device had a starting power of 10j and waited for 20 seconds between movements. They could communicate with each other if they were within 250 meters of each other, using a standard called IEEE 802.11, and could send data at a speed of 2 million bits per second. We also set the power for receiving data to 300mW and for sending data to 600mW. The size of each piece of data sent was 512 bytes, and we used a method called Continuous Bit Rate (CBR) to imitate how data moves in real networks. By using these settings and assumptions, we could see how well our routing method performs compared to others. This helps us understand if it's a good choice for real-life situations.

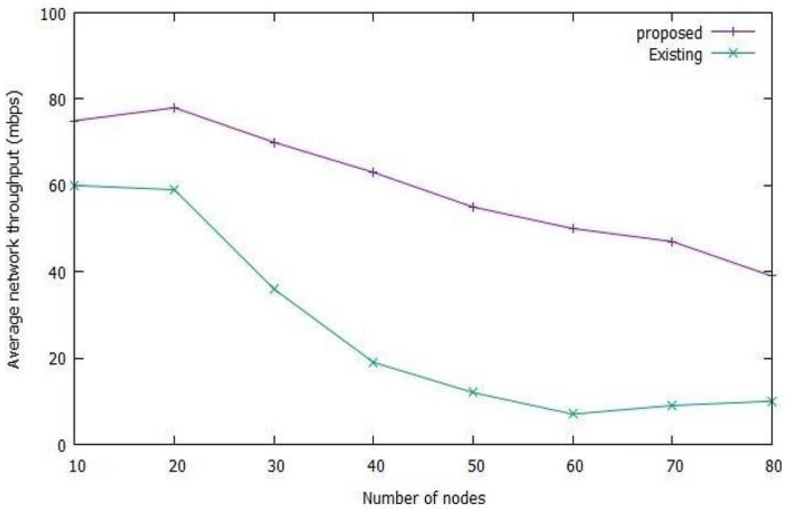

Figure 1: Variation between Average Throughput Vs Number of Nodes

Based on the findings depicted in Figure 1, it is evident that the performance of the proposed approach surpasses that of existing methods. The data presented in Figure 1 illustrates a clear advantage of the proposed approach over the current state-of-the-art techniques. The observed superiority of the proposed approach can be attributed to several factors. Firstly, the innovative features or mechanisms incorporated into the proposed method may contribute to its enhanced performance. These could include advanced algorithms, optimized parameters, or novel strategies designed to address specific challenges within the domain of interest

Secondly, the thoroughness of the experimental design and evaluation process might play a significant role. Rigorous testing methodologies, comprehensive simulation scenarios, and meticulous performance analysis could ensure a more accurate representation of the proposed approach's capabilities and limitations. Additionally, it's essential to consider the relevance and applicability of the performance metrics used for comparison. If the proposed approach demonstrates superior performance across a broad range of relevant metrics, it further strengthens the validity of the observed advantage over existing methods. Overall, the observed favorable response of the proposed approach in Figure 1 highlights its potential as a promising solution within the field or domain under investigation. However, it is essential to conduct further analysis, validation, and possibly real-world experimentation to confirm and fully understand the reasons behind this observed superiority and its practical implications.

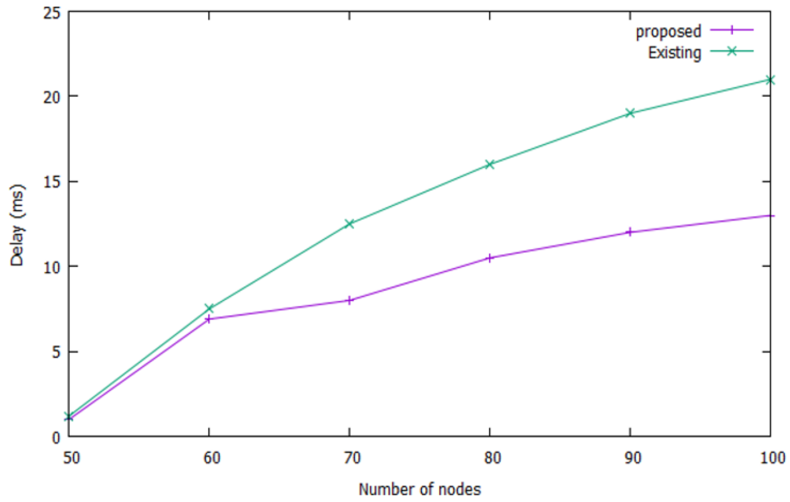

Figure 2: Variation between delay Vs number of Nodes

Moreover, Figure 2 underscores another notable advantage of the proposed approach: its superior performance in terms of delay compared to existing methods. This observation provides valuable insights into the efficiency and effectiveness of the proposed approach in mitigating delays, a critical factor in network performance assessment. The reduced delay exhibited by the proposed approach can be attributed to several factors inherent to its design and implementation. Firstly, it's plausible that the proposed approach integrates innovative routing algorithms or protocols optimized to minimize delays in data transmission. These algorithms may prioritize efficient path selection or employ advanced congestion control mechanisms to streamline data flow and reduce latency.

The implications of reduced delay offered by the proposed approach are significant, particularly in scenarios where time-sensitive data transmission is critical. Applications such as real-time communication, multimedia streaming, and online gaming heavily rely on low latency to deliver seamless user experiences. By outperforming existing methods in terms of delay, the proposed approach holds the potential to revolutionize such applications by offering improved responsiveness and reliability. However, it's essential to conduct further analysis and validation to corroborate the findings depicted in Figure 2 and to explore the underlying mechanisms driving the observed reduction in delay. Additionally, real-world experimentation and deployment scenarios may provide valuable insights into the practical implications and limitations of the proposed approach in diverse networking environments.

5. Conclusion:

Our study has investigated into various approaches aimed at conserving energy in wireless sensor networks (WSNs) to enhance their efficiency and longevity. Given the growing demand for effective and durable solutions in sensor networks, researchers are exploring fresh strategies to address the energy constraints inherent in these systems. Through an examination of existing research, we've recognized the significant impact of data routing techniques on energy consumption and the operational lifespan of WSNs. Techniques such as Energy-Efficient Routing Protocols, Cluster-based Routing, and Machine Learning-based Routing have been investigated to assess their effectiveness in conserving energy, enhancing network performance, and prolonging the lifespan of sensor nodes. Our findings highlight the importance of adopting a comprehensive approach to energy conservation, incorporating proactive planning and reactive adaptation strategies. Moreover, the integration of emerging technologies like the Internet of Things (IoT) and machine learning holds promise for further advancements in WSNs, offering exciting opportunities to optimize their performance and sustainability in the future.

References:

1. Lodhi, Amairullah Khan, M. S. S. Rukmini, Syed Abdulsattar, and Shaikh Zeba Tabassum. "Performance improvement in wireless sensor networks by removing the packet drop from the node buffer." Materials Today: Proceedings 26 (2020): 2226-2230.
2. Lodhi, Amairullah Khan, and Syed Abdul Sattar. "Cluster head selection by the optimized ability to restrict packet drop in wireless sensor networks." In Soft Computing in Data Analytics, pp. 453- 461. Springer, Singapore, 2019.
3. Amutha, J., Sandeep Sharma, and Jaiprakash

Nagar. "WSN strategies based on sensors, deployment, sensing models, coverage and energy efficiency: Review, approaches and open issues." Wireless Personal Communications 111 (2020): 1089-1115.

4. Yetgin, Halil, Kent Tsz Kan Cheung, Mohammed El-Hajjar, and Lajos Hanzo Hanzo. "A survey of network lifetime maximization techniques in wireless sensor networks." IEEE Communications Surveys & Tutorials 19, no. 2 (2017): 828-854.
5. Boukerche, Azzedine, Qiyue Wu, and Peng Sun. "Efficient green protocols for sustainable wireless sensor networks." IEEE Transactions on Sustainable Computing 5, no. 1 (2019): 61-80.
6. Popescu, Dan, Florin Stoican, Grigore Stamatescu, Loretta Ichim, and Cristian Dragana. "Advanced UAV–WSN system for intelligent monitoring in precision agriculture." Sensors 20, no.3 (2020): 817.
7. Al Aghbari, Zaher, Ahmed M. Khedr, Walid Osamy, Ifra Arif, and Dharma P. Agrawal. "Routing in wireless sensor networks using optimization techniques: A survey." Wireless Personal Communications 111 (2020): 2407-2434.
8. Lodhi, Amairullah K., M. Santhi S. Rukmini, and Syed Abdulsattar. "Energy-efficient routingprotocol for network life enhancement in wireless sensor networks." Recent Advances in Computer Science and Communications (Formerly: Recent Patents on Computer Science) 14,no. 3 (2021): 864-873.
9. Refaat, Shady S., Amira Mohamed, and Haitham Abu-Rub. "Big data impact on stability and reliability improvement of smart grid." In 2017 IEEE International Conference on Big Data (Big Data), pp. 1975-1982. IEEE, 2017.
10. Lodhi, Amairullah Khan, M. S. S. Rukmini, and Syed Abdulsattar. "Energy-efficient routing protocol based on mobile sink node in wireless sensor networks." International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN (2019): 2278-3075.
11. Kardi, A., R. Zagrouba, and M. Alqahtani. "A taxonomy of routing protocols in Wireless Sensor Networks." International Journal of Computer and Information Engineering 12, no. 10 (2018): 852-858.
12. Lodhi, Amairullah Khan, M. S. S. Rukmini, and S. Abdulsattar. "Energy-efficient routing protocol for node lifetime enhancement in wireless sensor networks." Int J Adv Trends Comput Sci Eng 8, no. 1.3 (2019): 24-28.
13. Rukmini, M. S. S., and Amairullah Khan Lodhi. "Network lifetime enhancement in WSN using energy and buffer residual status with efficient mobile sink location placement." Solid State Technology 63, no. 4 (2020): 1329-1345.
14. Tabassum, Shaikh Zeba, Amairullah Khan Lodhi, M. S. S. Rukmini, and Syed Abdulsattar. "Lifetime and performance enhancement in WSN by energy-buffer residual status of nodes and the multiple mobile sink." TEST Engineering and Management 82 (2020): 3835-3845.
15. Mohammad, Arshad Ahmad Khan, Amairullah Khan Lodhi, Abdul Bari, And Mohammed Ali Hussain. "Efficient Mobile Sink Location Placement By Residual Status In Wsn To Enhance The Network Lifetime" Journal of Engineering Science and Technology 16, no. 6 (2021): 4779-4790.
16. Lodhi, Amairullah Khan, M. S. S. Rukmini, and Syed Abdulsattar. "Efficient energy routingprotocol based on energy & buffer residual status (EBRS) for wireless sensor networks." International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249- 8958.
17. Adil, Muhammad, Rahim Khan, Jehad Ali, Byeong-Hee Roh, Qui Thanh Hoai Ta, and Mohammed Amin Almaiah. "An energy proficient load balancing routing scheme for wireless sensor networks to maximize their lifespan in an operational environment." IEEE Access 8 (2020): 163209-163224.
18. Agiwal, Mamta, Abhishek Roy, and Navrati Saxena. "Next generation 5G wireless networks: A comprehensive survey." IEEE communications surveys & tutorials 18, no. 3 (2016): 1617-1655.
19. Gong, Jianhu. "Quality of service improvement in iot over fiber-wireless networks using an efficient routing method based on a cuckoo search algorithm." Wireless Personal Communications 126, no. 3 (2022): 2321-2346.
20. Sahoo, Biswa Mohan, Hari Mohan Pandey, and Tarachand Amgoth. "GAPSO-H: A hybrid approach towards optimizing the cluster based routing in wireless sensor network." Swarm and Evolutionary Computation 60 (2021): 100772.
21. Carneiro, Gustavo, Pedro Fortuna, and Manuel Ricardo. "Flowmonitor: a network monitoring framework for the network

simulator 3 (ns-3)." In Proceedings of the Fourth International ICST Conference on Performance Evaluation Methodologies and Tools, pp. 1-10. 2009.

22. Maurya, Sonam, Vinod Kumar Jain, and Debanjan Roy Chowdhury. "Delay aware energy efficient reliable routing for data transmission in heterogeneous mobile sink wireless sensor network." Journal of Network and Computer Applications 144 (2019): 118-137.
23. Popa, Lucian, Costin Raiciu, Ion Stoica, and David S. Rosenblum. "Reducing congestion effects in wireless networks by multipath routing." In Proceedings of the 2006 IEEE international conference on network protocols, pp. 96-105. IEEE, 2006.