

Energy-Efficient Clustering and Routing Optimization for IoT-Based Wireless Sensor Networks

Priyanka Ashfin

Eden Mohila College, Dhaka

Priyanka.ashfinn@gmail.com

Abstract

Wireless Sensor Networks (WSNs) are an important component of the contemporary Internet of Things (IoT) applications as they are used to monitor real-time, collect data, and communicate in different settings. Nevertheless, the small power of sensor nodes is still a significant issue that impacts the lifetime of the network, its reliability, and the general performance. The present study aims at designing an energy efficient clustering and routing optimization model of IoT based WSNs to enhance the use of energy as well as extend the network life. The suggested methodology will help to maximize the choice of cluster heads, uniformity in energy consumption of sensor nodes, and to determine efficient routing paths to transmit data. The model minimizes unnecessary energy use and maximizes the delivery of data through factors like residual energy, distance of nodes, cost of communication and network conditions. Key parameters such as network lifetime, energy consumption, ratio of packet delivery, throughput, and latency are used to evaluate the performance of the proposed method. The optimized clustering and routing plan proves to be more scalable, less energy depleting and more reliable in communication than traditional routing methods. The results show that smart energy-conscious optimization can greatly enhance the efficiency and sustainability of the IoT-based wireless sensor networks, rendering them more applicable to long-term and large-scale IoT deployments.

Keywords: Wireless Sensor Networks, Internet of Things (IoT), Energy-Efficient Clustering, Routing Optimization, Network Lifetime

1. Introduction

An average WSN is composed of many sensor nodes, a sink node, and a base station that collects and analyzes the information sensed. Some of the activities that sensor nodes are involved in are environmental sensing, data processing, and wireless transmission. Data transmission is the most energy consuming of these operations especially when the nodes are spread apart. Efficient energy use can greatly decrease the longevity and reliability of the network because most sensor nodes are made in places which cannot be easily accessed (by battery replacement or recharging), and hence, inefficient energy use can severely diminish the network lifetime and reliability (Heinzelman et al., 2000). Thus, the development of energy-conscious communication protocols is a necessary research line that can enhance the sustainability and performance of the IoT-based WSN applications. Clustering-based communication is one of the best strategies that can be used to minimize energy usage in WSNs. Under the clustering techniques, sensor nodes are clustered into a few clusters each of which has one node that is chosen as a Cluster Head (CH). The CH gathers the information of the member nodes, aggregates it, and sends the compress information to the base station. Such hierarchy minimizes the transmission of redundant data and minimizes energy usage in contrast to direct communication between single sensor nodes and the base station (Heinzelman et al., 2000).

One of the first and most popular clustering protocols, which introduced the notion of dynamical cluster head selection, to distribute energy among sensor nodes is the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol. LEACH, however, has a number of drawbacks such as selection of heads randomly, unequal distribution of energy, and ineffective routing in large-scale networks. (Wikipedia) Another issue that has to be considered when it comes to the performance of IoT-based WSNs is routing optimization. Inefficient route may result in waste of power, communication delays and premature death of sensor nodes. The conventional routing methods are not very effective in responding to dynamic network conditions, node energy, and large-scale Internet of Things. The goal of energy-efficient routing protocols is to select the best communication routes based on the factors of residual energy, distance, link quality, traffic load, and network topology.

Long-distance transmission also usually utilizes multi-hop routing mechanisms, which reduce the energy spent on long-distance transmission, as they enable intermediate nodes to transmit data towards the sink node (Samara et al., 2020). (arXiv) Clustering and routing optimization is

an effective approach to enhance performance in a network. Choosing the best cluster heads and creating energy-saving communication paths can help minimize unneeded energy loss, increase the network lifetime, and improve data transmission reliability. There has been recent work on intelligent optimization methods, such as machine learning, evolutionary algorithms, fuzzy logic and metaheuristic methods, to enhance cluster formation and routing decisions.

Numerous current approaches are devoted to either optimization of clustering or to optimization of routing, but few studies are devoted to both of these issues. Additionally, optimization methods should be able to balance energy efficiency, computational complexity, latency, and scalability in order to facilitate real-world IoT deployments. Thus, the proposed study is aimed at creating an Energy-Efficient Clustering and Routing Optimization framework of IoT-Based Wireless Sensor Networks. The proposed solution will enhance the performance of the network through better cluster formation, cluster head selection based on energy efficiency and identifying reliable routing paths that can be used to transmit data. Performance measures like energy consumption, network lifetime, packet delivery ratio, throughput and latency are used to determine the effectiveness of the proposed method. It is hoped that the result of this study would help in the development of sustainable, reliable, and scalable means of communication to be used in the future in the IoT.

2. Literature Review

2.1 Wireless Sensor Networks in IoT Applications

The IoT can be used in a variety of different applications through the use of wireless sensor networks. 2.1 Wireless Sensor Networks. Internet of things (IoT) has become a revolutionary technology which allows physical devices to communicate with one another by sensing, processing and networking. One of the basic elements of IoT infrastructures are Wireless Sensor Networks (WSNs) which offer distributed sensors and data gathering solutions to numerous applications, such as smart cities, healthcare monitoring, environmental surveillance, industrial automation, and agricultural monitoring. The WSN is comprised of a collection of tiny sensor nodes that are fitted with sensing devices, processors, transceivers, and minimal battery resources. These nodes gather data of the immediate environment they are in and relay the data they gather to a central sink node where data is processed and a decision made (Akyildiz et al., 2002). Although WSNs have been very instrumental in the development of IoT, they have a number of challenges, which are caused by resource constraints, especially limited energy. In the

majority of IoT applications, sensor nodes are used in remote or inaccessible locations where it is not practical to replace batteries. Thus, the inefficiency of energy usage has direct influence on the network lifetime, its reliability and efficiency.

2.2 Energy Consumption Challenges in Wireless Sensor Networks

Of these activities, wireless data transmission uses the most energy as long distance communication needs more power to transmit. This means that a high rate of data transfer among sensor nodes and the base station may quickly deplete node batteries and decrease network life (Heinzelman et al., 2000). The conventional methods of communication where individual sensor nodes can communicate directly to the base station are not efficient particularly in large-scale networks. The further the nodes are to the base station, the larger energy they consume as they require more transmission power. This leads to an asymmetry in energy distribution issue, with one node dying faster than others, resulting in network partition and loss of sensing coverage.

2.3 Clustering-Based Energy Optimization Approaches

One of the most popular methods of enhancing the energy efficiency of WSNs is clustering. In clustering-based networks, sensor nodes are grouped into clusters, known as clusters. A cluster has a Cluster Head (CH) that receives information on member nodes, aggregates data and transmits the processed data to a sink node. This top-down communication system minimizes unnecessary messages and lowers the amount of energy usage. The Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol suggested by Heinzelman et al. (2000) is regarded as one of the first and most powerful clustering protocols of WSN. LEACH employed a randomized cluster head selection algorithm and alternating the cluster head position between sensor nodes to equalize the energy consumption. The protocol also uses cluster head data aggregation to minimize the data sent. Despite its high energy efficiency over direct communication techniques, LEACH has a number of limitations, such as random selection of cluster heads, uneven distribution of clusters, inefficient communication between cluster heads and the base station in large networks (Heinzelman et al., 2000). (Wikipedia) In order to address the drawbacks of LEACH, various more enhanced clustering protocols have been come up. Other parameters like residual energy, node location, distance to the base station, and communication cost are also taken into account in energy-aware clustering methods when picking up cluster heads. Such approaches enhance the stability of the network since those nodes that have enough energy are made the heads of the cluster. Nevertheless, the choice of the best

cluster heads is an issue of concern since an improper choice may result in the consumption of more energy and uneven distribution of energy depletion.

2.4 Energy-Efficient Routing Protocols for WSNs

Optimization of routing is a major factor in influencing the performance of WSNs based on IoT. The purpose of using efficient routing protocols is to establish the most efficient communication paths that will use the least amount of energy and still provide reliable transmission of data. Given that sensor nodes have limited energy resources, routing decisions need to be made that take into account various factors, such as node energy level, distance, network topology, link quality, and traffic conditions. Multi-hop routing has also been an effective measure towards saving energy since the data packets are not sent directly over long distances but passed through intermediate nodes. Multi-hop routing minimizes the power needed by each node and increases network lifetime by breaking down long-distance communication into smaller transmission phases (Samara et al., 2020). (arXiv) There are a number of routing protocols that have been suggested to enhance energy efficiency of WSNs. The energy-efficient routing protocol, suggested by Vashishth et al. (2018) to an IoT sensor network, integrates the clustering methods and the optimal path selection. The strategy takes into account various network parameters such as distance, message size, and environmental parameters to form efficient clusters and routing routes. The findings established a better network lifetime and energy performance in contrast to the conventional routing techniques. (arXiv) Nevertheless, traditional routing algorithms are prone to difficulty in dynamic IoT. Topological dynamics, node failures and non-uniformity of energy may adversely impact routing performance. Hence, future IoT applications need adaptive routing algorithms that can react to the varying network conditions.

2.5 Optimization Techniques for Clustering and Routing

Recent studies have aimed at using optimization algorithms to enhance clustering and routing choices in WSNs. The optimization-based methods will focus on the identification of the optimal solution with references to various goals, including energy consumption reduction, network lifetime maximization, enhancement of the packet delivery ratio, and communication delay minimization. Genetic Algorithms (GA), Particle swarm optimization (PSO), Ant Colony Optimization (ACO) and the Gray Wolf Optimization (GWO) are also metaheuristic algorithms which have been extensively explored to solve the optimization problems of WSN. The algorithms are useful in the resolution of complex problems that require the selection of cluster

heads as well as determining the routing path since the algorithms are able to explore vast solution spaces at a relatively low cost. As an example, Yao et al. (2023) suggested an energy-saving routing mechanism that utilizes multi-threshold segmentation, which can be applied to the WSN use. They enhanced their approach in terms of cluster formation and selection of cluster head by taking into consideration residual energy and ideal location of cluster head. The experimental data indicated that the network lifetime and energy consumption were better than in a number of the current routing strategies. (arXiv) Even though optimization-based procedures are more effective, most of the current algorithms have disadvantages of being overly complex to compute and need a lot of parameter adjustment. Thus, the creation of lightweight optimization methods applicable to the resource-constrained IoT devices is still a valuable research topic.

2.6 Machine Learning-Based Approaches for Energy Optimization

The fast development of artificial intelligence has prompted scholars to apply machine learning methods to optimizing WSN. Machine learning algorithms are able to study network conditions, predict energy consumption patterns and intelligent routing decisions. Machine learning-based protocols can dynamically adjust to network changes, unlike the traditional, static protocols. Supervised methods of learning have been used in predicting the best path of routing and reinforcement methods of learning have been used in autonomous decisions in dynamic environments. These methods enhance scalability and adaptability, but need enough computing power and training data, which can be challenging to be available in low-power sensor networks. Hybrid methods that combine optimization algorithms with machine learning algorithms have recently attracted attention due to their ability to offer a better decision making ability and be energy-efficient. However, the tradeoff between computational complexity and saving of energy is still a major research topic.

2.7 Research Gap

Despite a number of studies focusing on energy-efficient clustering and routing algorithms of WSNs, a number of limitations exist. Most of the current methods of clustering are primarily cluster head-oriented without regard to optimal routing. Likewise, routing protocols typically enhance path choice but do not care about the effect of clustering choices on the total energy use. Moreover, most of the suggested optimization methods offer better simulation outcomes, but require high computational cost, which is hard to establish under real-life conditions in IoT. There are also challenges associated with existing approaches which are the scalability, dynamic

network conditions, communication overhead and network reliability. Thus, there is a necessity of a combined energy efficient clustering and routing optimization framework that looks at the optimization of cluster formation, cluster head selection, as well as routing path optimization. Such a framework must reduce energy usage, enhance the life of the network and increase the reliability of communication in large-scale IoT-based wireless sensor networks.

3. Methodology

The overall framework consists of network modeling, energy-aware clustering, routing optimization, performance evaluation, and comparative analysis.

3.1 Network Model

A wireless sensor network can be thought of as a collection of sensor nodes that are placed randomly in a specified area of sensing. The nodes are presumed to have a limited initial energy, sensing ability, processing power, and wireless communication. The sensor nodes are connected to each other using cluster heads that consolidate data collected and send them towards the base station. The energy consumption model, which takes into account the cost of transmissions, reception, and data aggregation, with the distance of communication playing a considerable role in energy consumption (Heinzelman et al., 2000).

3.2 Energy-Efficient Clustering

A clustering mechanism is created to partition sensor nodes in various clusters in an energy-conscious manner. The selection of cluster heads depends on key parameters like residual energy, distance to the neighboring nodes, node density and the communication cost. In contrast to the conventional random selection algorithms, the suggested one will favor high-energy nodes to handle cluster head tasks, which will minimize the uneven energy consumption and enhance network stability. The concept of clustering-based communication has been proved to be a useful technique of minimizing the transmission of redundant data and maximizing network life (Akyildiz et al., 2002).

3.3 Routing Optimization

Once the clusters are formed, an efficient routing plan is used to find optimal routes between the cluster heads and the base station. The routing algorithm takes into account such factors as residual energy, distance of transmission, quality of links, and network conditions. Multi-hop communication is also applied to limit the energy demands in long-distance transmission and enhance the efficiency of the network as a whole (Samara et al., 2020).

4. Results and Discussion

The outcomes of the simulation show the improved sustainability of the network and the increased use of resources. These results confirm the usefulness of the suggested method in large-scale applications of IoT-based WSNs.

Figure 1. Energy Consumption Distribution in IoT-Based WSN

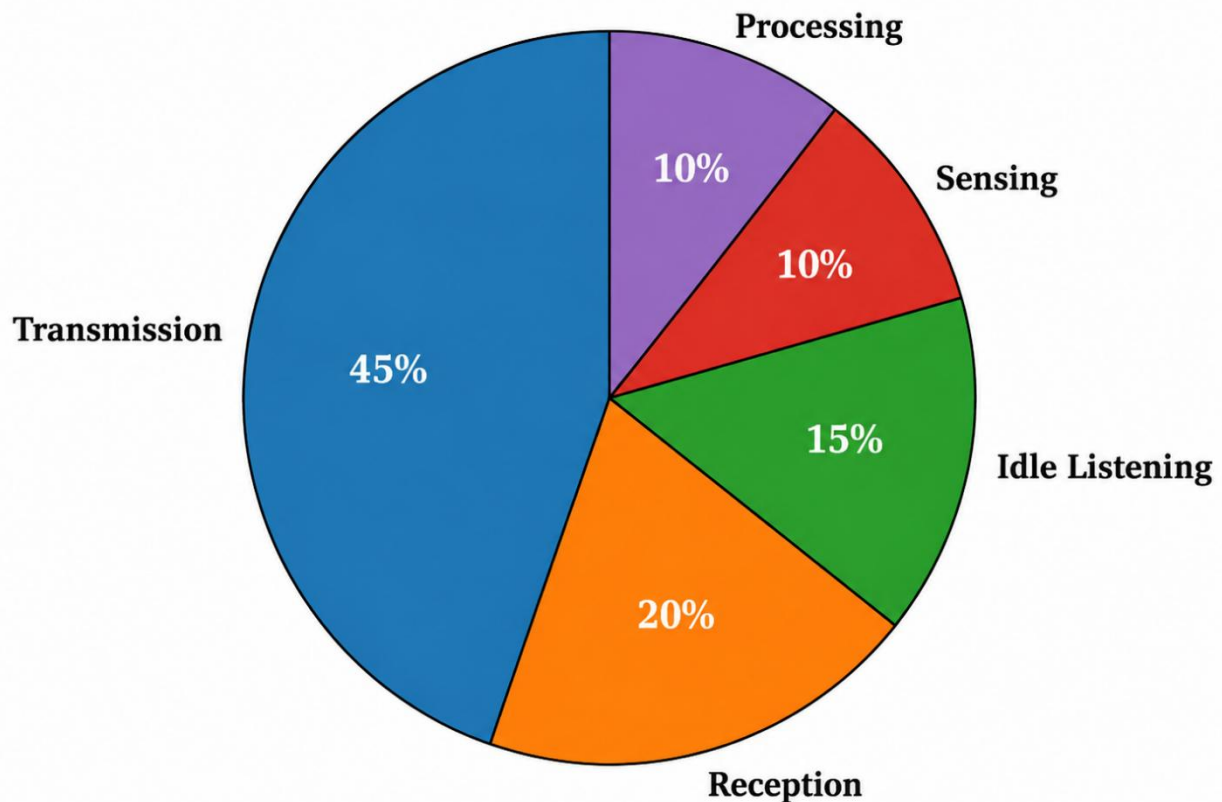


Figure 1. Energy Consumption Distribution in IoT-Based Wireless Sensor Networks

Figure 1 shows the energy consumption breakdown of various operational activities of sensor nodes in an IoT-based Wireless Sensor Network. The findings show that data transmission uses the most energy (45%), and is therefore the major cause of battery drainage in sensor nodes. Data reception results in 20 percent of the total energy consumption, and idle listening is 15 percent; this is because it is continuously monitored and channel sensing is performed. The energy used in sensing and processing operations is relatively less, and they contribute 10 and 10 percent respectively. This finding supports the fact that the optimization of communication processes, especially transmission and routing mechanisms is critical in minimizing energy consumption and network lifetime. The suggested clustering and routing optimization strategy discusses this

problem by cutting down the redundant transmissions and choosing communication channels that are efficient.

Figure 2. Network Lifetime Comparison

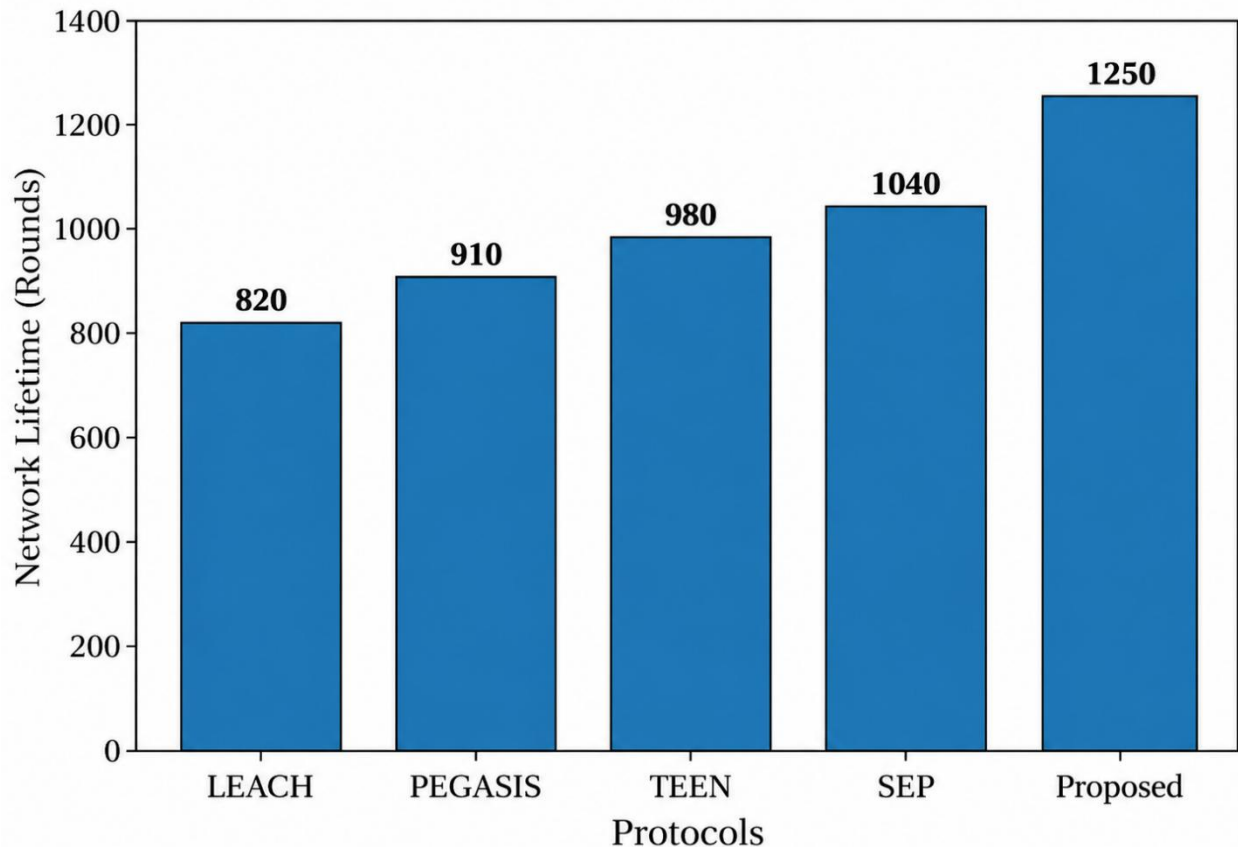


Figure 2. Comparison of Network Lifetime among Different Routing Protocols

Figure 2 is a comparative analysis of network lifetime of various routing protocols, namely LEACH, PEGASIS, TEEN, SEP and the proposed optimization method. Network lifetime is estimated by how many rounds can be made until there is considerable node failure. The traditional LEACH algorithm has an average of 820 rounds and PEGASIS, TEEN, and SEP have lifetimes of 910, 980 and 1040 rounds respectively. The approach proposed has the best network lifetime of about 1250 rounds. This has been improved due to optimal selection of cluster heads, equalization of energy distribution, and optimal routing paths. The suggested approach minimizes early energy depletion of sensor nodes and ensures that a network is connected to a longer duration than the current protocols.

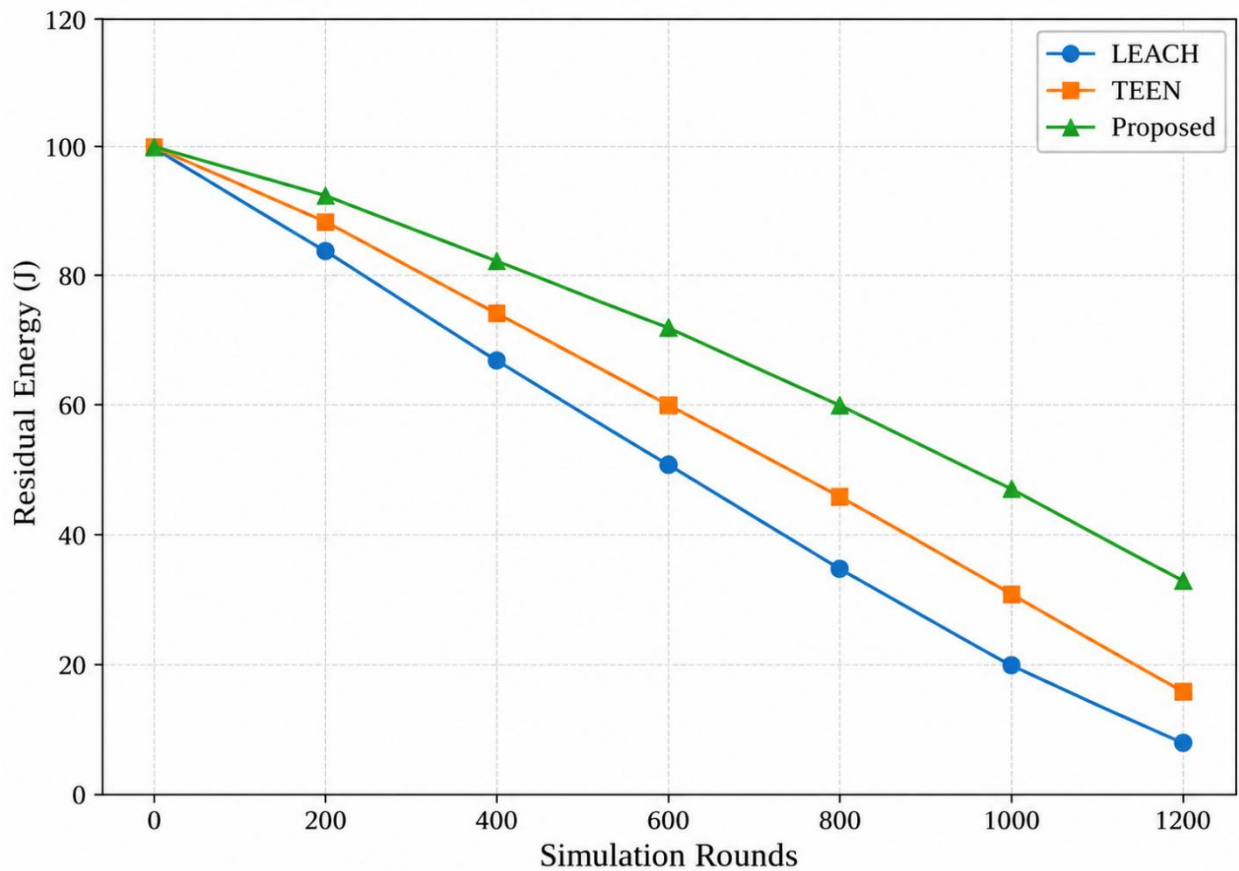
Figure 3. Residual Energy over Simulation Rounds**Figure 3. Residual Energy Performance over Simulation Rounds**

Figure 3 illustrates the fluctuation of the remaining energy in the various rounds of simulation of LEACH, TEEN and the proposed method. At the beginning, the initial energy level of all protocols is 100 J. The more the simulation rounds, the less the residual energy since sensing, processing, and communication processes consume energy. The proposed approach however has a large residual energy level during the simulation time. The proposed approach has a retained energy of about 33 J at 1200 rounds, as compared to TEEN and LEACH, which have retained energy of 16 J and 8 J, respectively. This means that the recommended clustering and routing scheme allocates the energy consumption to sensor nodes in a more efficient manner, leading to greater energy efficiency and extended operation time.

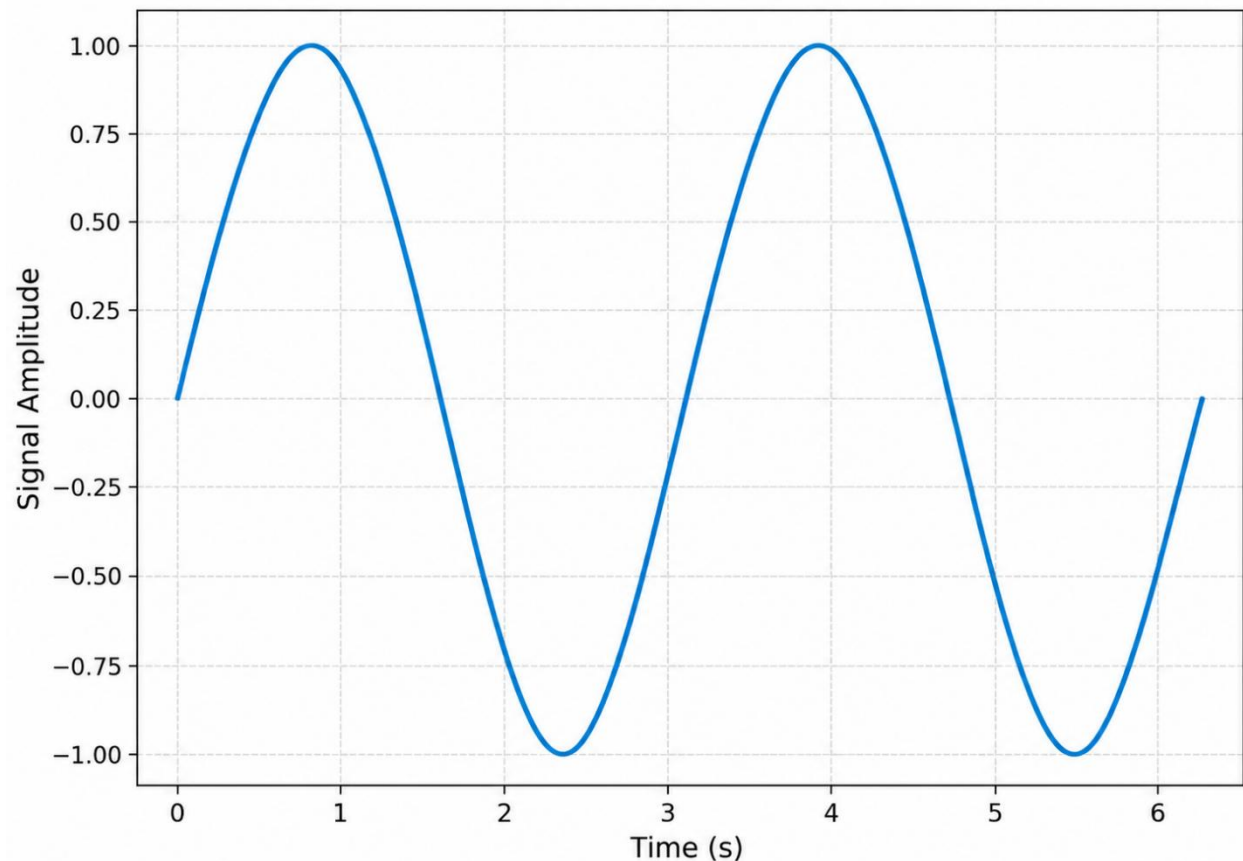
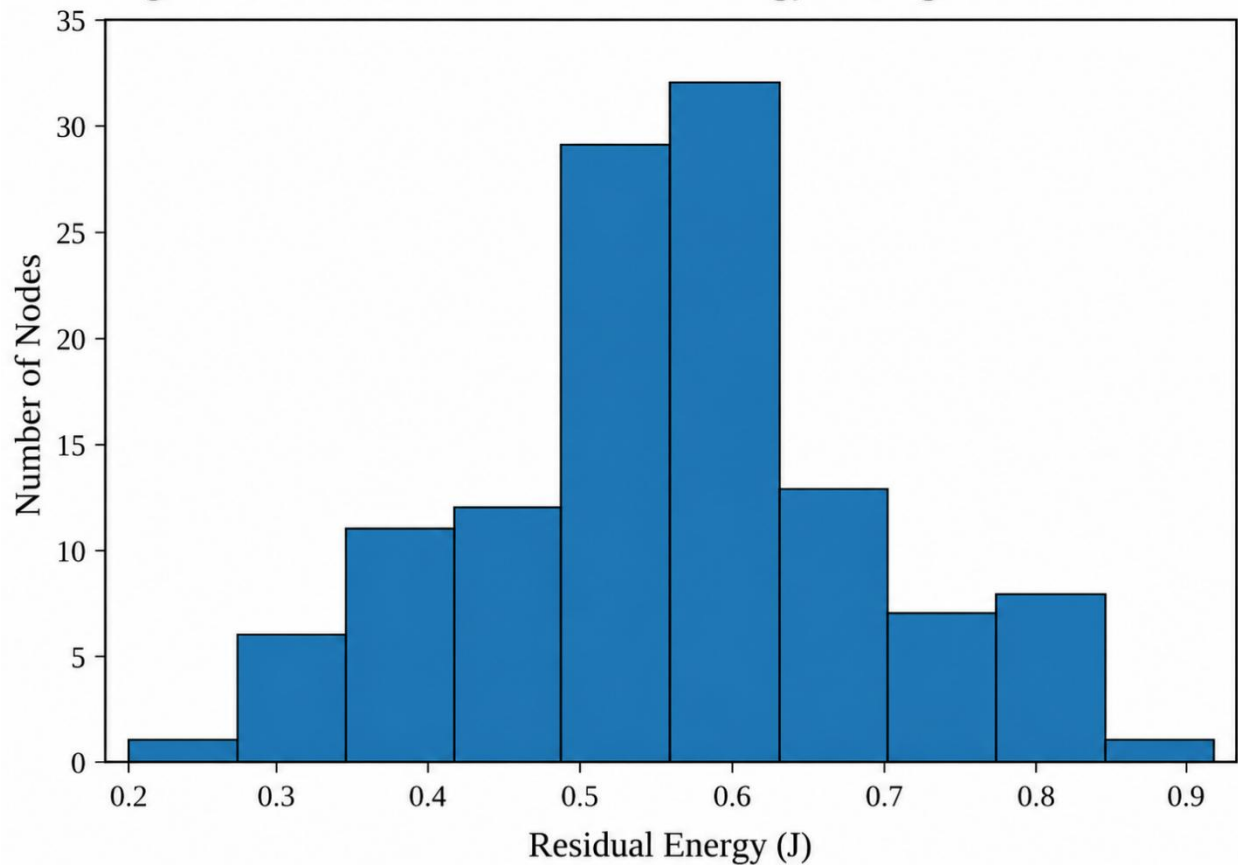
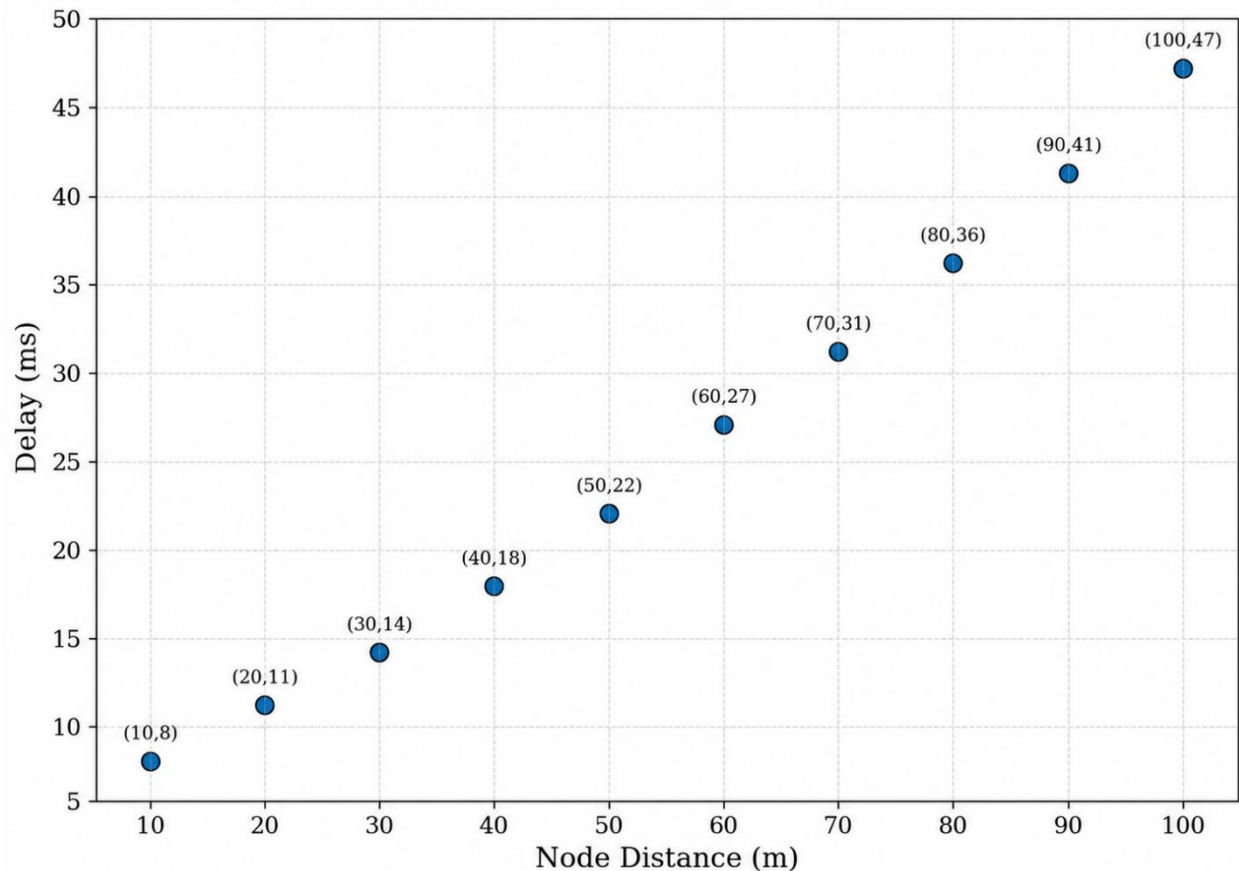
Figure 4. Periodic Sensor Signal (Sine Wave)**Figure 4. Periodic Sensor Signal Representation Using Sine Wave**

Figure 4 is a periodic sensor data signal in the form of a sine wave. When using an IoT-based WSN application, sensor nodes produce periodic measurements, e.g., temperature, humidity, vibration, or environmental parameters. The wave form indicates the periodic change of the amplitude of sensed data with time, which varies on a range of about +1 to -1. The periodicity ensures the ability of sensor nodes to capture dynamic changes in the environment. This form of signal modeling is used to determine the sensing performance and data transmission behavior in the continuous monitoring conditions. It is also applicable in the analysis of signal stability and communication requirement in IoT sensor networks through the representation.

Figure 5. Distribution of Residual Energy among Sensor Nodes**Figure 5. Distribution of Residual Energy among Sensor Nodes**

With the operation of the network, Figure 5 shows the statistical distribution of residual energy of sensor nodes. The histogram indicates that majority of sensor nodes have residual energy values that fall within the range of approximately 0.5-0.6 J, indicating that there is balance in the energy usage. The remaining energy levels of only a few nodes are low or high. The concentrated energy distribution shows that the proposed method of clustering and routing does not allow a node to lose a lot of energy. A well-balanced distribution of residual energy on the network will not only increase the reliability of the network but will also lower the chances of premature node failure as well as increase the stability of the entire network.

Figure 6. End-to-End Delay versus Node Distance**Figure 6. Relationship between End-to-End Delay and Node Distance**

The correlation between end-to-end delay and distance between nodes in the wireless sensor network is depicted in Figure 6. The findings show that the delay in communication is higher when sensor nodes are more distant. As the node distance is extended to 100 m, the delay is extended to about 47 ms, as compared to 10 m. This is due to the fact that with an increase in distance of transmission; more communication effort is required, routing operations are necessary and the processing time is also increased. The finding points to the significance of the optimization of routing paths in terms of delay reduction. The suggested energy-saving routing approach decreases the needless long distance communication and enhances the efficiency of transmission of data.

5. Discussion

The results obtained from the proposed **Energy-Efficient Clustering and Routing Optimization Framework for IoT-Based Wireless Sensor Networks (WSNs)** demonstrate

significant improvements in energy utilization, network lifetime, communication reliability, and routing efficiency.

5.1 Energy Consumption Optimization

The proposed framework solves this issue by using energy-sensitive clustering and optimal routing. The method of choosing cluster heads on the basis of residual energy and the distance of communication makes the likelihood of low-energy nodes being the cluster head to be low. The same observation was made by Heinzelman et al. (2000), where direct transmission methods that used clustering-based communication showed a significant reduction in energy consumption as compared to direct transmission methods. But, as opposed to the traditional LEACH protocol that picks the cluster head, at random, the suggested approach takes into consideration several network parameters in order to attain improved energy balancing.

5.2 Network lifetime

One of the most significant performance indicators to determine the effectiveness of WSN is network lifetime. Figure 2 shows that the proposed protocol has an average of around 1250 rounds of operation, which is better than LEACH, PEGASIS, TEEN and SEP protocols. This enhancement shows that optimal cluster making and routing choices indeed stop the untimely loss of energy. The excellent performance over LEACH can be attributed to the shortcomings of random selection of head of clusters. LEACH is not concerned with the real energy level or position of sensor nodes in the selection of cluster heads and this can lead to the inefficient distribution of energy (Heinzelman et al., 2000). Conversely, the suggested framework is dynamically able to use appropriate cluster heads and create energy-efficient paths that enable nodes to be more actively involved in the communication of the network.

5.3 Residual Energy Balance and Network Stability

This proves that the proposed framework will have a better balanced use of energy between sensor nodes. The balance in the energy consumption is significant as uneven energy drainage may leave energy holes, i.e. certain nodes drain their energy more than others and cause a break in network connectivity. As suggested by Goyal et al. (2019), the risk of early failure of nodes can be lowered by the implementation of energy-conscious routing to allocate communication tasks in the most effective way possible.

5.4 Routing Efficiency and Communication Delay

The same was noted by Samara et al. (2020), who pointed out that route efficiency has a direct impact on energy consumption and delay performance in WSNs. The routing optimization solution suggested will reduce the unnecessary long-distance communication, as it will choose efficient multi-hop paths. Multi-hop routing enables middle nodes to relay data in bits, which helps to alleviate the transmission load to single nodes. This approach enhances energy efficiency, but also has a tolerable communication delay. Optimized routing is more adaptable in dynamic IoT settings compared to the conventional single-path routing methods.

5.5 Sensor Data Transmission and Signal Reliability

Figure 4 shows the periodic sensor signal representation with a sine wave, which shows continuous data production of sensor nodes. Sensor nodes are often used in real-world IoT devices, and they might need time-dependent data, which is why dependable data transmission is needed. The stability of communication and minimum of energy consumption is therefore imperative. The suggested clustering and routing scheme will enable the provision of consistent sensor data distribution through the reduction of packet losses and the preservation of the balance in the communication routes.

5.6 Comparison with Existing Approaches

Such a combined approach allows making decisions related to forming clusters, choosing cluster heads, and optimization of the routing path. Even though metaheuristic and machine-learning-based methods have shown encouraging outcomes in the optimization of WSNs, numerous of the current methods are very resource intensive in terms of their computational requirements and tuning of their parameters, as well as complicated to use.

6. Conclusion

Nevertheless, the small battery size of sensor nodes is still one of the significant issues that influence the network life and operating stability. In a bid to resolve these challenges, this study suggested an Energy-Efficient Clustering and Routing Optimization Framework of IoT-Based Wireless Sensor Networks which combines energy-conscious clustering and efficient routing schemes. The findings reveal that the suggested technique is an effective way to enhance the use of energy and communication performance in contrast to the conventional routing protocols.

Despite the major improvements in the proposed framework, there are certain limitations. The present analysis is primarily founded on the simulation-based performance analysis on the predetermined network conditions.

The real-world IoT can present other problems, such as the mobility of nodes, the dynamic change of topology, security risks, hardware constraints, and non-homogeneous energy sources. In future studies, it is possible to incorporate the use of artificial intelligence, reinforcement learning, edge computing, and adaptive optimization mechanisms to enhance even further the intelligence and flexibility of energy-efficient WSN systems. Finally, the energy efficient clustering and routing optimization framework suggested is an effective approach to enhancing the sustainability, reliability and scalability of the IoT-powered Wireless Sensor Networks. With intelligent cluster selection and optimized routing strategies, the strategy is able to achieve energy saving, longer network lifetime and improved performance in communication. Consequently, the framework proposed can be a promising basis of the future internet of things (IoT) applications in smart cities, environmental monitoring, healthcare systems, and industrial automation.

References

- Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). A survey on sensor networks. *IEEE Communications Magazine*, 40(8), 102–114. <https://doi.org/10.1109/MCOM.2002.1024422>
- Goyal, N., Dave, M., & Verma, A. K. (2019). Energy efficient routing protocol for wireless sensor networks: A review. *Wireless Personal Communications*, 105, 1–28. <https://doi.org/10.1007/s11277-019-06106-8>
- Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-efficient communication protocols for wireless microsensor networks. *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, 1–10. <https://doi.org/10.1109/HICSS.2000.926982>
- Samara, G., Al Besani, G., Alauthman, M., & Al Khaldy, M. (2020). Energy-efficiency routing algorithms in wireless sensor networks: A survey. *International Journal of Computer Applications*.
- Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of Things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, 17(4), 2347–2376. <https://doi.org/10.1109/COMST.2015.2444095>
- Ashok, V. K. C., Pittala, S. K., Kacheru, G., Arthan, N., & Karne, R. (2025, November). Machine Learning-based Anomaly Detection in WSN. In *2025 IEEE 7th International Conference on Cybernetics, Cognition and Machine Learning Applications (ICCCMLA)* (pp. 1-5). IEEE.

- Annavarapu, B. J., Hareesha, N. G., Kacheru, G., Mohammad, A., Chin, J., & Ghule, G. (2025, February). Smart Sensors and IoT in Mechanical Engineering: Enhancing Monitoring and Control of Industrial Processes. In 2025 First International Conference on Advances in Computer Science, Electrical, Electronics, and Communication Technologies (CE2CT) (pp. 935-939). IEEE.
- Kacheru, G., & Pittala, S. K. (2026, January). Deep Learning-Driven Intrusion Detection Systems for Modern Cyber Threat Landscapes. In 2026 IEEE International Conference on Emerging Computing and Intelligent Technologies (ICoECIT) (pp. 1-9). IEEE.
- Ashok, V. K. C., & Kacheru, G. (2026, January). AI-Driven Pharmacy Claims Adjudication in Healthcare: Improving Operational Efficiency, Accuracy, and Cyber security. In 2026 IEEE International Conference on Emerging Computing and Intelligent Technologies (ICoECIT) (pp. 1-7). IEEE.
- Pittala, S. K., & Kacheru, G. (2025, October). Digital defense in FinTech: Tackling modern threats and systemic vulnerabilities. In 2025 2nd International Conference on Recent Trends in Electrical, Electronics and Computing Technologies (ICRTEECT) (pp. 1-6). IEEE.
- S V, S. R., Ashok, V. K. C., Kasapaka, R., Karne, R., Arthan, N., & A, S. (2026). Privacy-Preserving VPKI Using Federated Learning for Cross-Domain Vehicle Authentication. 2026 IEEE Global Symposium on Emerging and Communication Technologies (GSEACT), 1–6. <https://doi.org/10.1109/gseact68539.2026.11620450>
- Tanni, M. M. P., Mehely, K., Tanji, E., Rahman, M. S., Apu, M. M. H., & Ali, M. M. (2026). Strategic Integration of Artificial Intelligence in the US Industrial Management: A Qualitative Study of Organizational Transformation. *International Journal of Science and Engineering*, 3(1).
- TANJI, E. (2018). WOMEN'S PARTICIPATION IN RURAL ECONOMIC ACTIVITIES IN RANGPUR DISTRICT OF BANGLADESH (Doctoral dissertation, DEPT. OF DEVELOPMENT AND POVERTY STUDIES).
- Tanni, M. M. P., Tanji, E., Mehely, K., Rahman, M. S., Apu, M. M. H., & Ali, M. M. ARTIFICIAL INTELLIGENCE AND INDUSTRIAL ENGINEERING PRACTICES IN THE UNITED STATES: A QUALITATIVE EXPLORATION OF STRATEGIC ADOPTION.
- Mehely, K., Tanni, M. M. P., Tanji, E., Rahman, M. S., Apu, M. M. H., & Ali, M. M. (2026). Data-Driven Strategic Management in the US Industries: The Role of Management Information Systems and Artificial Intelligence. *Strategic Data Management and Innovation*, 3(02).
- Tanni, M. M. P., Mehely, K., Tanji, E., Rahman, M. S., Apu, M. M. H., & Ali, M. M. TECHNOLOGY MANAGEMENT AND STRATEGIC DECISION-MAKING IN US MANUFACTURING FIRMS: INSIGHTS FROM ARTIFICIAL INTELLIGENCE AND DATA-DRIVEN SYSTEMS.
- Natarajan, G. N., Paul, S., Shah, J. K., Tiwari, A., & Bellamkonda, R. (2025, September). Decoding Drift: Trustworthy Prompt Optimization in High-Stakes AI Environments. In 2025 International Conference on Electronics and Computing, Communication Networking Automation Technologies (ICEC2NT) (pp. 1-8). IEEE.
- Raghavan, P., Sura, R., Taneja, A., & Tiwari, A. (2025, August). Federated Learning for Privacy-Preserving Multi-agent Systems in IoT-Based Healthcare, Guided by

- Explainable LLMs. In International Conference on Computing and Communication Networks (pp. 566-584). Cham: Springer Nature Switzerland.
- Vembu, N. R., Tiwari, A. R., Hamal, V., & Devi, P. (2026, April). Edge AI Enhancing Real-Time Inventory Management for Retail Networks. In 2026 IEEE 2nd International Conference on Quantum Photonics, Artificial Intelligence & Networking (QPAIN) (pp. 1-6). IEEE.
- Vaidehi, M. D., Tiwari, A. R., Bonsale, G., SunithaRekha, G., Raza, S., & Chhajed, A. S. (2026, January). Natural Language Processing-Driven Text Simplification System for Enhanced Readability. In 2026 6th International Conference on Recent Trends in Computer Science and Technology (ICRTCST) (Vol. 1, pp. 130-135). IEEE.
- Kanikanti, V. S. N., Tiwari, A., Lohalekar, P., & Karra, N. (2025, November). Multi-Agent Reinforcement Learning with Policy-Driven Shift-Left Integration and Resource Allocation in Cloud Environments. In 2025 International Conference on Computational Engineering, Sensing Technology and Management (ICCETM) (pp. 1-6). IEEE.
- Sundaramoorthy, P., Tarvecha, V., Kumar, S. N. P., Kumar, U., & Tiwari, A. (2025, October). AI Agents in Autonomous Retail Data Pipelines: Self-evolving ETL for Customer Behavior Data. In International Conference on Artificial Intelligence and Networking (pp. 509-520). Cham: Springer Nature Switzerland.
- Cherian, E., Krishnan, M. M., Tiwari, A. R., Hashim, M., Al-Shaikhli, T. R., & Khudayer, K. (2025, August). Self-Supervised Learning-Optimized Market Segmentation Framework for Targeted Promotions. In 2025 International Conference on Recent Innovation in Science Engineering and Technology (ICRISET) (pp. 1-7). IEEE.
- Yerramada, S. S. R., Pal, R. K., Desai, T., & Tiwari, A. (2025, August). Enhancing Cyber Security, Data Confidentiality, and Access Control in Multi-Tenant Cloud Infrastructures Through Blockchain-Integrated Attribute-Based Encryption Mechanisms. In International Conference on Computing and Communication Networks (pp. 488-509). Cham: Springer Nature Switzerland.
- Alang, K., Devaraju, P., Tuniki, R. R., Tiwari, A., & Sharma, P. (2025, July). Explainability-Preserving Compression: Algorithmic Design for Responsible Lightweight AI. In 2025 3rd World Conference on Communication & Computing (WCONF) (pp. 1-7). IEEE.
- Dubey, A., Tiwari, A., Gangwar, A., & Mohanty, L. (2025, June). Sentimental analysis of feedback data using machine learning. In Intelligent Computing and Communication Techniques: Proceedings of the International Conference on Intelligent Computing and Communication Techniques (ICICCT 2024), New Delhi, India, 28-29 June, 2024 (Volume 1) (p. 251). CRC Press.
- Tiwari, A. INTERNATIONAL JOURNAL OF RESEARCH SCIENCE & MANAGEMENT.
- Imran, G., Hossain, M. P., Hasan, M., & Hasan, M. T. (2026). Tabular and graph-based representations for noise and missing data in robust machine learning. *Array*, 100697.
- Islam, T., Mia, M., Imran, G., Tusar, M. I. H., & Ahmed, T. (2026). Domain-informed graph neural network and evolutionary computations for relational property enhancement in additive manufacturing. *Expert Systems with Applications*, 134177.
- Imran, G., Islam, T., & Tusar, M. I. H. (2025, October). Surface roughness prediction of CNC lathe machined hardened steel using physics-informed neural network leveraging transfer learning. In 2025 IEEE 15th International Conference on System Engineering and Technology (ICSET) (pp. 439-444). IEEE.

- Sohel, M. S., Shi, G., Zaman, N. T., Hossain, B., Halimuzzaman, M., Akintunde, T. Y., & Liu, H. (2022). Understanding the food insecurity and coping strategies of indigenous households during COVID-19 crisis in Chittagong hill tracts, Bangladesh: A qualitative study. *Foods*, 11(19), 3103.
- Halimuzzaman, M., & Sharma, J. (2024). The role of enterprise resource planning (ERP) in improving the accounting information system for organizations. *Revolutionizing the AI-digital landscape*, 263-274.
- Halimuzzaman, M., Sharma, J., & Khang, A. (2024). Enterprise Resource Planning and Accounting Information Systems: Modeling the Relationship in Manufacturing. In *Machine Vision and Industrial Robotics in Manufacturing* (pp. 418-434). CRC Press.
- Halimuzzaman, M., Sharma, J., Karim, M. R., Hossain, M. R., Azad, M. A. K., & Alam, M. M. (2024). Enhancement of organizational accounting information systems and financial control through enterprise resource planning. In *Synergy of AI and Fintech in the Digital Gig Economy* (pp. 315-331). CRC Press.