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Clustering, Data Collection, and IoT Frameworks in WSNs: A Review and Future Directions

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Abstract: Wireless Sensor Networks (WSNs) integrated with the Internet of Things (IoT) have gained significant attention due to their wide range of applications in smart environments. However, challenges such as energy efficiency, scalability, and reliable data transmission remain critical. This paper presents a comprehensive review of existing approaches in IoT-based WSNs, categorized into three major domains: clustering-based routing, data collection techniques, and IoT frameworks with supporting mechanisms. Clustering techniques focus on efficient node grouping and energy-aware communication, while data collection strategies utilize mobile sinks and optimized routing to enhance network lifetime and reduce latency. IoT frameworks provide system-level integration along with supporting techniques such as compression, scheduling, and intelligent routing. The study highlights the advantages and limitations of each approach and identifies key research gaps. It is observed that although significant improvements have been achieved, challenges related to computational complexity, real-time adaptability, and system integration still persist, motivating the need for more intelligent and hybrid solutions.

Keywords: Wireless Sensor Networks (WSN), Internet of Things (IoT), Clustering-Based Routing, Mobile Sink, Energy Efficiency.

1. Introduction:

The existing literature on IoT-based Wireless Sensor Networks (WSNs) can be broadly categorized into three major domains: clustering-based routing, data collection techniques, and IoT frameworks with supporting mechanisms. Each category addresses specific challenges such as energy efficiency, scalability, and reliable data transmission. The clustering-based routing approaches focus on improving network lifetime by organizing sensor nodes into energy-efficient clusters. Studies such as Chaurasiya et al. (2022) [1] and Chaurasiya et al. (2023) [3] emphasize hybrid clustering strategies that incorporate residual energy and hierarchical mechanisms to enhance scalability. Similarly, Abbad et al. (2022) [2] and Sravanthi et al. (2023) [5] demonstrate improvements in routing stability and throughput using optimized clustering techniques. Works like Vimal et al. (2021) [6] address connectivity challenges by handling isolated nodes, while Yin et al. (2022) [8] and Mishra et al. (2021) [9] provide comparative insights into clustering protocols. Mugerwa et al. (2023) [10] further extend clustering efficiency through multi-sink integration. Overall, these methods significantly improve energy utilization and load balancing but often introduce computational and control overhead.

The data collection techniques primarily aim to reduce energy consumption and latency through the use of mobile sinks and intelligent data gathering strategies. Chaurasiya et al. (2022) [1] integrates clustering with mobile sinks to minimize transmission distance. Thomson et al. (2021) [13] and Amutha et al. (2022) [14] focus on optimizing sink mobility and hybrid sink architectures to prevent energy holes. Roy et al. (2021) [15] enhances data collection through hierarchical and coverage-aware approaches, while Verma and Jain (2022) [16] optimize sink visiting points for efficient data acquisition. Gowda and Jayasree (2021) [17] introduce AI-based rendezvous point selection for intelligent routing. These approaches effectively improve network lifetime and reduce delay, although they suffer from increased algorithmic complexity and dependency on optimal sink movement.

The IoT frameworks and supporting techniques provide a broader perspective on system design, communication protocols, and complementary optimizations. Manchanda and Bansal (2023) [4] and Shahraki et al. (2021) [11] offer comprehensive surveys of clustering and IoT integration, highlighting key research directions. Wason et al. (2021) [7] discusses smart sensor architectures for IoT environments. Supporting techniques such as the TDMA-DSSS scheduling model by Darabkh et al. (2022) [12] improve communication efficiency, while Khafaga et al. (2023) [18] focus on data compression for IoMT applications. Elyyan and Darabkh (2023) [19] incorporate computational intelligence for energy-aware routing. These contributions enhance system-level performance and enable advanced applications but often involve higher implementation complexity and limited real-world validation.

In summary, clustering techniques improve energy efficiency and scalability, data collection strategies enhance network lifetime and latency performance, and IoT frameworks provide system-level support and optimization mechanisms. However, a common research gap across all categories lies in balancing energy efficiency, computational complexity, and real-time adaptability, which motivates the need for more integrated and intelligent solutions.

The remainder of this paper is organized as follows. Section I presents the introduction and background of IoT-based WSNs. Section II provides a detailed literature review categorized into clustering-based routing, data collection techniques, and IoT frameworks with supporting mechanisms. Section III discusses the comparative analysis of existing approaches along with their advantages and limitations. Section IV presents the overall findings and identifies research gaps in current methodologies. Finally, Section V concludes the paper and outlines potential future research directions.

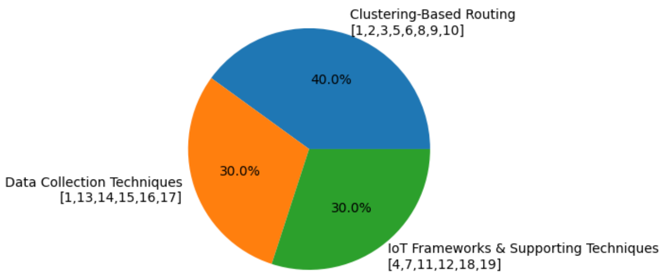

Figure 1. Distribution of references by category

Table 1. References wise distribution under different category

Category	References (by Ref. No.)
Clustering-Based Routing	[1], [2], [3], [5], [6], [8], [9], [10]
Data Collection Techniques	[1], [13], [14], [15], [16], [17]
IoT Frameworks & Supporting Techniques	[4], [7], [11], [12], [18], [19]

2. Review On Clustering-Based Routing:

Clustering-based routing organizes sensor nodes into groups called clusters. Each cluster has a Cluster Head (CH) that collects data from member nodes and forwards it to the base station. This reduces direct communication, saving energy and improving network lifetime. Methods like hybrid clustering and LEACH-based protocols focus on optimizing CH selection using energy, distance, or probability.

Chaurasiya et al. proposed an energy-efficient clustering scheme incorporating mobile sinks and rendezvous nodes. The method selects cluster heads based on residual energy and communication distance. Results show improved network lifetime and reduced energy consumption while balancing node load. However, additional control overhead is introduced due to sink coordination [1].

Abbad et al. compared location-based Markov clustering with density-based clustering protocols to improve routing efficiency. Their results indicate better packet delivery ratio and lower energy usage, especially in stable environments. The approach enhances cluster stability and communication performance. However, it is less effective in dynamic or mobile network scenarios [2].

Chaurasiya et al. introduced EEHCT, a hybrid clustering technique designed for heterogeneous IoT networks. It combines hierarchical and energy-aware strategies to improve scalability and lifetime. Results show efficient energy distribution among nodes. The method performs well in multi-level networks. However, it increases computational complexity [3].

Sravanthi et al. developed an improved energy-efficient routing protocol based on clustering optimization. The approach enhances throughput and reduces packet loss in IoT-based WSNs. Results demonstrate better energy conservation compared to traditional methods. It is suitable for structured environments. However, adaptability to topology changes is limited [5].

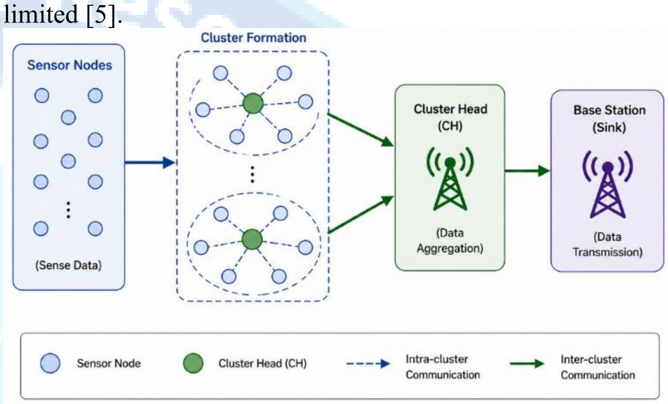

Figure 2. Clustering-Based Routing

Vimal et al. addressed the issue of isolated nodes by integrating them into nearby clusters. This improves connectivity and extends network lifetime. Results show reduced energy wastage and better coverage. The method enhances robustness in sparse deployments. However, clustering overhead increases with network size [6].

Yin et al. presented a survey on LEACH-based clustering protocols, analyzing various improvements in energy efficiency. The study highlights advancements in cluster head selection mechanisms. It provides a comparative understanding of multiple approaches. However, it lacks experimental validation and implementation details [8].

Mishra et al. evaluated several cluster-based routing protocols for IoT sensor networks. The study compares delay, throughput, and energy consumption metrics. Results reveal trade-offs among different approaches. It helps in selecting suitable protocols for specific applications. However, no new model is proposed [9].

Mugerwa et al. proposed a hybrid distributed clustering protocol with multiple sinks. The method improves scalability and balances energy consumption across the network. Results indicate reduced latency and extended lifetime. It is effective for large-scale IoT deployments. However, implementation complexity remains high [10].

S. No.	Author et al. (Year) [Ref No.]	Approach	Pros	Cons
1	Chaurasiya et al.	Energy-efficient	Improves network	High control overhead

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	(2022) [1]	clustering with mobile sink & rendezvous nodes	lifetime, balances load	
2	Abbad et al. (2022) [2]	Markov vs density-based clustering	Better stability and packet delivery	Poor in dynamic networks
3	Chaurasiya et al. (2023) [3]	Hybrid EEHCT clustering for heterogeneous WSN	High scalability, energy balancing	High computational complexity
4	Sravanthi et al. (2023) [5]	Improved energy-efficient routing protocol	Better throughput, low packet loss	Limited adaptability
5	Vimal et al. (2021) [6]	Clustering of isolated nodes	Improves connectivity and coverage	Increased clustering overhead
6	Yin et al. (2022) [8]	Survey of LEACH-based protocols	Comprehensive comparison	No experimental validation
7	Mishra et al. (2021) [9]	Performance evaluation of clustering protocols	Helps protocol selection	No new method proposed
8	Mugerwa et al. (2023) [10]	Hybrid distributed clustering with multiple sinks	High scalability, low latency	Complex implementation

3. Review on Data Collection Techniques

This category focuses on how data is gathered efficiently from sensor nodes. Instead of static sinks, mobile sinks or rendezvous points are used to collect data, reducing long-distance transmissions. Techniques optimize sink movement, visiting points, or scheduling to avoid energy holes and reduce delay.

Thomson et al. proposed an energy balancing solution using a mobile sink with optimized trajectory planning. The method minimizes energy holes near static sink regions. Results show improved network lifetime and balanced energy consumption. It effectively reduces node overuse near sink areas. However, path optimization increases computational cost [13].

Amutha et al. developed a hybrid optimization algorithm combining static and mobile sinks. The approach enhances reliability and reduces energy consumption during data collection. Results demonstrate improved performance compared to single-sink models. It ensures better coverage and fault tolerance. However, system complexity is increased [14].

Roy et al. introduced a hierarchical data collection approach focusing on energy and coverage sensitivity. The method ensures efficient data gathering while maintaining sensing coverage. Results show improved energy efficiency and reduced redundancy. It is suitable for large-scale deployments. However, it requires careful parameter tuning [15].

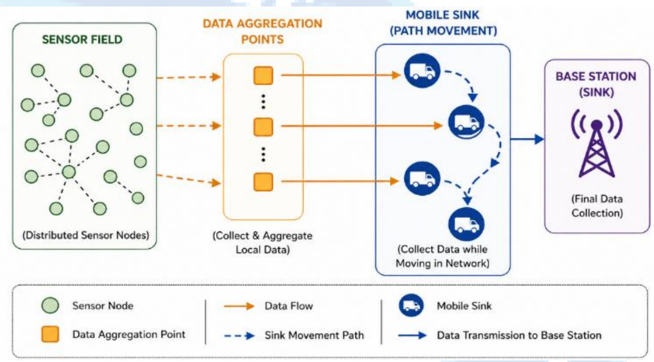

Figure 3. Data Collection Technique

Verma and Jain proposed an optimal visiting point selection method for mobile sinks. The approach reduces delay and enhances data acquisition efficiency. Results indicate improved performance in terms of latency and energy usage. It effectively optimizes sink movement. However, it may not scale well in highly dense networks [16].

Gowda and Jayasree proposed a rendezvous-based routing approach using a hybrid neural network. The method predicts optimal data collection points for mobile sinks. Results show improved energy efficiency and reduced transmission cost. It integrates AI for better decision-making. However, training overhead and complexity are significant [17].

S. No.	Author et al. (Year) [Ref No.]	Approach	Pros	Cons
1	Chaurasiya et al. (2022) [1]	Mobile sink with clustering	Reduces transmission distance	Coordination overhead
2	Thomson et al. (2021) [13]	Mobile sink trajectory optimization	Avoids energy holes	High computation cost
3	Amutha et al. (2022) [14]	Hybrid static + mobile sink optimization	Better reliability, coverage	Increased system complexity

4	Roy et al. (2021) [15]	Hierarchical data collection	Energy efficient, reduces redundancy	Needs parameter tuning
5	Verma et al. (2022) [16]	Optimal visiting points for sink	Low delay, efficient data collection	Poor scalability in dense networks
6	Gowda et al. (2021) [17]	Rendezvous points + neural network	Intelligent path prediction	High training overhead

5. Review on IoT Frameworks & Supporting Techniques

This category deals with the overall system architecture and supporting technologies such as communication protocols, compression, scheduling, and AI-based routing. It connects WSNs to IoT applications, enabling smart environments like healthcare (IoMT), smart cities, etc.

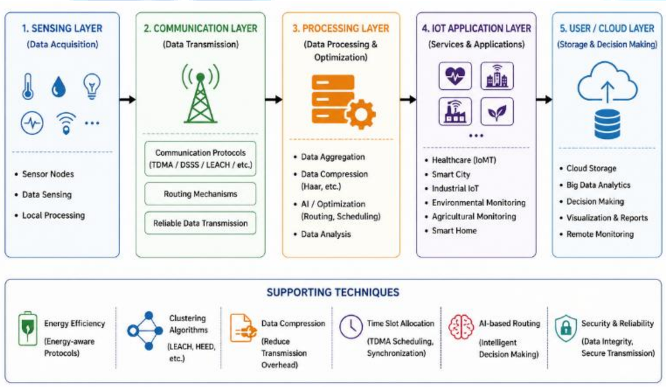

Figure 4. IoT Frameworks & Supporting Techniques

Manchanda and Bansal presented a review of clustering algorithms for IoT-based WSN applications. The study highlights different techniques and their performance characteristics. It provides a comprehensive understanding of clustering strategies. Results help identify suitable methods for various scenarios. However, it is limited to theoretical analysis [4].

Wason et al. discussed smart sensor networks using IoT technologies, focusing on system architecture and communication models. The study explains integration challenges and solutions. Results emphasize improved automation and connectivity. It is useful for designing IoT-based systems. However, it lacks detailed performance evaluation [7].

Shahraki et al. provided a comprehensive survey on clustering from WSNs to modern IoT paradigms. The paper discusses future research directions and challenges. It highlights scalability and energy efficiency issues. Results offer valuable insights into evolving technologies. However, practical implementation aspects are limited [11].

Darabkh et al. proposed an impairments-aware time slot allocation model using TDMA and DSSS protocols. Method improves communication efficiency in energy-constrained IoT nodes. Results show better bandwidth utilization and reduced interference. It enhances network reliability. However, implementation complexity is high [12].

Khafaga et al. introduced a compression technique using Haar wavelet transform for IoMT systems. The approach reduces data size and transmission cost. Results indicate efficient bio-signal compression with minimal loss. It is suitable for healthcare applications. However, computational requirements are relatively high [18].

Elyyan and Darabkh proposed a computational intelligence-based routing protocol for power-limited IoT networks. The method optimizes routing decisions using intelligent algorithms. Results show improved energy efficiency and network performance. It supports advanced IoT applications. However, algorithm complexity may limit real-time deployment [19].

S. No.	Author et al. (Year) [Ref No.]	Approach	Pros	Cons
1	Manchanda et al. (2023) [4]	Review of clustering algorithms	Broad understanding	No experimental results
2	Wason et al. (2021) [7]	IoT-based smart sensor architecture	Good system design insights	Limited evaluation
3	Shahraki et al. (2021) [11]	Survey on clustering evolution	Covers future directions	Limited implementation
4	Darabkh et al. (2022) [12]	TDMA-DSSS time slot allocation	Efficient communication	Complex implementation
5	Khafaga et al. (2023) [18]	Haar wavelet compression for IoMT	Reduces data size	High computation cost
6	Elyyan et al. (2023) [19]	AI-based routing protocol	Improved energy efficiency	Complexity in real-time use

6. Conclusion:

This paper presented a comprehensive review of IoT-based Wireless Sensor Networks by categorizing existing research into clustering-based routing, data collection techniques, and IoT frameworks with supporting mechanisms [20,21]. Clustering approaches significantly improve energy efficiency and network lifetime through effective node grouping and load balancing. Data collection techniques, particularly those utilizing mobile sinks and rendezvous points, reduce transmission distance and mitigate energy hole problems. IoT frameworks and supporting techniques provide system-level enhancements through efficient communication protocols, data compression, and intelligent routing mechanisms. Despite these advancements, several limitations remain, including increased computational complexity, scalability challenges, and dependency on optimal parameter selection. The analysis reveals that no single approach fully addresses all performance metrics, highlighting the need for integrated and adaptive solutions.

Future research in IoT-based WSNs should focus on developing hybrid models that integrate clustering, mobile sink strategies, and intelligent routing mechanisms to achieve optimal performance. The use of artificial intelligence and machine learning can enhance decision-making for cluster head selection, sink mobility, and data routing. Additionally, real-time adaptability and dynamic network handling should be improved to support large-scale and heterogeneous IoT environments. Energy harvesting techniques and low-power communication protocols can further extend network lifetime. Security and data privacy also remain critical concerns, especially in applications such as healthcare (IoMT). Finally, practical implementation and real-world validation of proposed models are essential to ensure reliability and scalability in real deployments.

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