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Enhancing Security and Energy Efficiency in Wireless Sensor Network Routing with IOT Challenges: A Thorough Review

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ABSTRACT

Wireless sensor networks (WSNs) have emerged as a crucial component in the field of networking due to their cost-effectiveness, efficiency, and compact size, making them invaluable for various applications. However, as the reliance on WSN-dependent applications continues to grow, these networks grapple with inherent limitations such as memory and computational constraints. Therefore, effective solutions require immediate attention, especially in the age of the Internet of Things (IoT), which largely relies on the effectiveness of WSNs. This study undertakes a comprehensive review of research conducted between 2018 and 2020, categorizing it into six main domains: 1) Providing an overview of WSN applications, management, and security considerations. 2) Focusing on routing and energy-saving techniques. 3) Reviewing the development of methods for information gathering, emphasizing data integrity and privacy. 4) Emphasizing connectivity and positioning techniques. 5) Examining studies that explore the integration of IoT technology into WSNs, with an eye on secure data transmission. 6) Highlighting research efforts aimed with a strong emphasis on energy efficiency. The study addresses the motivation behind employing WSN applications in IoT technologies, as well as the challenges, obstructions, and solutions related to their application and development. It underscores that energy consumption remains a paramount issue in WSNs, with untapped potential for improving energy efficiency while ensuring robust security. Furthermore, it identifies existing approaches' weaknesses, rendering them inadequate for achieving energy-efficient routing in secure WSNs. This review sheds light on the critical challenges and opportunities in the field, contributing to a deeper understanding of WSNs and their role in secure IoT applications.

Keywords: IoT, WSNs, Coverage, Routing, Wireless, Wireless Energy Saving, Localization, Data Aggregation.

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INTRODUCTION

Wireless sensor networks (WSNs) play an increasingly pivotal role in wireless communication. These networks, often seen as the backbone of modern data collection systems, differ significantly from conventional communication setups. They necessitate new operating systems designed specifically to cater to their unique requirements and constraints Yaqoob et al. (2019). WSNs, characterized as multi-hop network systems, are ingeniously constructed by employing distributed, self-organizing, and energy-constrained wireless sensor nodes and actuators. These nodes tirelessly collect data relevant to a particular application from their designated monitoring area, greatly enhancing the performance of monitoring systems and simultaneously reducing overall costs (Raji & Gbolagade, 2019). A wireless sensor network, at its core, comprises a conglomerate of diminutive sensor nodes interconnected through wireless communication channels, collaboratively striving to detect and report specific events or phenomena within an area of interest. Each sensor node is outfitted with necessary parts, such as processing power, memory, an RF transceiver for wireless communication, a power source, and, occasionally, a Global Positioning System (GPS). WSNs are used in a variety of industries and provide real-time insights regarding the demands placed on and the operation of the infrastructure being monitored. Depending on the unique application requirements, these networks can be customized to different network topologies (Yousif et al., 2018).

While wireless sensor networks bring an array of benefits, they are not without limitations. They grapple with challenges such as restricted energy resources, limited communication range, low bandwidth, and constrained processing capabilities. Nonetheless, they remain a cost-effective and efficient solution for diverse applications. Within WSNs, sensor nodes work in harmony to reach specific decisions by pooling data from a multitude of nodes that relay information to central base stations (BSs). The collaboration of hundreds or even thousands of sensor nodes is required for a number of network applications, hence this is an important factor (Gupta, 2019) Wireless sensor networks typically consist of fixed nodes, but because nodes have limited lifespans, the network topology is constantly changing. Communication network protocols therefore need to be able to dynamically adapt to topology changes. Additionally, because there are so many sensor nodes involved, deploying software changes can be a time-consuming task. The network infrastructure's tight links between data control and forwarding make it expensive to expand and administer the network. Wireless sensor networks typically consist of fixed nodes, but because nodes have limited lifespans, the network topology is constantly changing. Communication network protocols therefore need to be able to dynamically adapt to topology changes. Additionally, because there are so many sensor nodes involved, deploying software changes can be a time-consuming task. The network infrastructure's tight links between data control and forwarding make it expensive to expand and administer the network (Duan et al., 2018). These challenges underscore the importance of research and innovation in the field of wireless sensor networks, as they continue to evolve and redefine the landscape of modern data collection and monitoring systems.

This paper is structured into distinct sections to ensure a comprehensive and logical presentation of the research. In Section 1, we provide a concise literature review to establish the context. Section 2 is dedicated to the methodology, outlining the process we followed in our research. In Section 3, we present the results of our extensive article search. Section 4 offers an in-depth review of Wireless Sensor Networks (WSNs), elucidating their intricate components and characteristics. Section 5 engages in a meaningful discussion that synthesizes the gathered insights. Section 6 delves into the underlying motivations driving the study, shedding light on the significance of the research. In Section 7, we meticulously explore the challenges that WSNs confront and present a series of recommendations to address them effectively. Finally, Section 8 encapsulates our findings and contributions, offering a

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conclusive summary of the research and its implications. This structured organization ensures that the paper delivers a comprehensive and coherent exploration of the subject matter.

LITERATURE REVIEW

In previous studies, Wireless Sensor Networks (WSNs) have been identified as a transformative technology with broad applications (Sohraby et al., 2007; Worlu et al., 2019), encompassing environmental monitoring, healthcare, industrial automation, and more. WSNs consist of an array of small, resource-constrained sensor nodes (Zoumboulakis & Roussos, 2009) that collaborate to collect and wirelessly transmit data. However, the extensive potential of WSNs is accompanied by a range of pressing challenges and issues that warrant in-depth examination to unlock their full capabilities. One prominent challenge examined in the study is the constraint of energy resources within sensor nodes. Often deployed in remote or inaccessible areas (Patel & Kumar, 2018), replacing or recharging batteries in these nodes is impractical. Consequently, the study emphasizes the imperative to develop energy-efficient algorithms and optimize hardware (Umer et al., 2023) to maximize the network's lifespan. Additionally, this research delves into the challenge posed by the short communication range of sensor nodes, particularly in large-scale networks. Addressing this issue requires the development of routing protocols that efficiently transmit data over multiple hops while conserving energy, as outlined in previous studies.

The scalability of WSNs is a recurring topic of discussion in previous research (El Khediri, 2022; Sachan et al., 2021). Accommodating a large number of nodes while maintaining efficient data collection and communication is a multifaceted challenge that necessitates careful network organization, addressing, and data aggregation mechanisms. Security and privacy are focal points in the literature review, reflecting the sensitivity of WSN applications (Majid et al., 2022; Zin et al., 2014). Various security threats, such as eavesdropping and data tampering, have been identified in previous studies. Therefore, ensuring data integrity, confidentiality, and privacy is recognized as a critical concern (Abidin et al., 2021).

Data quality and reliability are areas of significance in the study, given the potential for errors or data loss due to environmental factors, hardware constraints, and communication interference (Freschi & Lattanzi, 2019). In response, research underscores the importance of techniques for data validation, redundancy, and error correction to enhance data accuracy. Self-organization and self-healing mechanisms are also examined in prior studies as strategies for addressing dynamic network topologies and node failures in WSNs (Fu & Yang, 2020; Younis et al., 2014). These mechanisms help to ensure network resilience in response to changing environmental conditions. Efficient data aggregation and fusion are identified as strategies for managing the vast volume of data generated by sensor nodes. Previous research highlights the need for algorithms that can extract meaningful information from this wealth of data. Addressing hardware constraints (Alaerjan, 2023; Hempstead et al., 2008) is a common theme in the literature. Researchers have explored ways to optimize algorithms and protocols to operate effectively within the limited processing power and memory of sensor nodes while maintaining efficient data processing. The literature review acknowledges the challenge of dealing with heterogeneous sensor nodes (Elfouly et al., 2021), each with varying capabilities and sensing modalities. Coordinating and integrating these nodes seamlessly is recognized as a substantial challenge. Time synchronization is addressed as a challenge in WSNs, where accurate timing among sensor nodes is crucial. Previous studies investigate methods to achieve synchronization while conserving energy. On the other hand, standardization in WSN protocols and hardware (Dhabliya et al., 2022; Zrelli, 2022), as identified in the literature, is essential for ensuring interoperability and the seamless integration of diverse WSN solutions into a unified network. The previous studies have also discussed Quality of Service (QoS)

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requirements (Hashish & Tawalbeh, 2017; Mazhar et al., 2023). These requirements, necessary for applications demanding specific guarantees, must be met while managing energy constraints effectively.

In the scope of this literature review, the challenges within the domain of Wireless Sensor Networks (WSNs) are extensively examined, with particular attention given to the diverse array of applications WSNs encompass. These networks have garnered significance due to their cost-effectiveness, compact dimensions, and operational efficiency, making them a pivotal component in the realm of networking. Nevertheless, despite their merits, WSNs are not devoid of limitations, which include constrained memory and computational capabilities. These challenges necessitate effective solutions, particularly in the context of the Internet of Things (IoT), where the efficiency of WSNs is paramount. The reviewed research conducted from 2017 to 2023 is categorized into six principal domains i.e. 1) Providing an overview of WSN applications, management, and security considerations. 2) Focusing on routing and energy-saving techniques. 3) Reviewing the development of methods for information gathering, emphasizing data integrity and privacy. 4) Emphasizing connectivity and positioning techniques. 5) Examining studies that explore the integration of IoT technology into WSNs, with an eye on secure data transmission. 6) Highlighting research efforts aimed with a strong emphasis on energy efficiency The central theme of energy efficiency and security persists throughout the analysis, primarily addressing the concern of energy consumption within WSNs. Simultaneously, the review identifies an untapped potential for augmenting energy efficiency while maintaining stringent security measures. By pinpointing the prevailing weaknesses in existing approaches, the review demonstrates the insufficiency of current methods for achieving energy-efficient and secure routing, delivering a comprehensive perspective on the challenges and opportunities in this field. In doing so, the review contributes to fostering an in-depth understanding of WSNs and their indispensable role in secure IoT applications. The examination broadens to encompass the challenges related to the deployment and maintenance of WSNs, with a particular focus on the complexities of situating sensor nodes in challenging and remote environments. Additionally, the review comprehensively addresses the logistical demands associated with node maintenance, offering a holistic view of the practical aspects of WSNs. Simultaneously, this comprehensive review conscientiously acknowledges the prominent role of privacy as both an ethical and technical challenge in the domain of WSNs, particularly within applications such as surveillance and healthcare monitoring. This aspect of the review accentuates the delicate balance required for data collection while ensuring the preservation of data privacy within secure WSNs, thereby making a significant contribution to the broader knowledge surrounding WSNs and their application within secure IoT ecosystems.".

Addressing these multifaceted challenges and issues, as identified in previous studies, necessitates interdisciplinary efforts involving computer science, electrical engineering, and domain-specific expertise. Researchers and engineers continually strive to develop innovative solutions and protocols to enhance the capabilities of WSNs and overcome these hurdles. As technology evolves, WSNs are expected to continue playing a pivotal role in shaping our interconnected world, providing valuable data for diverse applications while adapting to the ever-changing demands of the digital age.

METHODOLOGY

The articles identified through our systematic review encompassed an extensive exploration of Wireless Sensor Networks (WSNs), with a focus on various aspects, including technologies, applications, and their relevance to the Internet of Things (IoT). The search process involved the utilization of specific keywords such as "Wireless Sensor Networks," "WSNs technologies," "WSNs Applications," and related terms. These keywords were logically combined using operators like OR, AND, and NOT to

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refine the search results. For instance, combinations like "WSNs & Internet of Things (IoT)," "Wireless Sensor Networks & Internet of Things (IOT)," or "WSNs & Internet of Things (IoT)" were instrumental in pinpointing relevant studies.

The inclusion criteria emphasized studies written in English that delved into the development of technologies and algorithms aimed at enhancing the implementation of WSNs, as well as those exploring the applications of WSNs across various domains. IEEE Explore, MDPI, Elsevier, the recognized academic databases known for their collection of publications in the fields of electronic technologies, electrical engineering, and computer science, were ones of the digital databases used for this in-depth assessment. These databases were chosen because they have a wide range of studies on WSNs that are covered in depth.

The search initiative commenced in September 2023, and the collected studies were meticulously categorized based on their relevance to WSNs technologies and applications. This categorization formed a general and coarse-grained taxonomy with three primary classes, which had been derived from a preliminary survey of the existing literature.

This systematic review provides a robust framework for the identification and categorization of articles that are instrumental in understanding the various dimensions of Wireless Sensor Networks, their underlying technologies, and their diverse applications in the context of the Internet of Things. The utilization of comprehensive search strategies, logical keyword combinations, and exclusion criteria ensured the selection of studies that are most pertinent to the objectives of this review, thereby contributing to a well-rounded assessment of the current state of WSN research and its implications. This extensive review is designed to provide valuable insights for researchers, scholars, and practitioners seeking a deeper understanding of WSNs and their multifaceted applications.

ARTICLES SEARCH RESULTS

In this section, a rigorous filtering process was applied to identify articles published in the period spanning 2017 to 2023. Following this meticulous filtering, a total literature consisted of 100 articles, each addressing various facets of the communication components within Wireless Sensor Networks (WSNs)-based technologies has been included in the review.

The classification system developed for this research was carefully designed to include a broad range of categories and subcategories, defining the varied themes investigated within the communication landscape of WSNs-based technologies. Following are the main categories and their corresponding article counts:

i. The first category encapsulated 39 articles that represented comprehensive Surveys and Reviews of WSNs that also target the routing protocols in WSNs. These articles aimed to synthesize existing knowledge and provide a holistic view of the WSN landscape.

ii. The second category comprised 19 articles, each dedicated to various energy efficiency mechanisms in Wireless Sensor Networks (WSNs).

iii. The third category incorporated 7 articles, each dedicated to elucidating various Data Aggregation techniques. These studies emphasized methods for consolidating data from multiple sensor nodes efficiently.

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iv. The second category comprised 9 articles that revolved around the themes of Coverage within WSNs. These articles sought to enhance our understanding of how sensor nodes can be strategically positioned and localized within a network.

v. The fifth category was populated by 10 articles that examined the role of WSNs in the context of the Internet of Things (IoT). These studies explored the synergy between WSNs and the IoT ecosystem, highlighting their interconnectedness.

vi. The sixth and final category included 16 articles, all dedicated to the critical realm of WSNs Security. These articles probed into strategies and mechanisms for safeguarding the integrity and confidentiality of data within WSNs.

Throughout the analysis of these articles, a number of recurring patterns and themes emerged from the literature. These insights were instrumental in the creation of the taxonomy, as depicted in Figure 1. It is noteworthy that while the taxonomy encompassed distinct categories, some areas exhibited overlapping themes, underscoring the interconnected nature of research within the WSNs domain. This systematic review not only provides a thorough analysis of the publications published during the selected time period, but it also provides a structured taxonomy that highlights the key ideas in the communication-related parts of WSN-based technologies. For academics, researchers, and practitioners looking for a comprehensive knowledge of the changing environment of WSNs and their multiple uses, the various categories & subcategories offer a solid foundation, adding to the larger conversation in this dynamic subject.

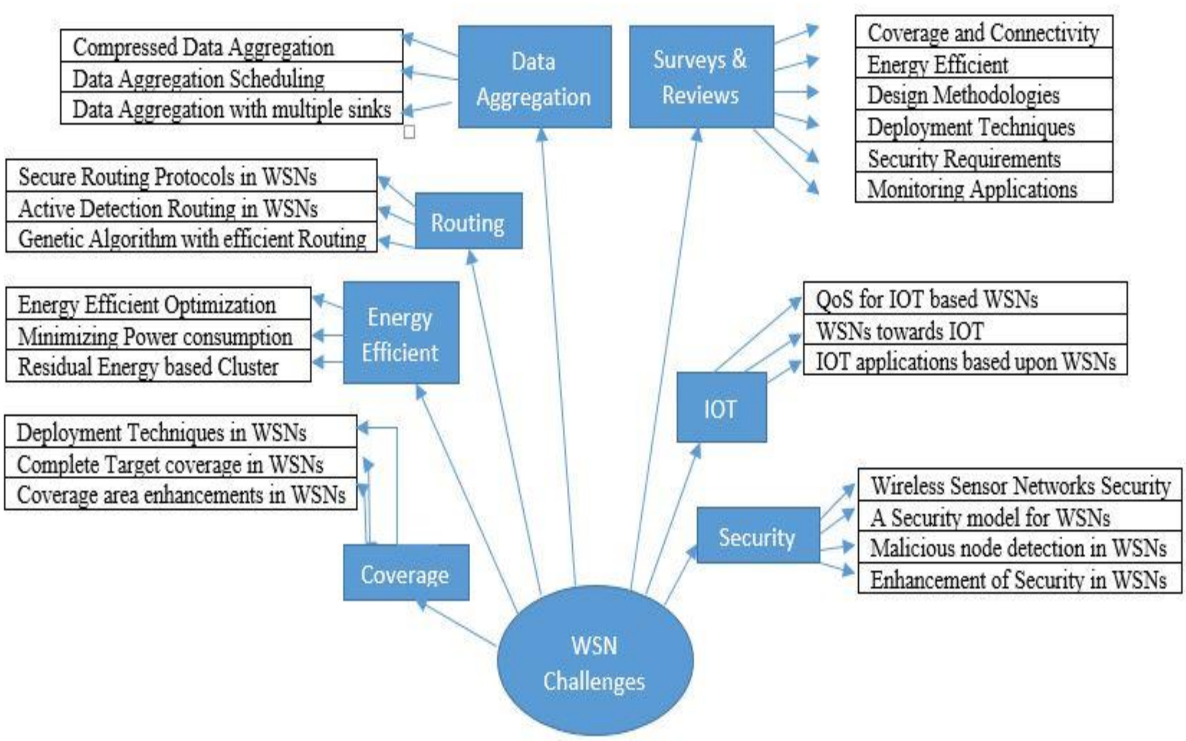

Figure 1. Overview of the literature review on WSNs-based technologies

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Review of WSNs

Applications of WSNs

Reviews are essential to understanding current knowledge in academics since they promote the need for further study in topics that have already undergone thorough examination. The articles in this study have been carefully divided into six different subcategories, each of which focuses on a different aspect of wireless sensor networks (WSNs) and related technologies:

Operating Systems in IoT Hardware (Yaqoob et al., 2019): This subcategory explores the wide range of operating systems used in IoT hardware for data transmission and transfer, emphasizing the critical function of these systems in enabling flawless connectivity across the IoT ecosystem.

Multi-Agent Systems and Real-World Applications (Derakhshan & Yousefi, 2019): Here, the focus is on multi-agent systems and their diverse applications. Both in real-world applications like unmanned aerial vehicles and medical and human-care systems as well as in simulations like object identification, healthcare, control, and security, these systems are useful.

Low-Power Wireless Sensor Networks (LWSN) Applications and Data Collection Methods (Yousif et al., 2018): This subcategory presents an overview of applications and classification within the realm of LWSNs. Additionally, it explores various data collection methods associated with LWSNs, providing valuable insights into the data-gathering processes.

Applications of Wireless Sensor Networks (Bhende et al., 2014): This segment elaborates on the diverse applications of wireless sensor networks. These applications encompass home control, medical uses, military applications, traffic control, agricultural applications, and more. Each application area has specific requirements and implications for the deployment of WSNs.

Software-Defined Networks (SDNs) Architecture and Features (Duan et al., 2018): The general architecture and essential components of software-defined networks (SDNs), a paradigm that transforms network administration and control, are fully described in this area.

Structural Health Monitoring (SHM) with WSNs (Lestari & Arafat, 2019) (Luo et al., 2022): SHM is a critical aspect in ensuring the functionality of offshore turbines. The study focuses on how wireless sensor networks (WSNs) play a pivotal role in reducing costs compared to wired solutions. It evaluates two crucial parameters for WSN deployment in SHM: data rate and bandwidth, which determine the efficiency of communication among nodes.

Monitoring-Oriented Applications (Subramani et al., 2022): This segment centers on applications with a monitoring focus, such as water quality assessments in watersheds and pollution monitoring in urban areas. These applications rely on the data gathered by WSNs to drive meaningful environmental insights.

Underwater Wireless Sensor Networks (UWSN) Review (Tan et al., 2011): This in-depth analysis of UWSNs takes into account elements including ambient variables, localization strategies, media access control, routing protocols, and the effect of packet size on communication effectiveness.

Localization in Sensor Networks (Wei et al., 2021): The final subcategory emphasizes the critical role of localization in sensor networks. It explores how accurately referencing sensor data to their specific

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locations is essential for meaningful data interpretation, making localization a crucial challenge in the field.

Security of WSNs

The articles within this section delve into various aspects of security, classification, and attack models within the context of Wireless Sensor Networks (WSNs) and the Internet of Things (IoT):

Threats to IoT and WSNs (Mamdouh et al., 2018): This article conducts a comprehensive survey of the diverse threats that pose risks to both IoT and WSNs. By exploring these threats in detail, it contributes to the understanding of the security challenges faced by these interconnected ecosystems.

Comprehensive Exploration of Wireless Sensor Networks (Ghani et al., 2019): This article provides a comprehensive analysis of wireless sensor networks, including information on their classification, types, network topologies, attack models, nodes, and related problems and difficulties. By providing an extensive overview, it acts as a valuable resource for understanding the intricacies of WSNs.

Analysis of Network Layer Attacks against RPL Routing Protocol (Tomić & McCann, 2017): The Cooja network simulator is used to analyze network layer attacks on the RPL routing protocol and determine how they affect network performance. It also paves the way for discussions on emerging research opportunities in the realm of network layer security.

Emphasizing Security Requirements for WSNs (Yu et al., 2020): Security requirements are paramount in the realm of WSNs. This article underscores the significance of these requirements and aims to raise awareness about them. It also analyzes existing literature and suggests potential areas for improvement by incorporating essential security aspects, such as characteristics, constraints, and threats.

Management of WSNs

This section encompasses a diverse range of studies and surveys covering numerous aspects of Wireless Sensor Networks (WSNs) and related technologies:

Enhancing Indoor Localization Algorithms in WSNs (Cheng et al., 2020): Enhancing indoor localization techniques in Wireless Sensor Networks (WSNs) is the goal of this review. Localization, which enables the determination of an object's position, is one of the crucial WSN approaches. This review explores how localization can be applied both indoors and outdoors, encompassing several algorithms, including distance estimation techniques such as range-based and range-free methods, while also discussing the applications where location information holds significant value.

Unequal Clustering Approaches and Cluster-Based Routing Protocols Review (Han et al., 2020; Mishra & Verma, 2020; Priyadarshi, Rawat, et al., 2020) : These articles offer a comprehensive review of unequal clustering approaches, providing insights into their objectives, characteristics, and other pertinent details. Furthermore, they critically review cluster-based routing protocols within WSNs, shedding light on their functionality and significance in these networks.

Categorization of Coverage Techniques (Priyadarshi, Rawat, et al., 2020) (Serper & Altın-Kayhan, 2022): This work categorizes various coverage techniques into four major parts: computational geometry-based techniques, force-based techniques, grid-based techniques, and metaheuristic-based techniques. It underscores the importance of the proper deployment of a large number of nodes to ensure efficient data processing and transmission, as highlighted in this review.

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Challenges in Solving Coverage and Connectivity Problems in WSNs Review (Serper & Altın-Kayhan, 2022) (Shafiq et al., 2020): This article reviews the existing challenges and issues in addressing coverage and connectivity problems within WSNs. It also conducts a thorough review of sensing models and provides an in-depth classification of coverage within these networks.

Systematic Literature Review (SLR) for Energy-Efficient Routing [20]: In this systematic literature review (SLR), the focus is on energy-efficient routing within WSNs. Initially, a pool of 172 papers is reviewed. After filtration based on quality evaluation and selection criteria, 50 papers are shortlisted in this review, ensuring their relevance to energy efficiency within WSNs.

Energy-Efficient Routing Protocols for Precision Agriculture Review (Abidin et al., 2021): This review addresses existing energy-efficient routing protocols, with a specific focus on precision agriculture, a critical application area for WSNs in the agricultural ecosystem.

Programming Methodologies for Sensor Network Development Review (Lakshmanna et al., 2022): This article provides a survey of current model-based development approaches and programming paradigms for sensor networks. It categorizes various WSN development approaches with the primary objective of exploring high-level-based methodologies that streamline WSN design, as outlined in this review.

Technical Issues, Challenges, and Design Metrics in WSNs Review (Singh et al., 2021): This review delves into technical issues, challenges, and design metrics within WSNs, offering valuable insights into the complexities and considerations associated with designing and managing these networks.

Applying Machine Learning Algorithms in Wireless Sensor Networks for Agriculture Review (Rahaman & Azharuddin, 2022): This review explores the application of various machine learning algorithms in sensor data analytics within the agricultural ecosystem. It highlights the potential for data-driven insights and informed decision-making within the context of agriculture, as covered in this comprehensive review.

Observation of Reinforcement Learning (RL) in WSNs Review (Kim et al., 2020): This extensive review, spanning over a decade, provides a complete observation of the connection between Reinforcement Learning (RL) and WSNs. It aims to offer valuable opportunities for conducting significant research on the latest challenges in WSNs, as thoroughly reviewed.

Overview of WSNs Architecture, Topologies, and Applications (El Khediri, 2022): This article provides a comprehensive overview of WSN architecture, topologies, and diverse types, along with their applications. It serves as an in-depth introduction to the fundamental aspects of WSNs, as outlined in this informative review.

Energy Efficiency in WSNs

Energy efficiency plays a pivotal role in Wireless Sensor Networks (WSN). Transmitting data wirelessly consumes more power than processing it, causing rapid battery drain when nodes handle large data loads. To mitigate this, it's crucial to focus on reducing data size and optimizing data merging methods for aggregation.

Diverse Approaches to Energy-Efficient Routing (Zhao et al., 2020): Energy-efficient routing within WSNs can be broadly classified into two procedures: These techniques make use of sensor node energy

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for activities like as environmental monitoring, data collection, and wireless data transmission, but they are constrained by the battery capacity limitations.

Centralized Energy-Aware Routing and Node Control (El-Fouly & Ramadan, 2020): Some studies have explored centralized energy-aware routing algorithms, suitable for both homogeneous and heterogeneous networks. The emphasis is on optimizing energy distribution among sensor nodes to enhance network lifetime and throughput.

Efficiency in Data Aggregation (Kandukuri, 2016): The research delves into techniques for maximizing sensor node lifespan while minimizing redundant data transmissions in terms of time and space, thereby promoting energy-efficient routing. Various aggregation styles are examined, such as hierarchical tree structures.

Innovations in Sensor Node Design (Chaudhari & Bansode, 2022): Novel energy-saving WSN nodes have been developed, particularly for temperature monitoring in the Industrial Internet of Things (IIoT). These self-powered nodes aim to improve the sustainability of sensor networks.

Data Aggregation Strategies for Efficiency (Hou & Chen, 2020): Researchers have proposed the "binary-based approach" for data aggregation, organizing it hierarchically in a tree-like structure. This hierarchical style designates leaf nodes as data sources and the root as the central hub for aggregation.
Harvesting Thermal Energy for Efficiency

Energy-Efficient Solutions for Agriculture (Joshi et al., 2022): Another article focuses on designing an architecture for smart agriculture, leveraging SWIPT-enabled WSNs. It explores energy efficiency optimization strategies to facilitate green communication within agricultural systems.

Enhanced Routing Protocols and Security Measures (Bordon et al., 2017): The key objective of a thesis is to enhance routing protocols in WSNs, ensuring efficient energy usage and guarding against threats such as "energy-draining attacks".

Cooperative Systems for Efficient Energy Utilization (Čoko et al., 2022): Presenting a cooperative system that optimizes energy utilization by adapting the actuation of circuitry based on probabilistic ON-OFF switching. This collaborative approach enhances energy efficiency.

Optimizing Data Distribution and Communication (William et al., 2022): The study presents a novel protocol for data distribution based on the Chord protocol and suggests using Distributed Hash Tables (DHTs) for efficient data communication. These techniques aim to reduce energy consumption during data exchange.

Machine Learning for Energy Efficiency: Exploring the role of machine learning in enhancing the energy efficiency of WSNs. Machine learning techniques are used to reduce energy consumption and prolong the lifespan of sensor networks, making them more cost-effective (Ram et al., 2019).

Solar Energy Harvesting for IoT Sustainability (Tagne Fute et al., 2022): Leveraging solar energy harvesting systems for IoT end nodes to ensure uninterrupted power availability. Solar cells are utilized as an input source, countering power failures and information loss in IoT.

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Routing Protocols in WSNs

Routing Protocols and Their Objectives: Routing serves as the method for establishing routes between source and destination nodes in Wireless Sensor Networks (WSNs). The primary goal of routing protocols is to determine the shortest path, optimizing energy consumption, minimizing delays, and ensuring the highest quality of service to extend the network's lifetime.

Categorization of WSN Routing Protocols (Hussein & Abd Khaled, 2020): Based on network layout, WSN routing protocols are divided into three main groups: flat routing protocols, hierarchical (cluster-based), and location-based protocols.

Enhancing Network Security Through Routing (Senthil Kumaran et al., 2021): Ensuring network security is a critical concern. Secure routing protocols are explored to enhance the security of WSNs. The work introduces a secure routing solution that uses multi-data flow topologies (MDT) to fend off threats and suggests energy-saving optimization techniques.

Optimizing Routing for Network Efficiency (Han et al., 2022): Effective routing solutions may greatly extend the life of the network, boost productivity, and provide a high level of service.

Energy-Efficient Routing with Mobile Sinks (Zhong & Ruan, 2018): The study investigates energy-efficient routing methods with mobile sinks and the impact of the number of mobile sinks on network lifetime. Simulation results highlight optimal network performance when the number of mobile sinks is approximately three.

Hierarchical Routing Protocols Enhanced with Swarm Intelligence (Zagrouba & Kardi, 2021): The taxonomy of hierarchical routing protocols is examined, with a focus on hybrid hierarchical routing protocols that incorporate intelligent routing. The proposed approach leverages swarm intelligence in cluster formation and hierarchical routing to enhance scalability and robustness.

DEEP: A Delay and Energy-Efficient Proactive Routing Protocol (Argoubi et al., 2018): The introduction of the "Delay and energy efficient proactive" routing protocol (DEEP), a hierarchical method for finding the shortest path and performing data aggregation. DEEP seeks to strike a balance between delay and energy consumption.

Exploring a Variety of WSN Routing Protocols (Biswas et al., 2023): An overview of various routing protocols applied in WSNs is presented.

Optimizing Routing Through Genetic Algorithms (Bhola et al., 2020): The study proposes the use of Genetic Algorithms (GA) to optimize and determine routes among nodes to/from the sink, reducing energy costs.

Analyzing Design Requirements for Routing Protocols (Behera et al., 2022): The network topology and node mobility of routing protocols are explored, and the design requirements for routing protocols are analyzed.

Routing Protocols for Efficient Communication (Bhushan & Sahoo, 2019): The critical role played by routing protocols in ensuring efficient communication between source and destination nodes is discussed. The selection of the best routing protocol is vital for network performance, service quality, and reliability.

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Coverage Methods in WSNs

Discovery Coverage and Network Connectivity – Crucial WSN Challenges: (Jain et al., 2023): Wireless Sensor Networks (WSNs) face two significant challenges: "discovery coverage" and "network connectivity." Coverage pertains to the sensor network's ability to monitor an area, while connectivity reflects the reliability of information collection and transmission to the processing station.

Sensing Coverage and Field of Interest (FoI) (Tripathi et al., 2018): Sensing coverage in the Field of Interest (FoI) is a crucial task for sensor nodes in linked WSNs. FoI is considered covered when at least one sensor node monitors every location in the FoI.

Significance of Network Connectivity (Toloueiashtian et al., 2022): Network connectivity is a critical topic in WSNs. A WSN is considered connected if every pair of nodes can communicate with each other, directly or indirectly. Coverage also serves as a quality of service (QoS) measure.

Addressing Coverage Challenges (Priyadarshi, Gupta, et al., 2020): To ensure that the entire sensor network is covered, studies examine two types of coverage issues, namely k-UC and k-NC, in WSNs.

Improving Quality of Coverage (Yao et al., 2021): A novel coverage challenge aims to enhance the quality of coverage in WSNs.

Expanding Coverage Area (Serper & Altın-Kayhan, 2022): Efforts are directed toward increasing the coverage area and identifying areas not covered by any sensor.

Analyzing Connectivity and Coverage (Yang et al., 2017): The study focuses on the challenges of WSN connectivity and coverage, analyzing their impact and proposing models for monitoring applications.

Energy-Efficient Solutions for Coverage (Renuga Devi & Sethukarasi, 2022): A study explores the advantages of energy transfer for addressing coverage challenges and introduces a new model, Mixed Integer Linear Program (MILP).

Optimizing Sensor Deployment for Quality Sensing (Wajgi & Tembhurne, 2023): Research aims to identify the best sensor deployment to improve sensing quality while considering factors like transmission range and network lifetime constraints. In both homogeneous and heterogeneous mobile wireless sensor networks, key requirements for sensor distribution are created.

WSNs towards IOT

Growing Significance of WSNs and IoT (Khattab & Youssry, 2020): In today's world, human life increasingly relies on smart devices, making Wireless Sensor Networks (WSNs) and the Internet of Things (IoT) highly significant. As these technologies gain importance, the challenges and the need for enhancement become more critical.

Leveraging Machine Learning in WSNs and IoT (Gupta et al., 2022): One study reviews the application of machine learning in WSNs and IoT, highlighting its potential and relevance.

Enhancing Energy-Efficient Communication (Shahraki et al., 2020): A proposal introduces a new structure for next-generation wireless sensor networks within IoT, featuring a three-layer transmission method to optimize energy-efficient communication among nodes.

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Addressing Key Challenges for IoT-Based WSNs (Fizza et al., 2021): The four issues at the center of this thesis are high node density, node mobility, traffic heterogeneity, and integration with cloud computing-based IoT systems. These issues all have an impact on the performance of IoT within WSNs.

Integration of WSNs and IoT for Diverse Services (Alablani & Alenazi, 2020): A dissertation provides insight into integrating WSNs with the Internet, offering a vision for services that include managing heterogeneous traffic in IoT-based WSNs.

Sensor Deployment Challenges in WSNs (Hasan & Mohd Hanapi, 2023): Sensor deployment is a crucial task in WSNs, especially for applications requiring low-latency communication. This study delves into the applications of WSNs that demand quick information dissemination.

Integrating WSNs into IoT Architecture (Campos & Cugnasca, 2014): The integration of WSNs into the broader IoT architecture is explored, with a focus on connecting WSNs to the Internet.

Applications of RFID and WSN Technologies in IoT (Landaluce et al., 2020): Five areas of application that use IoT's Wireless Sensor Networks (WSNs) and Radio Frequency Identification (RFID) technology are discussed in an article.

IoT-Based Temperature Monitoring in Hospitals (Leng et al., 2020): An article details an IoT approach for monitoring hospital temperatures, aiming to achieve cost-effective integration of smart sensors across large areas. It outlines the IoT architecture, encompassing the node layer, management layer, and cloud-based layer for remote monitoring.

Security

Additional important subject is a security of sensor nodes for data and network. Usually, security must be protection system more and stronger as possible.

Importance of Security in WSNs (Olakanmi & Dada, 2020): Security is a critical concern for both data and network protection in Wireless Sensor Networks (WSNs). The level of security must be robust enough to withstand potential threats. However, overly strong security measures can impact system performance, especially in resource-constrained devices.

Selecting the Appropriate Security Level (Gong, 2017): It's essential to strike a balance when implementing security techniques in WSNs, choosing an appropriate level of security that matches the device's resources. For instance, some security versions may not require high-level encryption for sensor nodes.

Enhancing Security Against Energy-Draining Attacks (Parenreng et al., 2019): The primary goal of this paper is to enhance security against attacks, specifically "energy-draining attacks" targeting WSNs.

Using ARSy Framework for Security (Parenreng et al., 2019): This study provides solutions for resource-limited WSNs and utilizes the ARSy Framework for enhancing security.

Evaluation of Cryptographic Methods in WSNs (Gulen et al., 2019): An evaluation of the performance of cryptographic methods such as RSA and Elliptic Curve in the WSN environment, with a focus on encryption time and energy consumption.

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Securing Over-The-Air Programming (OTAP) (Yakubu & Maiwada, 2023): Discussion of security techniques for Over-The-Air Programming using asymmetric cryptography in WSNs.

Addressing Security Risks in Routing Protocols (Lata et al., 2021): Examination of various security risks in WSN routing protocols and a list of protective methods.

Low Power Cyber-Security Mechanism (Hussain & Hanapi, 2023): Presentation of a low-power cyber-security mechanism for WSN monitoring applications, capable of detecting and mitigating various attacks.

Three-Tier Security for WSNs (Xu & Liu, 2018): Development of a three-tier wireless sensor network with physical layer security, random geometry optimization, and secure transmission methods.

Anti-Sinkhole Attack Detection (Vera-Perez et al., 2019): A proposal for detecting and mitigating sinkhole attacks using a Swarm Intelligence optimization algorithm.

Multi-Layered Security for WSNs (Kuthadi et al., 2022): Discussion of multi-layered methods to enhance security in WSNs, addressing challenges related to memory, energy, and computing power constraints
.

Machine Learning for Enhanced WSN Services (Qureshi et al., 2023): Emphasis on the use of machine learning methods to enable WSNs to provide various services effectively while optimizing cost, energy efficiency, and network lifespan.

Security Model for WSNs (Song & Zhou, 2019): A security model for WSNs is introduced together with a case study on water quality monitoring. This model is intended to help the deployment and upkeep of secure WSNs.

Security Encryption for WSNs (Ibrahim et al., 2021): The presentation of a novel security encryption framework for wireless sensor networks, designed to enhance security for sensor nodes.

Detecting Attacks in IoT Environments (Jain et al., 2023): With an emphasis on detecting Denial of Service attacks and assaults against 6LoWPAN and CoAP communication protocols, this proposal aims to identify and prevent attacks in Internet-integrated Constrained Application Protocol (CoAP) environments.

Channel-Aware Detection for Selective Forwarding Attacks (Ibrahim et al., 2021): Introduction of a channel-aware detection threshold to identify selective forwarding attacks in WSNs, estimate information sending performance, and examine packet loss.

Addressing Security Topics and Threats in WSNs (Agrawal & Ahlawat, 2020): Discussion of various security topics, objectives, and threats in WSNs, given their inherent vulnerabilities.

Authentication System for WSNs (Kwon et al., 2021): Focus on an authentication system suitable for the WSN architecture, enabling remote clients to undergo authentication processes effectively.

Securing IoT Sensor Data (Zeadally & Tsikerdekis, 2020): The study emphasizes the significance of secure communication and power-efficient detection of sensor data in the context of IoTs.

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DISCUSSION

The primary objective of this review is to provide a contemporary perspective on the structure, challenges, and applications of WSNs. This study involves a comprehensive analysis of WSNs by delving into prior research in this domain. To facilitate future research endeavors in this area, we introduce a taxonomy that offers various benefits.

For instance, this taxonomy organizes the existing body of literature into distinct categories, enabling a clearer understanding of the research landscape. Numerous researchers are engaged in exploring IoT-based WSN technologies, but many studies lack a well-structured framework, resulting in fragmented research activities. While some studies focus on the fundamental aspects of wireless networking, others emphasize enhancing the capabilities of WSNs. The proposed overview not only provides a cohesive research framework but also serves as a valuable resource for researchers seeking insights into the most pressing issues and potential solutions in this field. Additionally, it offers students and academics guidance in selecting research topics related to WSN technologies.

This study categorizes WSNs based on their applications and constraints, which piques the interest of researchers and encourages both consumers and users to engage with this field. By doing so, this classification aids researchers in identifying gaps and weaknesses within the existing body of literature.

In Table 1, we present a distribution of papers across the most significant directions in WSN limitations, solutions, and applications. This visual representation further illustrates the breadth and depth of research in this area.

Table 1: Division of papers among WSN limitations & Solutions

Topics	Number
Survey and Review of Applications of WSNs	10
Survey and Review of Security of WSNs	5
Survey and Review of Management of WSNs	13
Survey and review of WSNs towards IoTs	10
Improve Routing Protocols in WSNs	11
Improve Energy consumption in WSNs	19
Improve Data Aggregation Techniques	7
Improve Coverage and Connectivity in WSNs	9
Improve the security in WSNs	16

MOTIVATIONS

The investigation into the components of communication within WSN-based technologies has emerged as a promising and dynamic research area. Specifically, in the context of the Internet of Things (IoTs), we embark on a thorough survey of related studies that emphasizes the important roles played by a variety of parameters, such as topology, network structure, coverage, connection, localization, routing,

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clustering, energy efficiency, security, and the integration of WSNs with the Internet and cloud computing, are shown in this part.

The principal impetus behind this study is the emphasis on addressing several critical requisites (Koskela, 2018; Shafiq et al., 2020). These requirements encompass energy efficiency, bandwidth optimization, quality of service, scalability, throughput, mobility, and reliability. It is our endeavor to provide due attention to these essential elements in the context of WSNs and their communication dynamics. This attention not only sheds light on the current state of research but also paves the way for the development of advanced and innovative solutions in this ever-evolving field.

CHALLENGES AND RELATED RECOMMENDATIONS

Within this section, we delve into a comprehensive examination of the limitations associated with applications in the domain of Wireless Sensor Networks (WSNs). We aim to offer practical recommendations to enhance the performance of these sensor networks, bearing in mind the manifold challenges they present.

One of the primary concerns surrounding WSN-based technologies is their performance limitations. In this context, we underscore the need for a closer look at these limitations, followed by a set of recommendations geared toward optimizing the functionality of such systems. Although WSN-based technologies offer numerous advantages, they may not always provide the most optimal solutions when connecting WSNs to the Internet or IoT components. Researchers and academics frequently grapple with various issues and constraints when employing WSN technologies across diverse applications, especially those pertaining to environmental monitoring within IoT frameworks.

In this discussion, we elucidate several key challenges and concerns, particularly those related to energy efficiency, as it is paramount for prolonging battery life. These challenges encompass:

i. Security: The foremost challenge in all WSN applications revolves around security. Protecting sensitive data, such as personal health information or organizational business data, is of utmost importance. It is imperative to ensure the privacy and security of data transmitted across WSNs. While there are security mechanisms in place, such as authentication and encryption, they often fall short. The evolving landscape of technology, particularly the integration of IoT with WSNs, introduces new security challenges.

ii. Privacy: Safeguarding personal and confidential information is now a fundamental consumer requirement, necessitating a robust privacy framework.

iii. Energy Constraints: WSNs still heavily rely on energy-constrained batteries for data processing and transmission, despite significant advancements in the field.

iv. Resource Limitations: Wireless sensor nodes possess limited memory and computational capabilities, and these limitations persist, even when deployed in harsh and inaccessible environments.

v. Coverage and Connectivity: Ensuring that applications can effectively connect with sensors, people, and cloud resources is a persistent challenge.

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vi. Data Aggregation Techniques: The process of data aggregation and its efficient execution remain areas of concern.

vii. Sensor Deployment Methods: The strategies for deploying sensor nodes are critical for optimizing the network's performance.

viii. Clustering Algorithms: The choice of clustering algorithms plays a pivotal role in network efficiency.

ix. Localization Approaches: Effective localization is critical for numerous applications.

x. Routing Protocols: Selecting the most appropriate routing protocols is essential for seamless data transmission.

Through this exploration of challenges and recommendations, we aim to provide a comprehensive understanding of the complexities inherent in WSN-based applications and offer guidance for addressing these issues. This knowledge not only benefits the research community but also paves the way for practical solutions that can improve the performance and reliability of WSNs in a variety of applications.

Due to these challenges, and given the array of challenges and constraints that Wireless Sensor Networks (WSNs) encounter, particularly in terms of energy consumption and other limitations, we propose a series of recommendations to enhance their overall performance:

i. Security Enhancement: Continuously update and enhance security measures. This includes exploring advanced encryption techniques, intrusion detection systems, and anomaly detection mechanisms to safeguard data integrity and privacy. In addition, constant monitoring and adaptation to emerging security threats are vital.

ii. Privacy Preservation: Develop and implement rigorous privacy protection mechanisms to ensure personal and sensitive data remains confidential and inaccessible to unauthorized entities. Compliance with data protection regulations should be a top priority.

iii. Energy-Efficient Protocols: Opt for energy-efficient communication and routing protocols. Low-power and adaptive algorithms can significantly reduce energy consumption, prolonging the lifespan of sensor nodes. Consider the use of protocols designed specifically for energy conservation.

iv. Resource Management: Manage the limited resources of sensor nodes judiciously. Implement strategies such as intelligent data aggregation, data compression, and data filtering to optimize resource utilization.

v. Hybrid Energy Solutions: Explore hybrid energy solutions that combine traditional battery power with alternative energy sources like solar, kinetic, or thermal energy harvesting. This approach can mitigate the energy constraints of sensor nodes.

vi. Improved Hardware: Invest in advanced sensor hardware with improved energy efficiency, computational capabilities, and memory capacity. Ongoing advancements in sensor technology can contribute to better performance.

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vii. Coverage and Connectivity Planning: Ensure comprehensive coverage and reliable connectivity by strategically deploying sensor nodes, employing coverage-based deployment techniques, and implementing efficient clustering algorithms.

viii. Localization and Tracking: Utilize precise localization techniques and tracking mechanisms to enhance the accuracy of data collection. This is particularly important for applications that rely on location-specific information.

ix. Data Aggregation: Implement efficient data aggregation mechanisms, such as data fusion and in-network processing, to reduce redundant data transmissions and lower energy consumption.

x. Quality of Service (QoS): Prioritize Quality of Service in the network design to meet application-specific requirements. This includes optimizing data transmission, reducing latency, and ensuring data reliability.

xi. Research Collaboration: Foster collaboration among researchers, academia, and industry stakeholders to address WSN challenges collectively. Joint efforts can lead to innovative solutions and best practices.

xii. Continuous Monitoring and Adaptation: Regularly assess the performance of WSNs, monitor energy consumption patterns, and adapt strategies as needed. Proactive maintenance and management are essential for long-term efficiency.

These recommendations collectively aim to mitigate the challenges posed by energy constraints, limited resources, security concerns, and other performance limitations in WSNs. By embracing these strategies, researchers and practitioners can work toward improving the effectiveness and reliability of sensor networks across a wide range of applications.

CONCLUSION

This comprehensive review highlights the growing significance of wireless sensor networks (WSNs) in the realm of networking due to their efficiency, cost-effectiveness, and compact size. The expanding reliance on WSN-dependent applications has led to a critical need for effective solutions, particularly in the context of the Internet of Things (IoT), where WSN efficiency plays a pivotal role. The study systematically categorized research conducted from 2017 to 2023 into six key domains, encompassing WSN applications, management, and security; routing and energy-saving techniques; data integrity and privacy in information gathering; connectivity and positioning methods; integration of IoT technology into WSNs with a strong focus on secure data transmission; and research efforts dedicated to enhancing energy efficiency while ensuring robust security. By addressing the motivation behind WSN application integration in IoT and tackling the challenges, roadblocks, and potential solutions, this review offers valuable insights into the field. A central concern remains energy consumption, offering untapped potential for improvements in energy efficiency while maintaining stringent security measures. The study also spotlights the limitations of existing approaches, particularly in achieving energy-efficient routing within secure WSNs. Overall, this review contributes to a more profound understanding of WSNs' pivotal role in secure IoT applications, emphasizing the critical challenges and opportunities in this dynamic field.

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