Perspective
Volume 16:04, 2025

Global Journal of Technology and Optimization

ISSN: 2229-8711

Open Access

Wireless Sensor Networks: Challenges, Solutions, Applications

María Santacruz*

Department of Environmental Modeling and Biogeochemical Engineering, Universidad de Sevilla, 41012 Sevilla, Spain

Introduction

This review delves into the recent advancements in localization techniques for Wireless Sensor Networks (WSNs), a critical aspect for many WSN applications. It categorizes localization methods into range-based and range-free, discussing their underlying principles, performance metrics, and limitations. The paper highlights the evolution of these techniques, from traditional approaches to more sophisticated algorithms, and points towards challenges such as accuracy, energy efficiency, and scalability in dynamic WSN environments.[3].

This paper offers a comprehensive overview of the security challenges prevalent in Wireless Sensor Networks (WSNs), addressing issues like node capture, jamming, denial-of-service, and routing attacks. It systematically categorizes existing security solutions, highlighting their strengths and weaknesses across different layers of the WSN architecture. The review also discusses emerging threats and outlines potential future research directions to enhance WSN security.[2].

This comprehensive review examines various routing protocols designed for Wireless Sensor Networks (WSNs), categorizing them based on their network structure, operation mode, and energy efficiency. It discusses the strengths and weaknesses of popular protocols like LEACH, PEGASIS, and SPIN, along with more recent advancements. The paper evaluates how these protocols address critical WSN challenges such as energy conservation, scalability, and Quality of Service, concluding with insights into future research directions for developing more robust and adaptive routing solutions.[6].

This review provides a thorough examination of various energy harvesting techniques applicable to Wireless Sensor Networks (WSNs), covering solar, wind, thermal, and vibration energy sources. It explores the challenges and opportunities associated with integrating these methods, aiming to extend the operational lifespan of WSN nodes by reducing reliance on conventional batteries. The paper details different energy storage solutions and power management strategies vital for efficient energy utilization in self-sustaining WSN deployments.[1].

This survey paper investigates secure and privacy-preserving routing protocols developed for Wireless Sensor Networks (WSNs). It critically examines the vulnerabilities of routing in WSNs and evaluates various cryptographic and non-cryptographic techniques employed to protect data confidentiality, integrity, and node authenticity during communication. The review discusses different routing protocol classifications and their security enhancements, identifying current limitations and suggesting areas for future research to build more resilient and privacy-conscious WSN routing solutions.[9].

This research proposes a lightweight blockchain-based security framework specifically tailored for Wireless Sensor Networks (WSNs), addressing the inherent vulnerabilities of WSNs to various attacks. The framework leverages the distributed ledger technology of blockchain to provide enhanced data integrity, authenticity, and immutability without imposing excessive computational overhead on resource-constrained sensor nodes. It outlines the architectural design and evaluates its effectiveness in mitigating common security threats in WSN environments.[4].

This survey paper provides an in-depth analysis of Machine Learning (ML) approaches applied for anomaly detection in Wireless Sensor Networks (WSNs). It examines how various ML algorithms, including supervised, unsupervised, and semi-supervised techniques, are utilized to identify unusual patterns or malicious activities that deviate from normal WSN behavior. The review discusses the challenges in deploying ML for anomaly detection in resource-constrained environments and highlights the performance of different models in terms of accuracy, false positive rates, and computational complexity.[5].

This comprehensive survey focuses on data fusion techniques within Wireless Sensor Networks (WSNs), which are crucial for aggregating and processing redundant or complementary data from multiple sensor nodes to reduce transmission load and conserve energy. It categorizes data fusion methods based on different levels (low, intermediate, high), discussing various algorithms and their applicability across diverse WSN scenarios. The paper evaluates the trade-offs between accuracy, computational complexity, and energy efficiency, offering insights into optimal data fusion strategies for specific WSN deployments.[10].

This review paper explores the integration of edge computing paradigms with Wireless Sensor Networks (WSNs). It clarifies how edge computing can address the limitations of traditional cloud-based processing for WSNs, particularly regarding latency, bandwidth, and energy consumption. The article discusses various architectures and frameworks that facilitate edge-assisted data processing and analytics, enhancing real-time responsiveness and efficiency in diverse WSN applications. It also identifies open challenges and future research opportunities in this rapidly evolving domain.[7].

This paper presents a review focused on the application of Internet of Things (IoT) in smart agriculture, specifically highlighting the role of Wireless Sensor Networks (WSN) technologies. It covers how WSNs collect vital environmental data, discusses various data analytics techniques used to process this information, and explores different applications for optimizing agricultural practices such as irrigation, pest control, and yield management. The review emphasizes the potential of IoT-enabled WSNs to transform traditional farming into data-driven smart agriculture.[8].

Description

This review provides a thorough examination of various energy harvesting techniques applicable to Wireless Sensor Networks (WSNs), covering solar, wind, thermal, and vibration energy sources. It explores the challenges and opportunities associated with integrating these methods, aiming to extend the operational lifespan of WSN nodes by reducing reliance on conventional batteries. The paper details different energy storage solutions and power management strategies vital for efficient energy utilization in self-sustaining WSN deployments [1].

Recent advancements in localization techniques for Wireless Sensor Networks (WSNs) are critical for many applications. These methods, categorized into range-based and range-free, reveal their underlying principles, performance metrics, and limitations. The evolution from traditional approaches to sophisticated algorithms points towards ongoing challenges in accuracy, energy efficiency, and scalability within dynamic WSN environments [3].

This paper offers a comprehensive overview of the security challenges prevalent in Wireless Sensor Networks (WSNs), addressing issues like node capture, jamming, denial-of-service, and routing attacks. It systematically categorizes existing security solutions, outlining their strengths and weaknesses across different WSN architecture layers, alongside discussions on emerging threats. Further efforts investigate secure and privacy-preserving routing protocols, examining cryptographic and non-cryptographic techniques to protect data confidentiality, integrity, and node authenticity during communication [9].

To mitigate specific vulnerabilities, a lightweight blockchain-based security framework has been proposed for WSNs. This framework uses distributed ledger technology of blockchain to provide enhanced data integrity, authenticity, and immutability, ensuring minimal computational overhead on resource-constrained sensor nodes [4]. Meanwhile, various routing protocols are designed for Wireless Sensor Networks (WSNs) and evaluated based on their network structure, operation mode, and energy efficiency, addressing critical challenges like energy conservation, scalability, and Quality of Service [6]. Data fusion techniques are also vital for aggregating and processing redundant or complementary data from multiple sensor nodes to reduce transmission load and conserve energy, with methods categorized by levels and assessed for applicability across diverse WSN scenarios, balancing accuracy, computational complexity, and energy efficiency [10]. Additionally, Machine Learning (ML) approaches are applied for anomaly detection, employing supervised, unsupervised, and semi-supervised techniques to identify unusual patterns or malicious activities in WSNs, despite challenges in resource-constrained deployment [5].

This review paper explores the integration of edge computing paradigms with Wireless Sensor Networks (WSNs) [7]. This integration addresses the limitations of traditional cloud-based processing for WSNs, especially concerning latency, bandwidth, and energy consumption. Various architectures and frameworks facilitate edge-assisted data processing and analytics, enhancing real-time responsiveness and efficiency in diverse WSN applications. Looking ahead, the application of Internet of Things (IoT) in smart agriculture is transforming traditional farming. WSN technologies collect vital environmental data, which, combined with data analytics, optimizes agricultural practices such as irrigation, pest control, and yield management [8].

Conclusion

Wireless Sensor Networks (WSNs) present unique challenges and opportunities across various domains. Energy harvesting techniques, like solar, wind, thermal, and vibration sources, are essential for extending the operational lifespan of WSN nodes by reducing reliance on conventional batteries, with robust power management strategies being vital for efficient energy use. Security is another critical concern, addressing issues from node capture and jamming to denial-of-service and routing attacks, requiring categorized solutions and future research directions to enhance WSN security. Localization techniques, both range-based and range-free, are crucial for many WSN applications, facing challenges in accuracy, energy efficiency, and scalability in dynamic environments. Machine Learning (ML) approaches are being explored for anomaly detection in WSNs, utilizing supervised, unsupervised, and semi-supervised techniques to identify unusual patterns and malicious activities, despite deployment challenges in resource-constrained settings. Diverse routing protocols for WSNs are designed to balance network structure, operation mode, and energy efficiency, aiming to address energy conservation, scalability, and Quality of Service (QoS). Furthermore, the integration of edge computing paradigms with WSNs tackles limitations of traditional cloud-based processing by reducing latency, bandwidth, and energy consumption, enhancing real-time responsiveness. Internet of Things (IoT)-based smart agriculture leverages WSNs for environmental data collection and analytics to optimize practices like irrigation and pest control. Data fusion techniques are also crucial for aggregating and processing data from multiple sensor nodes, reducing transmission load and conserving energy, with various algorithms balancing accuracy, complexity, and efficiency in different WSN scenarios.

Acknowledgement

None.

Conflict of Interest

None.

References

1. Mahdi Bodaghi, Mohamed Amine Lahimer, Nima Razak. “A comprehensive review on energy harvesting techniques and their integration in wireless sensor networks.” *Renew. Sust. Energy Rev.* 147 (2021):111192.

2. Pradeep Kumar Singh, Manoj Kumar Mishra, Mahendra Kumar Singh. “Security challenges and solutions in Wireless Sensor Networks: A comprehensive review.” *J. Netw. Comput. Appl.* 159 (2020):102607.

3. Muhammad Awais Khan, Abdul Hanan Abdullah, K. B. E. Lim. “A review on recent advances in localization techniques for wireless sensor networks.” *J. Netw. Comput. Appl.* 129 (2019):30-46.

4. Sumit Kumar, Pardeep Kumar, Kamalpreet Singh. “Lightweight blockchain-based security framework for wireless sensor networks.” *J. Syst. Archit.* 125 (2022):102434.

5. Mehedi Masud, Md Zakirul Alam, K. Z. I. Nima. “Machine learning approaches for anomaly detection in wireless sensor networks: A survey.” *J. Netw. Comput. Appl.* 202 (2022):103362.

6. Arpan Gupta, Deepak Kumar Singh, Prasenjit Dey. “Routing protocols for wireless sensor networks: a comprehensive review and future directions.” *J. Supercomput.* 78 (2022):442-491.

7. Xiaoyang Liu, Wenjun Jin, Yan Li. “Edge computing for wireless sensor networks: A review.” *Future Gener. Comput. Syst.* 125 (2021):301-315.

8. Anjireddy Kondareddy, N. N. R. K. V. S. G. Konda. "Internet of Things-based smart agriculture: A review of WSN technologies, data analytics, and applications." *Meas. Sensors* 27 (2023):100755.

9. Feras Al-Zubi, Ghassan Al-Zoubi, Abdulrahman Al-Mothana. "A survey on secure and privacy-preserving routing protocols for wireless sensor networks." *J. Netw. Comput. Appl.* 161 (2020):102660.

10. Muhammad Rizwan Khan, Abdul Hanan Abdullah, Abdul Mateen. "Data fusion techniques in wireless sensor networks: A comprehensive survey." *J. Netw. Comput. Appl.* 151 (2020):102492.

How to cite this article: Santacruz, María. "Wireless Sensor Networks: Challenges, Solutions, Applications." *Global J Technol Optim* 16 (2025):459.

Address for Correspondence: María, Santacruz, Department of Environmental Modeling and Biogeochemical Engineering, Universidad de Sevilla, 41012 Sevilla, Spain, E-mail: m.santacruz@us.es

Received: 31-Jul-2025,ManuscriptNo.gjto-25-176007; **Editor assigned:** 04-Aug-2025,PreQCNo.P-176007; **Reviewed:** 14-Aug-2025,QCNo.Q-176007; **Revised:** 21-Aug-2025,ManuscriptNo.R-176007; **Published:** 28-Aug-2025, DOI: 10.37421/2229-8711.2025.16.459