Science Archives (2021) Vol. 2 (4), 373-380

Science Archives (ISSN:2582-6697)

Journal homepage: www.sciencearchives.org

Review Article

https://doi.org/10.47587/SA.2021.2418

A review of green and sustainable wireless sensor networks: challenges, solutions, and future directions

Rahul Gautam[1]✉, Pramod Kumar[2], Sumit Kumar Saini[3], and Ajay Kumar[4]

Department of Computer Application, Shri Ram College, Muzaffarnagar, UP, India

Received: Oct 18, 2023/ Revised: Nov 24, 2023/Accepted: Nov 25, 2023

Abstract

This review paper presents a comprehensive overview of green and sustainable wireless sensor networks (WSNs), focusing on strategies and technologies aimed at minimizing energy consumption, reducing environmental impact, and promoting long-term sustainability. Through an analysis of existing literature and case studies, this paper examines the challenges faced by traditional WSNs in terms of energy efficiency and environmental sustainability, and explores various approaches and solutions proposed to address these challenges. Additionally, the paper identifies emerging trends, research gaps, and future directions in the field of green and sustainable WSNs.

Keywords: WSN, energy efficiency, environmental sustainability, energy harvesting, and energy transfer

Introduction

Wireless Sensor Networks (WSNs) are networks composed of numerous spatially distributed autonomous sensors that collaboratively monitor physical or environmental conditions and relay collected data wirelessly to a central location or sink node. A Wireless Sensor (WSN) is a set of several (few tens or even thousands) spatially dispersed and wirelessly linked devices, called sensor nodes or simply nodes, along with at least one sink node that is called base station (BS) [Akyildiz et al, 2002]. Nodes aim to not only monitor and collect information related to the ambient conditions that exist in a field of Network interest (FoI) but also process and finally exchange the relative data with other nodes and the BS [Yick et al, 2008].

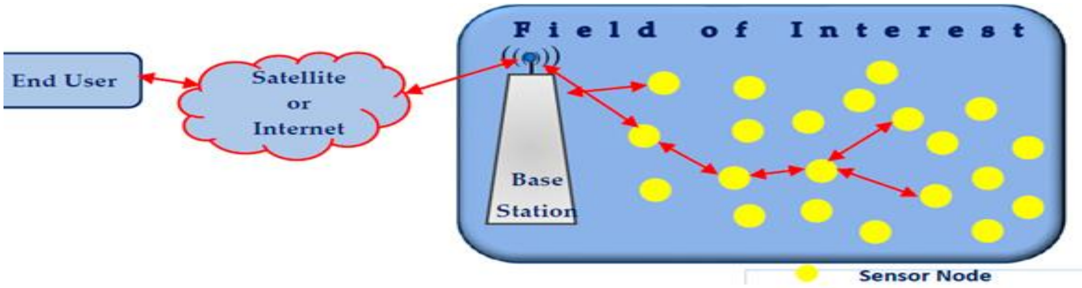

Fig. 1 Typical architecture of a wireless sensor network

WSNs, due to the collaboration of their sensor nodes and their BSs, are able to monitor the current conditions at widespread FoIs. This makes WSNs be ideal to support a constantly increasing range of human activities [Kandris et al, 2020]. Specifically, although the first WSNs ever used served only military purposes [Warneke et al, 2001], nowadays WSNs are not only still used in the military sector [Đuriši´c et al, 2012] but they also are utilized in an extensive variety of civil applications.

These networks play a crucial role in various applications across different domains due to their ability to collect, process, and transmit data from remote or inaccessible locations. Here's an overview of WSNs and their importance in various applications:

Environmental Monitoring

WSNs are extensively used for environmental monitoring applications such as air quality monitoring, water quality monitoring, forest fire detection, and biodiversity conservation. Sensors deployed in natural habitats or urban areas continuously collect data on temperature, humidity, pollution levels, and other environmental parameters, enabling early detection of environmental threats and informed decision-making for conservation efforts. To prevent human health from these adverse effects, the environmental monitoring is becoming a fundamental thing and is being made possible because of WSs [Lanzolla et al, 2021]. In an urban environment, a study have been proposed in [Luo et al, 2020] for measuring.

Infrastructure Monitoring

WSNs are deployed for monitoring critical infrastructure such as bridges, dams, pipelines, and buildings to detect structural integrity issues, corrosion, or potential failures. By continuously monitoring structural conditions in real-time, WSNs help prevent accidents, minimize downtime, and optimize maintenance schedules, thus enhancing the safety and reliability of infrastructure systems.

Healthcare and Medical Monitoring

In healthcare applications, WSNs are used for remote patient monitoring, elderly care, and medical diagnostics. Wearable sensors and implantable devices collect physiological data such as heart rate, blood pressure, glucose levels, and body temperature, allowing healthcare providers to monitor patients' health status remotely and provide timely interventions.

Smart Agriculture

WSNs play a pivotal role in precision agriculture by providing real-time monitoring of soil moisture, temperature, humidity, and crop conditions. By analyzing sensor data, farmers can optimize irrigation, fertilization, and pest control practices, reduce resource usage, increase crop yields, and improve overall farm productivity.

Industrial Monitoring and Control

WSNs are deployed in industrial environments for monitoring and controlling manufacturing processes, equipment performance, and energy consumption. By collecting data from sensors installed on machinery, production lines, and facilities, WSNs enable predictive maintenance, fault detection, and optimization of energy usage, leading to increased operational efficiency, reduced downtime, and cost savings for industrial enterprises. . In various industrial verticals, the WSs are proving to be cost effective, as it is estimated that a continuous WS monitoring setup can save energy consumption up to 18%, in comparison to traditional manual periodic checkups [Kim et al, 2019]. The real time monitoring is made possible by using WSs, which has played a major role in automating various industrial processes. For instance, the inventory can be managed effectively by using the WSs, and can eliminate the fear of over-stocking, replenishing the required products on time, removes burden on productions, etc., [Gungor et al, 2016].

Home Automation and Smart Cities

In smart home and smart city applications, WSNs are used for building automation, energy management, and urban infrastructure monitoring. Sensor nodes embedded in homes, buildings, and public spaces collect data on occupancy, temperature, lighting, and energy usage, enabling automated control of HVAC systems, lighting, and appliances for energy efficiency and comfort optimization.

Military and Defense

WSNs are employed in military and defense applications for battlefield surveillance, target tracking, and border security. Sensor nodes equipped with cameras, microphones, and motion detectors monitor hostile environments and detect unauthorized intrusions or threats, enabling timely response and situational awareness for military personnel.

Energy Efficiency in WSNS

Wireless Sensor Networks (WSNs) have emerged as a key technology for monitoring and controlling physical environments across diverse applications. However, the proliferation of WSNs has raised concerns about their environmental impact, particularly in terms of energy consumption and resource utilization. In response to these concerns, the concept of green and sustainable WSNs has gained prominence, emphasizing the need to design, deploy [Khan et at, 2014] and operate WSNs in an environmentally responsible manner.

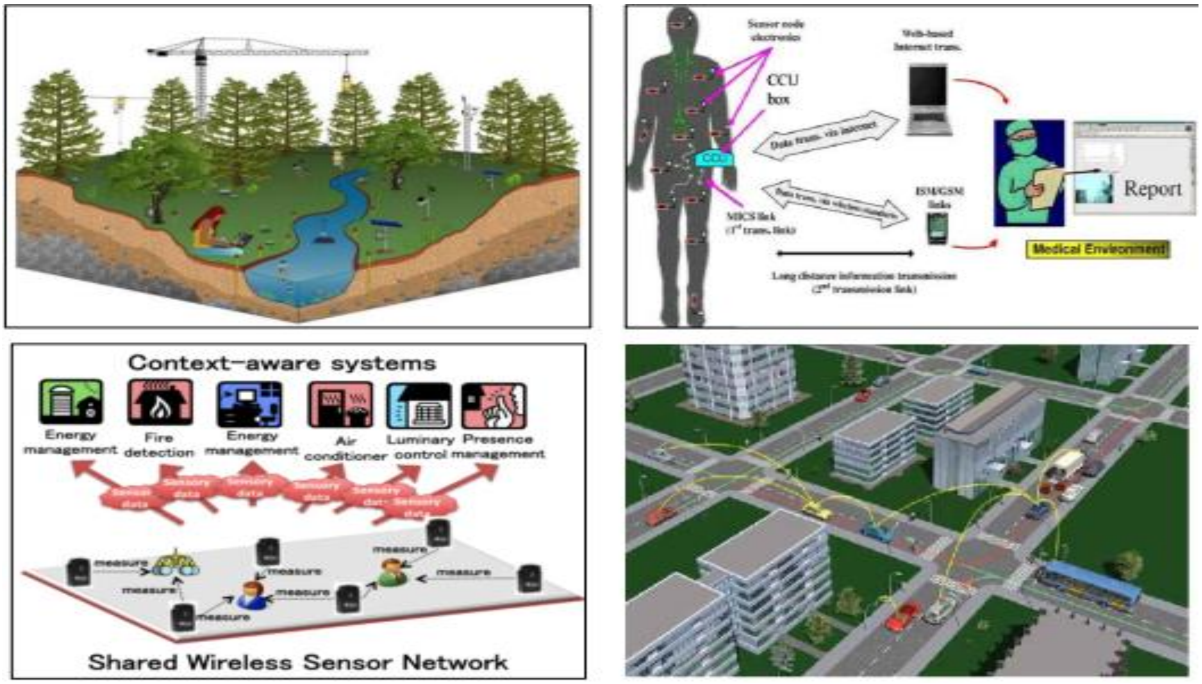

Fig. 2 Applications of WSN

Concept of Green and Sustainable WSNS

Green and sustainable WSNs refer to networks that are designed and managed to minimize their environmental footprint while achieving their intended objectives. This involves adopting energy-efficient technologies, optimizing resource usage, and implementing environmentally friendly practices throughout the lifecycle of the network. The goal is to reduce energy consumption, minimize waste generation, and mitigate adverse environmental impacts associated with WSN deployment and operation.

Significance for Reducing Energy Consumption and Environmental Impact

Energy Efficiency

Traditional WSNs often rely on battery-powered sensor nodes, which have limited energy resources and require frequent battery replacements or recharging. Green and sustainable WSNs prioritize energy efficiency by employing low-power hardware components, energy-efficient communication protocols, and advanced power management techniques. By minimizing energy consumption, these networks extend the operational lifespan of sensor nodes and reduce the need for frequent maintenance, thus lowering overall energy usage and associated costs.

Renewable Energy Integration

Another key aspect of green and sustainable WSNs is the integration of renewable energy sources such as solar, wind, and kinetic energy to supplement or replace battery power. Energy harvesting technologies enable sensor nodes to generate electricity from the surrounding environment, reducing reliance on conventional power sources and increasing network autonomy. By harnessing renewable energy, green WSNs reduce carbon emissions and contribute to the transition to clean and sustainable energy sources.

Environmental Impact Reduction

Green and sustainable WSNs aim to minimize their environmental impact throughout their lifecycle, from manufacturing and deployment to operation and disposal. This involves using eco-friendly materials in sensor node construction, optimizing network design to minimize resource usage, and implementing end-of-life recycling and disposal strategies. By adopting environmentally responsible practices, green WSNs reduce waste generation, pollution, and ecosystem degradation, contributing to overall environmental sustainability.

Wireless Sensor Networks (WSNs) are characterized by resource-constrained sensor nodes that are typically powered by batteries or energy harvesting systems. Understanding the energy consumption patterns in traditional WSNs is crucial for optimizing network design, communication protocols, and deployment strategies to maximize energy efficiency and prolong network lifetime [Kazem Sohraby et al., 2008]. This review examines the energy consumption patterns in three key aspects of traditional WSNs: sensor node operations, data transmission, and processing.

Sensor Node Operations

Sensor nodes in WSNs perform various tasks such as sensing environmental parameters, processing data, and communicating with neighboring nodes or base stations. The energy consumed during sensor node operations primarily depends on the sensing mechanism, sampling frequency, and data processing complexity.

Sensor nodes equipped with active sensors (e.g., temperature, humidity, light) consume energy during sensing activities, including powering sensor components, analog-to-digital conversion, and data processing. Continuous or frequent sensing operations can lead to significant energy drain, particularly in resource-constrained nodes with limited battery capacity.

Data Transmission

Data transmission accounts for a significant portion of energy consumption in WSNs, particularly in multi-hop communication scenarios where data packets are relayed through intermediate nodes before reaching the destination. The energy consumed during data transmission depends on factors such as transmission distance, data rate, modulation scheme, and channel conditions.

Radio communication is the primary mode of data transmission in WSNs, and energy consumption is directly proportional to the transmission distance and data rate. Longer transmission distances and higher data rates result in increased energy expenditure due to higher transmit power levels and longer transmission times.

Energy-efficient communication protocols, such as low-power listening (LPL), duty cycling, and adaptive transmission power control, aim to minimize energy consumption during data transmission by optimizing transmission parameters and reducing unnecessary overhead.

Data Processing

Data processing activities, including data aggregation, filtering, and analysis, also contribute to energy consumption in WSNs. Sensor nodes often perform data processing tasks to reduce redundant data, extract meaningful information, and make localized decisions before transmitting data to the base station.

The energy consumed during data processing depends on the complexity of algorithms and the computational resources available on sensor nodes. Resource-constrained nodes with limited processing capabilities may incur higher energy costs for computationally intensive tasks, leading to premature battery depletion.

Energy Harvesting Techniques and Power Management Strategies for Improving Energy Efficiency in WSNS

Wireless Sensor Networks (WSNs) often operate in remote or harsh environments where access to traditional power sources may be limited or impractical. To address the energy constraints of sensor nodes and prolong network lifetime, energy harvesting techniques and power management strategies are employed. This discussion explores various energy harvesting techniques and power management strategies used in WSNs to improve energy efficiency:

Energy harvesting techniques

Solar Energy Harvesting

Solar energy harvesting involves capturing sunlight using photovoltaic cells or solar panels and converting it into electrical energy to power sensor nodes. Solar energy harvesting is widely adopted in WSNs due to its abundance and reliability in outdoor environments.

Photovoltaic cells integrated into sensor nodes or deployed separately in solar panels capture sunlight and convert it into electrical energy, which is stored in rechargeable batteries or super capacitors for later use.

Kinetic Energy Harvesting

Kinetic energy harvesting utilizes mechanical motion or vibrations from the surrounding environment to generate electrical energy for powering sensor nodes. Common sources of kinetic energy include human movement, machinery vibrations, and vehicle motion.

Thermal Energy Harvesting

Thermal energy harvesting exploits temperature differentials between the sensor node and its surroundings to generate electrical energy using thermoelectric generators or thermoelectric modules. Thermoelectric materials such as bismuth telluride or lead telluride are used to convert heat gradients into electrical voltage through the Seebeck effect.

Power Management Strategies

Duty Cycling

Duty cycling involves periodically turning on and off sensor node components (e.g., radio, processor) to conserve energy while maintaining essential functionality. Nodes alternate between active and sleep states based on predetermined duty cycle schedules. Duty cycle refers to “the ratio between the duration when the sensor node is on and the sum of the times when the node is on and asleep” [Omodunbi et al, 2013]. The transceivers operate in active, listen and sleep modes. Idle listening consumes a significant amount of energy [Đuriši´c et al, 2012].

Duty cycling reduces energy consumption by minimizing the time spent in active mode, thereby extending battery life and network lifetime.

Adaptive Transmission Power Control

Adaptive transmission power control adjusts the transmit power level of sensor nodes dynamically based on the distance to neighboring nodes and the quality of the wireless channel.

Data Aggregation and Compression

Data aggregation and compression techniques reduce the amount of data transmitted by combining redundant or correlated sensor readings into compact packets. Data aggregation is a data reduction scheme for minimizing communication overhead. It is an approach that eliminates redundant data to reduce energy consumption and prolong the lifetime of WSNs [Carrano et al, 2014]. Data aggregation is defined as the process of "fusing data from multiple sensors to avoid redundant transmission to the sink node and, thereby, reduce the total energy cost" [Razzaque et al, 2014].

The quantity of energy consumed by a transceiver in a WSN strongly depends on the size of the transmitted data packets and the transmission distance. Data compression focuses on reducing the size of the sensed data. In this technique, information is encoded at the source nodes and decoded at the BS [Ramesh et al, 2006]. Communication energy is usually minimized at the expense of increased computational energy. "Compressed sensing" and "distributed compressed sensing" are potential strategies for enhancing energy efficient sensing in WSNs [Carrano et al, 2014].

Considerations for Sustainable Deployment of WSNS

Deploying Wireless Sensor Networks (WSNs) in a sustainable manner involves careful planning and decision-making to maximize the effectiveness and longevity of the network while minimizing its environmental impact. Sustainable deployment encompasses various factors, including site selection, node placement, and network topology design. Here are some considerations for each aspect:

Site Selection

Environmental Conditions

Choose deployment sites that offer optimal environmental conditions for sensor operation and longevity. Consider factors such as temperature, humidity, exposure to sunlight, and susceptibility to extreme weather events.

Accessibility

Ensure that deployment sites are easily accessible for maintenance and monitoring activities. Remote or hard-to-reach locations may require additional logistical support and incur higher operational costs.

Power Availability

Assess the availability of power sources, including traditional grid power, renewable energy (e.g., solar, wind), and energy harvesting options (e.g., kinetic, thermal). Select sites with access to reliable and sustainable power sources to support continuous sensor operation.

Node Placement

Coverage Requirements

Determine the desired coverage area and sensor density based on the application requirements and monitoring objectives. Distribute sensor nodes strategically to ensure adequate coverage while minimizing resource consumption and redundancy.

Environmental Impact

Consider the environmental impact of node placement on local ecosystems, wildlife habitats, and natural resources. Avoid disturbing sensitive ecosystems or protected areas and minimize habitat fragmentation and disruption.

Interference Mitigation

Mitigate potential sources of interference, such as electromagnetic interference (EMI) from nearby electronic devices, radio frequency interference (RFI) from other wireless networks, and physical obstructions that block or attenuate radio signals. Position sensor nodes to minimize interference and optimize communication reliability.

Network Topology Design:

Communication Range

Determine the communication range of sensor nodes based on the wireless transmission capabilities and environmental conditions. Select communication protocols and transmission power levels to ensure reliable communication within the desired range while conserving energy.

Network Scalability

Design the network topology to accommodate future expansion and scalability requirements. Choose scalable routing protocols and network architectures that can adapt to changes in network size, node density, and application demands.

Fault Tolerance

Incorporate redundancy and fault-tolerant mechanisms into the network topology to ensure robustness and resilience against node failures, communication disruptions, and environmental hazards. Implement multi-hop routing, data aggregation, and decentralized control to enhance network reliability and survivability.

Sleep Scheduling Algorithms

Sleep scheduling algorithms determine when sensor nodes should transition between active and sleep states to conserve energy while maintaining essential functionality. These algorithms schedule sleep periods during which sensor nodes deactivate non-essential components and enter low-power modes to reduce energy consumption.

Common sleep scheduling algorithms include Time-based sleep scheduling, where nodes enter sleep mode periodically based on predefined time intervals, and Event-based sleep scheduling, where nodes enter sleep mode in response to specific events or triggers (e.g., data collection, communication).

Advanced sleep scheduling algorithms incorporate adaptive and predictive strategies that dynamically adjust sleep schedules based on network conditions, traffic patterns, and energy levels. Examples include adaptive duty cycling and machine learning-based sleep scheduling algorithms.

Duty Cycling Mechanisms

Duty cycling mechanisms regulate the duty cycle of sensor nodes, defining the ratio of time spent in active mode (listening, sensing, processing) to sleep mode (inactive). Duty cycling helps balance energy consumption and network responsiveness by allowing nodes to conserve energy during idle periods while remaining available for data collection and communication.

Fixed duty cycling involves using a predefined duty cycle schedule where nodes alternate between active and sleep states at fixed intervals. While simple to implement, fixed duty cycling may not adapt well to dynamic network conditions or varying traffic loads.

Wake-Up Strategies

Wake-up strategies determine how sensor nodes synchronize their wake-up times to ensure timely communication and coordination while minimizing energy consumption. Nodes wake up periodically to listen for incoming communication or wake up in response to external triggers or events. Scheduled wake-up involves coordinating wake-up times among neighboring nodes based on predefined schedules or synchronization mechanisms. Scheduled wake-up reduces energy consumption by minimizing idle listening and contention overhead during communication.

Overview of Energy-Efficient Routing Protocols, Data Aggregation Techniques, and MAC Protocols Designed for Green WSNS

Wireless Sensor Networks (WSNs) often operate in resource-constrained environments where energy efficiency is paramount to prolong network lifetime and ensure sustainable operation. Energy-efficient routing protocols, data aggregation techniques, and Medium Access Control (MAC) protocols are essential components of green WSNs that optimize energy consumption and maximize network longevity. Here's an overview of these techniques:

Energy-Efficient Routing Protocols

Traditional routing protocols designed for WSNs, such as LEACH (Low Energy Adaptive Clustering Hierarchy), TEEN (Threshold-Sensitive Energy Efficient Sensor Network Protocol), and PEGASIS (Power-Efficient gathering in Sensor Information Systems), focus on minimizing energy consumption during data transmission by employing techniques such as data aggregation, clustering, and multi-hop communication.

LEACH is a popular clustering-based routing protocol that organizes sensor nodes into clusters and elects cluster heads to aggregate and transmit data to the base station. By aggregating data at cluster heads and using multi-hop communication, LEACH reduces energy consumption and prolongs network lifetime [Razzaque et al, 2014].

TEEN and PEGASIS are examples of hierarchical and chain-based routing protocols, respectively, that aim to minimize energy consumption by organizing sensor nodes into hierarchical structures or chains and optimizing data transmission paths to the base station.

Data Aggregation Techniques

Data aggregation techniques combine and summarize redundant or correlated sensor data at intermediate nodes before forwarding it to the base station [Sathya et al, 2018], thereby reducing the amount of data transmitted and minimizing energy consumption.

MAC Protocols for Green WSNs

MAC protocols control access to the wireless medium and coordinate communication between sensor nodes, optimizing energy consumption and minimizing contention and collisions. Traditional MAC protocols for WSNs, such as S-MAC (Sensor-MAC) and T-MAC (Timeout-MAC), incorporate mechanisms such as duty cycling, scheduled wake-up, and low-power listening to conserve energy during idle periods and reduce overhead during communication.

The review paper provides a comprehensive overview of green and sustainable Wireless Sensor Networks (WSNs), focusing on energy efficiency, environmental monitoring, and sustainability initiatives. Here are the key findings and insights:

Important of Green WSNS

Green WSNs play a crucial role in environmental monitoring, conservation, and sustainability initiatives by providing real-time data collection, analysis, and decision support across diverse applications. By optimizing energy consumption, maximizing network lifetime, and reducing environmental impact, green WSNs contribute to resource efficiency, ecosystem preservation, and environmental stewardship.

Energy Consumption Patterns

Traditional WSNs exhibit significant energy consumption patterns during sensor node operations, data transmission, and processing, leading to limited network lifetime and sustainability challenges. Energy-intensive tasks such as data transmission, sensing, and computation contribute to overall energy consumption, highlighting the need for energy-efficient solutions and optimization techniques.

Energy Harvesting Techniques

Energy harvesting techniques, including solar, kinetic, thermal, and vibration energy harvesting, offer renewable energy sources to power WSNs sustainably. Advancements in energy harvesting technologies enable autonomous operation, extended network lifetime, and reduced reliance on batteries, supporting long-term deployments in remote or off-grid environments.

Energy-Efficient Protocols and Algorithms

Energy-efficient routing protocols, data aggregation techniques, and Medium Access Control (MAC) protocols are essential components of green WSNs that optimize energy consumption and maximize network longevity. Cross-layer optimization approaches coordinate communication, routing, and energy management decisions to achieve significant energy savings while meeting application requirements in resource-constrained environments.

Sustainable Deployment Strategies

Sustainable deployment strategies, including site selection, node placement, and network topology design, play a critical role in maximizing energy efficiency and environmental impact reduction in WSNs.

Considerations such as geographic location, environmental conditions, and deployment constraints influence deployment decisions and determine the effectiveness of green WSN solutions.

Future Directions and Opportunities

Emerging technologies and trends, such as IoT integration, edge computing, and AI-driven optimization, offer new opportunities for advancing the field of green WSNs. Research gaps and unresolved issues, including scalability, reliability, and cost-effectiveness, present challenges and opportunities for further investigation and innovation in green and sustainable WSNs.

In conclusion, the review paper provides valuable insights into the principles, challenges, and opportunities in green and sustainable Wireless Sensor Networks (WSNs), highlighting the importance of energy efficiency, environmental monitoring, and sustainability initiatives in addressing pressing environmental challenges and promoting a more sustainable future. Reflection on the Importance of Green and Sustainable Wireless Sensor Networks (WSNs) for Mitigating Environmental Impact and Promoting Energy Efficiency: Green and sustainable Wireless Sensor Networks (WSNs) play a pivotal role in addressing environmental challenges, promoting energy efficiency, and fostering sustainability across various domains

References

Akyildiz, I., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: a survey. *Computer Networks*, *38*(4), 393–422. https://doi.org/10.1016/s1389-1286(01)00302-4

Carrano, R. C., Passos, D., Magalhaes, L. C. S., & Albuquerque, C. V. N. (2014). Survey and Taxonomy of Duty Cycling Mechanisms in Wireless Sensor Networks. *IEEE Communications Surveys & Tutorials*, *16*(1), 181–194. https://doi.org/10.1109/surv.2013.052213.00116

D., S., & P., G. K. (2018). Secured data aggregation in wireless sensor networks. *Sensor Review*, *38*(3), 369–375. https://doi.org/10.1108/sr-06-2017-0103

GON, H. W. (2008). Adaptive information brokerage in wireless sensor networks. *Academic Journal of Second Military Medical University*, *29*(1). https://doi.org/10.3724/sp.j.1001.2008.00100

Gungor, V., & Hancke, G. (2009). Industrial Wireless Sensor Networks: Challenges, Design Principles, and Technical Approaches. *IEEE Transactions on Industrial Electronics*, *56*(10), 4258–4265. https://doi.org/10.1109/tie.2009.2015754

Ingle, M., & Rao, P. P. (2018). Improving IF Algorithm for Data Aggregation Techniques in Wireless Sensor Networks. *International Journal of Electrical and Computer Engineering (IJECE)*, *8*(6), 5162. https://doi.org/10.11591/ijece.v8i6.pp5162-5168

Intanagonwiwat, C. (2012). Hybrid Macroprogramming Wireless Networks of Embedded Systems with Declarative Naming. *International Journal of Distributed Sensor Networks*, *8*(9), 490826. https://doi.org/10.1155/2012/490826

Kandris, D., Nakas, C., Vomvas, D., & Koulouras, G. (2020). Applications of Wireless Sensor Networks: An Up-to-Date Survey. *Applied System Innovation*, *3*(1), 14. https://doi.org/10.3390/asi3010014

Khan, J. A., Qureshi, H. K., & Iqbal, A. (2015). Energy management in Wireless Sensor Networks: A survey. *Computers & Electrical Engineering*, *41*, 159–176. https://doi.org/10.1016/j.compeleceng.2014.06.009

Lanzolla, A., & Spadavecchia, M. (2021). Wireless Sensor Networks for Environmental Monitoring. *Sensors*, *21*(4), 1172. https://doi.org/10.3390/s21041172

Luo, L., Qin, H., Song, X., Wang, M., Qiu, H., & Zhou, Z. (2020). Wireless Sensor Networks for Noise Measurement and Acoustic Event

Recognitions in Urban Environments. *Sensors*, *20*(7), 2093. https://doi.org/10.3390/s20072093

Omodunbi, B., O. Emuoyibofarhe, J., O. Arulogun, T., Oladosu, J., Adeyanju, I., Olaniyan, O., . . . Esan, A. (2021). Energy Optimization Algorithm for Path Selection in Wireless Body Sensor Networks. *Current Applied Science and Technology*. https://doi.org/10.55003/cast.2022.01.22.014

Razzaque, M., & Dobson, S. (2014). Energy-Efficient Sensing in Wireless Sensor Networks Using Compressed Sensing. *Sensors*, *14*(2), 2822–2859. https://doi.org/10.3390/s140202822

Warneke, B., Last, M., Liebowitz, B., & Pister, K. (2001). Smart Dust: communicating with a cubic-millimeter computer. *Computer*, *34*(1), 44–51. https://doi.org/10.1109/2.895117

Yick, J., Mukherjee, B., & Ghosal, D. (2008). Wireless sensor network survey. *Computer Networks*, *52*(12), 2292–2330. https://doi.org/10.1016/j.comnet.2008.04.002

Yoo, S. E., & Kim, T. (2020). Industrial Wireless Sensor Networks: Protocols and Applications. *Sensors*, *20*(20), 5809. https://doi.org/10.3390/s20205809

How to cite this article

Gautam, R., Kumar, P., Saini, S. K. and Kumar, A. (2021). A review of green and sustainable wireless sensor networks: challenges, solutions, and future directions. *Science Archives*, Vol. 2(4), 373-380. https://doi.org/10.47587/SA.2021.2418