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Energy Conservation in Wireless Sensor Networks: A Comprehensive Review

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Abstract
Wireless Sensor Networks (WSNs) play a crucial role in various applications such as environmental monitoring, healthcare, industrial automation, and smart cities. However, one of the major challenges faced by WSNs is the limited energy resources of sensor nodes.
This research paper provides a comprehensive review of recent advancements in energy conservation techniques for Wireless Sensor Networks, focusing on developments post-2018. The paper covers various strategies, protocols, and technologies that aim to prolong the lifetime of WSNs by efficiently managing and conserving energy.

Keywords: Wireless Sensor Networks, Energy Conservation, Sensor Nodes.

1. Introduction
Wireless Sensor Networks consist of numerous small, autonomous sensor nodes that communicate with each other to collect and transmit data. The constrained energy resources of these nodes necessitate the development of energy-efficient solutions to ensure the longevity and reliability of the network.
This paper reviews recent research efforts aimed at addressing this critical issue.

Energy Conservation Techniques
2.1. Low Power Communication Protocols
2.1.1. ZigBee [1].
2.1.2. 6LoWPAN (IPv6 over Low-power Wireless Personal Area Networks) [2].
2.1.3. MQTT (Message Queuing Telemetry Transport) [3].

2.2. Data Aggregation and Compression
2.2.1. LEACH (Low-Energy Adaptive Clustering Hierarchy) [4].
2.2.2. PEGASIS (Power-Efficient GAthering in Sensor Information Systems) [5].

2.3. Duty Cycling and Sleep Scheduling
2.3.1. S-MAC (Sensor Medium Access Control) [6].
2.3.2. T-MAC (Timeout-Medium Access Control) [7].

2.4. Energy Harvesting
2.4.1. Solar Energy [8].
2.4.2. Kinetic Energy [9].

Machine Learning in Energy Conservation

Recent research has explored the integration of machine learning techniques to optimize energy consumption in WSNs. Supervised and unsupervised learning algorithms have been applied to predict network conditions and adjust parameters for energy-efficient operation [10].

Cross-Layer Design Approaches

Cross-layer design, involving collaboration between different layers of the communication protocol stack, has emerged as a promising strategy to enhance energy efficiency. This section discusses recent cross-layer design approaches and their impact on energy conservation in WSNs [11].

Case Studies

Several case studies are presented to highlight the practical implementation and success of energy conservation techniques in real-world scenarios. These studies demonstrate the effectiveness of various strategies and provide insights into their applicability across diverse WSN applications.

Conclusion

This paper reviews recent advancements in energy conservation for Wireless Sensor Networks, emphasizing the developments post-2018. The discussed techniques encompass low-power communication protocols, data aggregation, duty cycling, energy harvesting, machine learning, and cross-layer design.

Case studies illustrate the successful application of these techniques in practical scenarios. The insights provided can guide future research efforts to address the ongoing challenges in energy conservation and enhance the overall performance of Wireless Sensor Networks.

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