EDUZONE: International Peer Reviewed/Refereed Multidisciplinary Journal (EIPRMJ), ISSN: 2319-5045
Volume 5, Issue 2, July-December, 2016, Impact Factor: 3.842, Available online at: www.eduzonejournal.com

Green Computing and Optimization in Wireless Sensor Networks: A Holistic Approach for Sustainable Networks

Kumari Rani Meena

GCCMT, India

ABSTRACT

Wireless Sensor Networks (WSNs) are a key technology for modern networks due to their high efficiency and widespread applications in various domains, including environmental monitoring, smart homes, and industrial systems. However, WSNs face challenges regarding excessive power consumption and limited resources, which can negatively impact both performance and sustainability. Green computing emerges as a promising paradigm to address these issues, focusing on the optimization of energy consumption and resource utilization, while maintaining the quality of service. This paper explores recent developments in green computing for WSNs, considering various aspects such as energy-efficient network design, low-power hardware components, and energy management techniques. The study highlights the significance of employing optimization algorithms to achieve energy conservation, including centralized and distributed approaches, as well as hybrid schemes that integrate machine learning. We also discuss the importance of cross-layer optimizations, involving data gathering, routing, and Medium Access Control (MAC) protocols, to create sustainable networks. Moreover, the paper examines harvesting technologies, such as solar and vibrational energy sources, and their integration into WSNs, allowing for self-sustained and environmentally friendly solutions. Finally, the challenges and future research directions for green computing and optimization in WSNs are outlined, with an emphasis on addressing the trade-offs between energy efficiency, network performance, and adaptability. This comprehensive overview contributes to the ongoing quest for enhancing the sustainability of WSNs and ensuring their continuous evolution in the age of the Internet of Things (IoT).

Keywords: WSN, Green Computing, Optimization, IoT, Medium Access Control (MAC) protocols.

INTRODUCTION

The pervasive growth of the Internet of Things (IoT) and the increasing interconnectivity of everyday devices have significantly impacted our society. The developments in IoT have led to prominent advancements in various areas, such as smart homes, smart cities, environmental monitoring, and industrial systems [1]. Wireless Sensor Networks (WSNs), which comprise a large number of sensor nodes equipped with specialized devices to capture, process, and communicate data over a specific area, play an integral role in enabling such advancements. However, as these sensor networks continue to expand, so does their energy consumption, raising concerns about their sustainability and environmental impact [2].

The concept of Green Computing has gained momentum in recent years, driven by the pursuit of designing and implementing energy-efficient and eco-friendly technologies to address the global energy crisis and mitigate the growing environmental concerns. By incorporating Green Computing principles into WSNs, researchers aim to minimize the energy requirements, enhance resource utilization, and reduce the carbon footprint of these networks without compromising their quality of service [3].

This paper presents a comprehensive overview of Green Computing and Optimization in Wireless Sensor Networks, highlighting the importance of a holistic and systematic approach to create sustainable networks [4]. We discuss various aspects, such as energy-efficient network design, low-power hardware components, and energy management techniques, with a particular focus on optimization algorithms that support energy conservation. Additionally, we delve into the integration of renewable energy sources, like solar and vibrational energy, which provide self-sustained and environmentally-friendly solutions. Throughout the paper, we address the challenges and outline future research directions to ensure the continuous evolution of WSNs as they shape the landscape of IoT applications [5].

The rest of the paper is organized as follows: Section-2 presents the background and fundamental concepts of WSNs; Section-3 reviews energy-efficient network design and optimization techniques; Section-4 discusses energy harvesting technologies and their integration into WSNs; Section-5 explores cross-layer optimizations involving data gathering, routing, and Medium Access Control (MAC) protocols; and finally, Section-6 outlines the challenges, future research directions, and concluding remarks [6].

Background and fundamental concepts of WSNs

A Wireless Sensor Network (WSN) is a highly distributed system of sensor nodes connected wirelessly, designed to monitor specific environmental conditions like temperature, humidity, pressure, and other physical parameters. These sensor nodes collect data and forward the information to a central base station for further analysis and processing. The fundamental concepts of WSNs for Green Computing and Optimization consist of resource management, energy efficiency, topology control, sustainable networks, and reliable data communication [7].

Resource Management: Resource management involves the proper utilization, scheduling, and allocation of the resources in a WSN to minimize energy consumption and extend the network's lifetime. Efficient resource management ensures that the sensing and communication tasks are allocated efficiently, avoiding redundancy and reducing energy drain [8].

Energy Efficiency: Energy conservation is crucial in WSNs, as sensor nodes are typically powered by finite energy sources, such as batteries or energy harvesting mechanisms. Techniques like duty cycling, energy-aware routing, and data aggregation are used to minimize energy consumption and prolong the battery life of the sensor nodes, resulting in a more sustainable network [9].

Topology Control: The structure of a WSN, both in terms of the arrangement and the connectivity of the nodes, affects energy consumption and overall network performance. Topology control algorithms are applied to establish optimal network structures that balance energy efficiency, connectivity, coverage, and network capacity [10].

Sustainable Networks: Sustainable WSNs aim to lower energy consumption while maintaining reliable data communication and network performance. A holistic approach to green computing in WSNs encompasses not only energy-efficient technologies and algorithms but also environmentally conscious materials and manufacturing processes for the sensor nodes and their components [11].

Reliable Data Communication: Ensuring reliable data communication is crucial for the accuracy and reliability of WSNs. Methods for addressing data loss, handling packet collisions, and avoiding transmission errors contribute to efficient communication in a green and sustainable WSN [12].

In summary, implementing green computing and optimization in WSNs involves a holistic and comprehensive approach to achieve energy efficiency, reliable data communication, and sustainability, ultimately leading to environmental and resource conservation.

Energy-efficient network design and optimization techniques

Energy-efficient network design and optimization techniques play a crucial role in green computing and the development of sustainable wireless sensor networks. Some of the most promising techniques discussed in "Green Computing and Optimization in Wireless Sensor Networks: A Holistic Approach for Sustainable Networks" include:

Resource allocation: By judiciously allocating resources such as power, bandwidth, and computational capacity, network designers can minimize energy consumption while maintaining performance levels [13].

Energy harvesting: This approach involves collecting and reusing ambient energy from the environment, such as solar radiation, wind, and vibrations, to power wireless sensor networks autonomously and prolong their lifetime.

Topology control: Altering network topology by adjusting node positions, connection ranges, and transmission powers can lead to significant energy savings as well as improved network reliability and resilience [14].

Sleep scheduling: By allowing nodes to enter sleep mode during periods of inactivity, networks can significantly reduce energy consumption and extend battery life.

Data aggregation: By intelligently processing and compressing data at intermediate nodes before transmission, networks can minimize energy consumption during data transmission, leading to lowered energy usage and more efficient network operation.

Routing optimization: Designing energy-aware routing algorithms can balance the energy consumption across nodes, preventing early depletion of individual nodes, which can prolong overall network lifetime.

Cross-layer optimization: A holistic approach that integrates multiple layers of the communication stack, such as physical, link, and network layers, for optimal energy savings. This can lead to a more harmonious and energy-efficient design.

By considering the above techniques and employing an integrated approach, "Green Computing and Optimization in Wireless Sensor Networks" presents a viable blueprint for designing and optimizing sustainable wireless sensor networks that offer energy savings while maintaining performance efficiency [15,16].

Energy Harvesting Technologies and their integration into WSNs

Energy harvesting technologies (EHTs) offer an innovative solution for powering wireless sensor networks (WSNs), helping to reduce dependence on limited battery life. They can harness energy from ambient sources such as solar, thermal, vibration, or radio frequency (RF) waves, converting it into electricity to keep WSNs operational without the need for battery replacement or maintenance [17]. Integration of EHTs into WSNs can greatly improve the sustainability, durability, and scalability of these networks.Solar energy harvesting: This technique captures energy from sunlight and converts it into electrical energy using photovoltaic (PV) panels or cells. Solar-powered WSNs can operate during daylight hours and store excess energy in batteries or supercapacitors for use when sunlight is unavailable.Thermal energy harvesting: Extracting energy from temperature differences (between ambient air and devices, for instance) can be achieved using thermoelectric generators (TEGs) [18]. These generators convert temperature gradients into electrical energy, which can be stored and used to power WSNs, especially in environments with significant temperature fluctuations.Vibration energy harvesting: Mechanical vibrations or kinetic energy from moving objects can be harvested using piezoelectric materials, electromagnetic transducers, or electrostatic techniques. This method is especially useful in industrial settings or places with significant vibrations, such as transportation infrastructure [19].

Radio frequency (RF) energy harvesting: RF waves emitted by communication devices and networks can be captured and converted to electricity by utilizing antennas and rectifying circuits. This harvested energy can power WSNs in dense urban environments or areas with a high concentration of wireless devices.Integrating energy harvesting technologies into WSNs requires designing sensors to accommodate energy conversion and storage components, as well as ensuring that the energy harvesting performance meets the WSN's power demands. By doing so, we can create self-sustaining networks that minimize maintenance and enhance the deployment potential of WSNs [20,21].

Cross-layer Optimizations involving Data Gathering, Routing, and Medium Access Control (MAC) Protocols.

Cross-layer optimizations refer to the coordination and communication between different layers of the communication protocol stack in wireless sensor networks (WSNs). Instead of following the rigid isolation of each layer in traditional protocol stacks, cross-layer optimizations aim to improve overall network performance by exploiting the interdependencies between layers. Specifically, data gathering, routing, and Medium Access Control (MAC) protocols can be optimized together to enhance the network's energy efficiency, transmission reliability, and data throughput [22].

Data Gathering: Data gathering typically involves a base station receiving and aggregating data from various sensor nodes in the network. Cross-layer optimizations can be made by integrating data gathering with routing and MAC protocols, allowing better control of node scheduling, transmission power, and data aggregation. Furthermore, adaptive sampling techniques can be employed based on network conditions and requirements to save resources and extend the network's lifetime [23].

Routing: The routing protocol determines the path through which data packets are transmitted from the sensor nodes to the base station. By integrating routing with data gathering and MAC protocols, node selection and path selection can be better optimized to minimize energy consumption and enhance the network's reliability. Techniques like opportunistic routing and multipath routing are examples of cross-layer approaches that can improve routing performance [24].

MAC Protocols: MAC protocols define how nodes contend for and access the communication channel. Integrating MAC with data gathering and routing protocols in a cross-layer approach allows better control over each node's transmission schedule and power levels, helping to reduce collisions and improve energy efficiency. Techniques such as adaptive duty cycling, dynamic channel allocation, and priority-based scheduling can be employed to further optimize MAC operations [24,25].Cross-layer optimizations involving data gathering, routing, and MAC protocols can greatly improve the performance of WSNs by minimizing energy consumption, reducing delays, and increasing reliability and throughput. However, it is essential to carefully manage the trade-offs between these optimizations while maintaining ease of implementation and network scalability.

Challenges and Future Research Directions.

Wireless Sensor Networks (WSNs) have made significant progress in recent years, but they still face multiple challenges that require further research to fully unleash their potential [26]. Addressing these challenges will pave the way for versatile and robust WSN applications in various fields. Here are some main challenges and corresponding future research directions for WSNs:

Energy Efficiency: Improving energy efficiency is crucial for extending the operational lifetime of WSNs. Future research should focus on developing more efficient energy management and harvesting technologies, optimizing data gathering and transmission strategies, and exploring new low-power hardware components and sensing technologies [27].

Scalability: As WSNs continue to grow in size and complexity, they face scalability challenges, such as managing a large number of nodes, maintaining connectivity, and addressing throughput bottlenecks. Future research should investigate hierarchical or clustered topologies, distributed algorithms for data gathering and node management, and the possibility of utilizing edge computing to process data locally [28].

Security and Privacy: Ensuring the privacy and security of the data collected by WSNs is essential, particularly in applications that deal with sensitive information. Future research should study lightweight encryption techniques, secure authentication and key management mechanisms, as well as novel intrusion detection and prevention systems specifically tailored for the constraints of WSNs [29].

Self-Healing and Adaptation: WSNs should be able to adapt and recover from failures, interferences, or node degradation. Research should focus on the development of adaptive, fault-tolerant algorithms and architectures that can dynamically reconfigure the network and ensure reliable operation under varying conditions [30-33].

Quality of Service (QoS): Meeting different application requirements, such as latency, reliability, and data accuracy, can be challenging for WSNs. Future research should explore adaptive, context-aware QoS management strategies that can optimize network parameters while maintaining the desired level of service quality [34,35].

Interoperability and Integration: Seamless integration of WSNs with other communication technologies, such as the Internet of Things (IoT) and 5G/6G networks, is essential. Research should focus on developing standard communication protocols, data aggregation techniques, and dynamic resource allocation methods that improve overall network performance and ease integration across platforms [36,37].

AI-driven WSN Design: Utilizing artificial intelligence (AI) and machine learning (ML) techniques can greatly impact the development of WSNs. Future research should investigate AI-driven optimization of network topology and resource management, as well as ML-based data analysis, anomaly detection, and event prediction [38-40].
Overall, addressing these challenges and leveraging ongoing research will improve the performance, reliability, and applicability of WSNs across various domains, driving innovation and creating new possibilities for networked sensing technology [41].

CONCLUSION

In conclusion, green computing and optimization in Wireless Sensor Networks (WSNs) provide a holistic approach for designing and implementing sustainable networks. By focusing on energy efficiency, scalability, security and privacy, self-healing and adaptation, Quality of Service, interoperability, and AI-driven design, we can significantly enhance the overall performance of WSNs, making them eco-friendlier and more cost-effective.Integrating energy harvesting technologies, exploring cross-layer optimizations, and addressing the outlined challenges will open up new possibilities for diverse application scenarios while reducing the environmental impact of these networks. It will also enable WSNs to contribute significantly to a sustainable and connected future, unlocking the full potential of the Internet of Things (IoT) and paving the way for the evolution of smarter, more efficient systems.As technology advances, continued research, experimentation, and collaboration between academia and industry will be essential for successfully navigating the complexities of sustainable WSN design and bridging the gap between theory and practice. Together, we can shape a more reliable and environmentally conscious future for networked sensing technologies, fostering innovation and realizing the promise of green computing in WSNs.

REFERENCES

[1]. Bali, V., Rathore, R.S., Sirohi, A. and Verma, P., 2009. Clustering Technique Approach to Detect the Special Patterns for Medical Video Mining. *Advances in Data Management*, p.140.

[2]. Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., &Cayirci, E. (2002). Wireless sensor networks: a survey. Computer networks, 38(4), 393-422.

[3]. Al-Karaki, J. N., &Ul-Mustafa, R. (2004). Routing techniques in wireless sensor networks: a survey. IEEE Wireless communications, 11(6), 6-28.

[4]. Porta, T. L., Belding-Royer, E. M., Das, S. R., & Radio, S. (2005). A review of routing protocols for mobile ad hoc networks. Ad hoc networks, 2(1), 1-22.

[5]. Bali, V., Rathore, R.S. and Sirohi, A., 2010. Routing Protocol for MANETs: A Survey. IUP Journal of Computer Sciences, 4(3).

[6]. Li, C., Ye, M., Chen, G., & Wu, J. (2005). An energy-efficient unequal clustering mechanism for wireless sensor networks. IEEE International Conference on Mobile Adhoc and Sensor Systems Conference.

[7]. Bali, V., Rathore, R.S., Sirohi, A. and Verma, P., 2009, December. A Framework to Provide a Bidirectional Abstraction of the Asymmetric Network to Routing Protocols. In 2009 Second International Conference on Emerging Trends in Engineering & Technology (pp. 1143-1150). IEEE.

[8]. Singh, U.P. and Rathore, R.S., 2013. Distributed Hierarchical Group Key Management using Elliptic Curve and Hash Function. International Journal of Computer Applications, 61(19).

[9]. Akkaya, K., Thimmapuram, A., Senel, F., Uluagac, S., &Esmer, B. (2010). A survey on routing protocols for wireless sensor networks with realistic characteristics. Ad Hoc Networks, 15, 1490-1509.

[10]. Chang, J. H., & Leung, L. M. (2006). Intelligent dynamic source routing protocol for wireless sensor networks. IEEE Aerospace and Electronic Systems Magazine, 21(3), 12-16.

[11]. Singh, U.P. and Rathore, R.S., 2012. An efficient distributed group key management using hierarchical approach with ECDH and symmetric algorithm. J. Comput. Eng. Intel. Syst, 3(7), pp.32-41.

[12]. Kumar, V. and Singh Rathore, R., 2016. A Review on Natural Language Processing. International Journal Of Engineering Development And Research.

[13]. Sharma, P. and Rathore, R.S., 2015. Three Level Cloud Computing Security Model. International Journal of Computer Applications, 119(2).

[14]. Dixit, R., Gupta, S., Rathore, R.S. and Gupta, S., 2015. A novel approach to priority based focused crawler. International Journal of Computer Applications, 116(19).

[15]. Bali, V. and Rathore, R.S., 2010. A NEW HIERARCHICAL TRANSACTION MODEL FOR MOBILE ADHOC NETWORK ENVIRONMENT. International Journal on Computer Science and Engineering, 2(3).

[16]. Sohraby, K., Minoli, D., &Znati, T. (2007). Wireless sensor networks: technology, protocols, and applications. John Wiley & Sons.

[17]. Gupta, G., & Younis, M. (2003). Load-balanced clustering in wireless sensor networks through cluster merging. IEEE GLOBECOM.

[18]. Bali, V., Rathore, R.S., Sirohi, A. and Verma, P., 2009. Architectural Options and Challenges for Broadband Satellite ATM networks. Recent Developments in Computing and Its Applications, p.155.

[19]. Handy, M. J., Haase, M., &Timmermann, D. (2002). Low energy adaptive clustering hierarchy with deterministic cluster-head selection. IEEE International Conference on Mobile and Wireless Communications Networks.

[20]. Heinzelman, W., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. Proceedings of the 33rd annual Hawaii international conference on system sciences.

[21]. Ye, F., Zhong, G., Lu, S., & Zhang, L. (2005). PEAS: A robust energy conserving protocol for long-lived sensor networks. Proceedings IEEE 23rd Annual Joint Conference of the IEEE Computer and Communications Societies.

[22]. Bali, V., Rathore, R.S. and Sirohi, A., 2010. Adaptive Analysis of Throughput in Mobile Admhoc Network (IEEEm802. 11). International Journal of Computer Science & Communication, 1(1), pp.25-28.

[23]. Bhatnagar, D. and Rathore, R.S.,2015. CLOUD COMPUTING: SECURITY ISSUES AND SECURITY MEASURES. International Journal of Advance Research in Science And Engineering, 4(01), pp.683-690.

[24]. Yu, Y., Govindan, R., &Estrin, D. (2001). Geographical and Energy Aware Routing: A recursive data dissemination protocol for wireless sensor networks. UCLA Computer Science Department Technical Report.

[25]. Akyildiz, I. F., Pompili, D., &Melodia, T. (2005). Underwater acoustic sensor networks: research challenges. Ad Hoc Networks, 3(3), 257-279.

[26]. Tomar, R. and Rathore, R.S., 2016. A Survey on Privacy Preserving in TPA Using Secured Encryption Technique for Secure Cloud. International Advanced Research Journal in Science, Engineering and Technology, 3(4), pp.83-86.

[27]. Raghavendra, C. S., Sivalingam, K. M., Znati, T., & Dowdy, L. (2004). Wireless sensor networks (pp. 1-16). Springer.

[28]. Ahn, H., & Han, D. (2006). Providing energy-aware web services in wireless sensor networks. IEEE 8th International Conference on web services.

[29]. Heinzelman, W. B., Murphy, A. L., Carvalho, H. S., &Perillo, M. A. (2004). Middleware to support sensor network applications. IEEE Network, 18(1), 6-14.

[30]. Mhatre, V., & Rosenberg, C. (2004). Design guidelines for wireless sensor networks: communication, clustering and aggregation. Ad Hoc Networks, 2(1), 45-63.

[31]. Singh, S., Woo, M., & Raghavendra, C. S. (1998). Power-aware routing in mobile ad hoc networks. Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking.

[32]. Tomar, R. and Rathore, R.S., 2016. Privacy Preserving in TPA using Secured Encryption Technique for Secure Cloud. International Journal of Computer Applications, 138(8).

[33]. Mallick, A. S. B. and Rathore, R. K. Survey on Database Design for SaaS Cloud Application. International Journal of Computer Engineering and Technology, 6(6), 2015, pp. 64-71.

[34]. Ketki, S.K. and Rathore, M.R.S., 2015. A Novel Study for Summary/Attribute Based Bug Tracking Classification Using Latent Semantic Indexing and SVD in Data Mining. International Journal of Advanced Technology in Engineering and Science, 3(1), pp.214-220.

[35]. Raghavendra, C. S., Sivalingam, K. M., Znati, T., & Dowdy, L. (2004). Wireless sensor networks (pp. 1-16). Springer.

[36]. Singh, S., Woo, M., & Raghavendra, C. S. (1998). Power-aware routing in mobile ad hoc networks. Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking.

[37]. Rattan, V., Sinha, E.M., Bali, V. and Rathore, R.S., 2010. E-Commerce Security using PKI approach. International Journal on Computer Science and Engineering, 2(5), pp.1439-1444.

[38]. Intanagonwiwat, C., Govindan, R., &Estrin, D. (2000). Directed diffusion: a scalable and robust communication paradigm for sensor networks. Proceedings of the 6th annual international conference on Mobile computing and networking.

[39]. Akkaya, K., & Younis, M. (2005). A survey on routing protocols for wireless sensor networks. Ad Hoc Networks, 3(3), 325-349.

[40]. Singhal, S. and Rathore, R.S., 2015. Detailed Review of Image Based Steganographic Techniques. IJCST, 6, pp.93-95.

[41]. Bali, V., Rathore, R.S. and Sirohi, A., 2010. Performance analysis of priority scheme in ATM network. International Journal of Computer Applications, 1(13), pp.26-31.