

Deployment and Testing of Wireless Sensor Networks for Real-Time Monitoring of Environmental Parameters

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Abstract: The rapid increase in environmental variability and climate-related challenges has intensified the need for efficient, scalable, and autonomous monitoring systems. Wireless Sensor Networks (WSNs) provide a promising solution for real-time environmental surveillance due to their distributed architecture, low power consumption, and ability to operate in remote or inaccessible regions. This study presents the design, deployment, and comprehensive performance evaluation of a multi-node WSN used to monitor temperature, humidity, air quality, and soil moisture. The system architecture integrates low-power IEEE 802.15.4 communication, mesh-based routing, and calibrated environmental sensors. Field experiments were conducted over twenty days under varying atmospheric and terrain conditions to analyze packet delivery ratio, latency, throughput, and energy consumption. Results indicate that while the WSN demonstrated stable performance with a packet delivery ratio above 90 percent during optimal conditions, environmental obstructions and rainfall caused noticeable degradation in signal strength and network reliability. The findings align with established studies on the vulnerabilities of WSN communication to environmental interference. Overall, the deployed system exhibited strong potential for long-term environmental monitoring applications, including precision agriculture, pollution analysis, and smart city infrastructures. Future improvements should integrate energy harvesting modules, adaptive routing algorithms, and enhanced self-healing capabilities for extended autonomous operation.

Keywords: Wireless Sensor Networks, Real-Time Monitoring, Environmental Parameters, Network Performance, Low-Power Sensors

1. Introduction

Wireless Sensor Networks have emerged as one of the most important enabling technologies for environmental monitoring due to their flexibility, autonomy, and scalability. A typical WSN comprises nodes equipped with sensors, microcontrollers, and wireless communication modules, collectively capable of sampling and transmitting environmental data across large spatial regions. The ability of WSNs to operate without extensive infrastructure allows them to outperform traditional monitoring systems that rely on manual sampling or fixed monitoring stations. Previous research has shown that WSNs can support applications including habitat monitoring, agricultural automation, pollution assessment, and disaster alert systems [1]. The need for real-time environmental data has grown significantly in recent years as global climatic changes continue to intensify. Monitoring parameters such as air pollution levels, soil moisture, temperature, and humidity is crucial for urban planning, agricultural resource management, and climate prediction models. WSNs offer a distributed and energy-efficient solution by enabling continuous data acquisition and reducing human intervention. Their self-configuring and self-organizing capabilities further enhance their adaptability, making them suitable for harsh or inaccessible environments. However, real-world deployment introduces challenges such as signal attenuation, environmental noise, device malfunction, and limited power resources. Studies have highlighted that sensor accuracy declines without proper calibration, while environmental conditions such as fog, rain, and temperature shifts significantly impact wireless communication reliability [2]. Energy consumption remains one of the most critical concerns, as nodes operating on finite battery resources face rapid depletion if inefficient communication

protocols are used. Additional concerns include data integrity, routing failures, and latency in multi-hop networks. This research aims to address these issues by deploying and analyzing a WSN prototype in real-world conditions. The objective is to evaluate network performance through parameters such as packet delivery ratio, network stability, latency, and battery endurance. Drawing upon established research emphasizing reliability and energy optimization in WSNs [3], this work examines both the operational strengths and limitations of the deployed system. The outcomes contribute to the advancement of efficient environmental monitoring systems capable of supporting large-scale, long-term ecological studies.



Fig. 1 Real time monitoring of environmental parameters.

2. Methodology

The research methodology involved the development, field deployment, and performance assessment of a wireless sensor network consisting of fifteen nodes. Each node was equipped with digital sensors capable of measuring temperature, humidity, particulate matter concentration, and soil moisture. Communication between nodes was established using the IEEE 802.15.4 standard, known for its low-power operation and suitability for short-range sensor networks. The system adopted a mesh topology to enhance resilience by allowing alternative routing paths if individual nodes failed or experienced degraded connectivity. Prior to deployment, all sensors underwent laboratory calibration against reference-grade instruments following model-driven validation techniques consistent with prior sensor accuracy studies [2]. The calibration process ensured that deviations in measurements remained within acceptable error margins. Each node was powered using lithium batteries with onboard monitors for tracking real-time energy consumption. The field deployment was conducted across varying terrain featuring vegetation, minor obstructions, and open clearings to simulate realistic environmental

complexities. Node placement distances ranged from fifteen to thirty meters. Data sampling occurred every sixty seconds, with readings transmitted to a central base station through multi-hop communication. Environmental conditions during the twenty-day testing period included temperature fluctuations, high humidity, and multiple rainfall events. Data analysis focused on evaluating packet delivery ratio, latency, throughput, and power usage across the network. Statistical analysis tools were used to compare performance results under different environmental conditions, providing insights into the factors affecting system reliability.

3. Results and Discussion

The results revealed that the wireless sensor network performed reliably across the majority of the testing period. The average packet delivery ratio (PDR) remained at 92.4 percent, aligning with performance expectations for multi-hop environmental monitoring systems and consistent with findings reported in prior WSN research [1], [3]. However, during rainfall events, the PDR dropped to 83.6 percent due to increased signal attenuation. This performance decline supports earlier observations that environmental conditions have a measurable impact on wireless communication strength [3]. Latency averaged 340 milliseconds during optimal conditions but increased to approximately 500 milliseconds during peak interference periods. While these values remained acceptable for real-time environmental applications, they indicate that routing protocols must account for dynamic environmental changes. Throughput remained stable across nodes positioned in open areas but showed a noticeable decline in nodes deployed behind dense vegetation. This further confirms the influence of physical obstructions on radio transmission efficiency [5]. Sensor readings demonstrated high reliability, with temperature and humidity sensors exhibiting minimal drift throughout the testing period. Soil moisture readings remained stable and consistent, although air particulate sensors displayed partial inaccuracies during extremely humid morning hours. This observation correlates with existing environmental sensor studies that highlight moisture interference in particulate sensing [2]. Energy consumption analysis showed significant variations among nodes, with those participating in frequent routing operations exhausting battery power faster. Nodes located at the network's core consumed approximately 35 percent more energy due to their increased communication responsibilities. This pattern reaffirms the well-established relationship between routing load and energy depletion in WSNs [4]. The network demonstrated strong adaptive behavior, automatically rerouting data when individual nodes temporarily failed. Mesh topology significantly enhanced network robustness by avoiding single points of failure. The overall performance validated the viability of WSNs for long-term environmental surveillance and emphasized the need for optimized power-management techniques to extend system lifespan.

4. Conclusion

This deployment and testing of the wireless sensor network confirmed its suitability and effectiveness for real-time monitoring of environmental parameters. The system provided accurate measurements and stable communication under diverse environmental conditions, demonstrating the practical value of WSNs for applications ranging from agricultural monitoring to climate research and urban environmental analysis. Although environmental factors such as rainfall and physical obstructions introduced communication variability, the mesh topology and low-power communication standard helped maintain robust network performance. Energy consumption patterns indicated the necessity of incorporating energy-aware routing and scheduling mechanisms to maximize network longevity. Sensor calibration played an essential role in maintaining measurement accuracy, reinforcing its importance in any environmental monitoring application. The study's findings align closely with established literature on WSN reliability, performance optimization, and environmental sensitivity. Future research should explore integration of energy harvesting systems, machine learning-based adaptive routing, and enhanced self-healing algorithms capable of responding autonomously to node failures. Expanding the system to large-scale deployments across different climatic zones will further validate its generalizability. Overall, the results support the conclusion that WSNs represent a highly effective

and scalable approach for real-time environmental monitoring, contributing significantly to sustainable resource management and intelligent environmental decision-making.

References

1. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, A survey, " Computer Networks, vol. 38, no. 4, pp. 393–422, 2002. "Wireless sensor networks:
2. D. Hasenfratz, O. Saukh, and L. Thiele, "Model-driven accuracy bounds for noisy sensor readings," IEEE International Conference on Pervasive Computing and Communications, pp. 1–9, 2012.
3. M. Sha, D. Gunatilaka, C. Wu, and C. Lu, "Reliable wireless sensor networks for environmental monitoring, " IEEE Transactions on Instrumentation and Measurement, vol. 65, no. 4, pp. 850–860, 2016.
4. K. Sohraby, D. Minoli, and T. Znati, Wireless Sensor Networks: Technology, Protocols, and Applications. Hoboken, NJ, USA: Wiley, 2007.
5. J. Yick, B. Mukherjee, and D. Ghosal, Networks, vol. 52, no. 12, pp. 2292–2330, 2008. "Wireless sensor network survey," Computer



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