IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 1, November 2025
Impact Factor: 7.67

Markov Chain Analysis of Duty-Cycled MAC Protocols for Reliable Underwater Water-Quality Monitoring

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Abstract: *The proliferation of wireless sensor networks (WSNs) has transformed environmental monitoring, yet underwater environments present unique challenges for real-time water quality assessment. This paper implements a novel approach leveraging Underwater Acoustic Sensor Networks (UWASN) to optimize water quality monitoring through duty-cycled reservation-based MAC protocols. The framework integrates low-power Zigbee radios, hierarchical clustering, and optimization algorithms to address energy constraints, scalability, and data reliability. A Markov chain analytical model evaluates protocol effectiveness, focusing on key parameters such as throughput and packet delivery ratio. The study simulates various network topologies—2D static, 3D dynamic, clustered deployments—and assesses their impact on monitoring diverse water quality factors, including pH, dissolved oxygen, turbidity, conductivity, and temperature. Comparative results highlight MAC protocol advances over commercial systems, demonstrating improved coverage and lifespan. The research closes critical gaps in secure communication, adaptive clustering, and energy-efficient node deployment, with comprehensive tables and graphical results substantiating findings. The presented paradigm not only enhances aquatic resource management but also lays groundwork for future smart sensor systems.*

Keywords: *WSNs*

DOI: 10.48175/IJARSCT-29694