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A Synchronous Duty-Cycled Reservation-Based MAC Protocol for Deep-Sea Underwater Acoustic Sensor Networks

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Abstract: *Designing an efficient MAC protocol for Underwater Acoustic Sensor Networks (UASNs) is critical due to unique challenges such as long propagation delays, limited bandwidth, and high energy constraints. This study presents a novel synchronous duty-cycled reservation-based MAC protocol specifically designed for deep underwater bottom monitoring. The protocol aims to enhance key performance metrics including energy efficiency, packet delivery ratio (PDR), throughput, and network lifetime, making it suitable for long-duration, remote deployments. The proposed protocol employs a hybrid strategy that combines synchronous time-slot reservations with adaptive duty-cycling. This design significantly reduces idle listening and collisions, improves channel utilization, and ensures fairness in slot allocation. The reservation mechanism is managed by a lightweight control strategy that minimizes signalling overhead and supports efficient scheduling of transmission slots. Simulation experiments were conducted using the Aqua-Sim Next Generation (Aqua-Sim NG) framework within the NS-3 environment. The underwater network scenario consisted of 50 sensor nodes deployed over a 2 km × 2 km area at a 1000-meter depth. Performance was evaluated using metrics such as PDR, throughput, end-to-end delay, energy consumption per bit, retransmissions, control overhead, and slot utilization. Results show the proposed protocol outperformed T-Lohi, Slotted FAMA, and UWAN-MAC, achieving 97.6% PDR, 485.2 bps throughput, and only 0.019 J energy consumption per bit. Additionally, it extended the network lifetime to 296 days and reduced retransmissions and overhead significantly. Cumulative radar and bar plots confirmed its superior overall performance. These findings establish the protocol as a promising candidate for deep-sea monitoring applications requiring reliable and energy-aware communication.*

Keywords: Underwater Acoustic Sensor Networks (UASNs), Duty-cycling, Packet Delivery Ratio (PDR), Slot utilization, Collision avoidance