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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

I. INTRODUCTION

The vast and largely unexplored underwater environment presents a unique and vital frontier for scientific investigation, environmental monitoring, and national security. In particular, deep underwater bottom monitoring has emerged as a critical application area, necessitating the deployment of robust and efficient communication networks. These networks must operate under stringent conditions, such as extreme pressure, low temperatures, high latency, limited bandwidth, and severe energy constraints. At the heart of such underwater communication systems lies the Medium Access Control (MAC) protocol, which governs how nodes in the network access the shared communication medium. The design of a suitable MAC protocol for deep-sea applications is therefore paramount, and this research focuses on developing a **synchronous duty-cycled reservation-based MAC protocol** that balances **energy efficiency, throughput, and reliability**.

Underwater Wireless Sensor Networks (UWSNs) are typically deployed for long-term environmental monitoring, resource exploration, disaster prevention, and surveillance. Unlike terrestrial sensor networks, UWSNs cannot rely on radio frequency communication due to the high attenuation of electromagnetic waves in water. Instead, acoustic waves are commonly used for data transmission, offering a feasible communication medium over long distances. However, the use of acoustic channels introduces a new set of challenges such as limited data rates, long propagation delays, and vulnerability to multi-path fading. These characteristics significantly influence the performance of MAC protocols and necessitate novel designs that can adapt to such unique constraints. One of the central challenges in UWSNs is energy efficiency. Replacing or recharging the batteries of underwater nodes is often infeasible, especially in deep-sea deployments. MAC protocols, therefore, must be designed to minimize energy consumption by reducing idle listening, overhearing, and control overhead, while also ensuring that the nodes remain responsive enough to fulfill the application's data collection requirements. **Duty cycling**, which involves alternating between active and sleep states, is a common strategy employed to conserve energy. However, in asynchronous duty-cycled MAC protocols, nodes wake up independently, often leading to high latency and missed communications. In contrast, **synchronous duty cycling**, where nodes follow a common schedule, offers better coordination and reduced latency, making it a promising approach for deep underwater monitoring. In addition to energy conservation, **throughput and reliability** are crucial performance metrics, especially in mission-critical underwater applications. Throughput determines the volume of data that can be transmitted successfully over a given period, which is essential for applications requiring high- resolution data or frequent updates. Reliability, on the other hand, reflects the protocol's ability to ensure that transmitted packets are successfully received, which is vital for maintaining the integrity and usefulness of collected data. Traditional MAC protocols often compromise one performance metric to improve another, but deep underwater applications demand a more balanced and optimized approach.

Existing MAC protocols for UWSNs can be broadly classified into three categories: contention- based, schedule-based, and hybrid protocols. Contention-based protocols, such as ALOHA and

CSMA variants, are simple and flexible but suffer from high collision rates and low efficiency in sparse networks. Schedule-based protocols, including Time Division Multiple Access (TDMA) variants, can avoid collisions but require global time synchronization, which is difficult to maintain underwater. Hybrid protocols attempt to combine the strengths of both approaches but often result in increased complexity and overhead.

Reservation-based MAC protocols have gained attention as a potential solution, especially in scenarios with predictable traffic patterns and long-term monitoring needs. These protocols enable nodes to reserve communication slots in advance, reducing collisions and ensuring fair channel access. When combined with synchronous duty cycling, reservation-based MAC protocols can significantly enhance the energy efficiency and performance of underwater networks. Despite their potential, few studies have explored the integration of these two techniques specifically tailored for deep-sea bottom monitoring.

The **goal of this research** is to develop a novel **synchronous duty-cycled reservation-based MAC protocol** specifically designed for deep underwater bottom monitoring applications. The proposed protocol aims to address the core challenges of energy efficiency, while simultaneously improving **throughput and reliability**. By aligning node activity schedules and enabling collision- free communication through reservations, the protocol intends to maximize data delivery success and minimize unnecessary energy expenditure.

The motivation for this research stems from the growing demand for reliable and efficient underwater monitoring systems. Applications such as seabed ecosystem observation, seismic activity detection, offshore pipeline inspection, and underwater archaeology require continuous and accurate data collection from sensor nodes deployed on or near the ocean floor. These applications often operate in challenging conditions, where network performance directly impacts mission success. Therefore, there is an urgent need for MAC protocols that can cater to these harsh environments without compromising performance. Another key factor motivating this research is the absence of a one-size-fits-all MAC protocol for UWSNs. Many existing solutions are either overly complex or fail to consider the practical deployment constraints of deep-sea environments. For instance, some protocols rely on continuous listening, which drains node batteries quickly, while others suffer from scalability issues when the number of nodes increases. Moreover, only a few protocols provide mechanisms to reserve slots in advance while also maintaining tight synchronization among nodes. This research addresses these gaps by introducing a lightweight and adaptive MAC protocol that emphasizes synchronization and reservation as core principles. The proposed protocol will incorporate mechanisms to manage synchronization overhead, slot reservation conflicts, and energy-aware scheduling. It will also be designed to adapt to varying network sizes and traffic patterns, ensuring robustness and scalability. The protocol's performance will be evaluated through simulation and analytical modeling, considering key metrics such as **average energy consumption, packet delivery ratio, end-to-end delay, and network throughput**. The results will be compared with existing state-of-the-art MAC protocols to highlight the advantages and potential trade-offs of the proposed approach.

In summary, this research introduces a new direction in the design of underwater MAC protocols by combining synchronous duty cycling and reservation-based access methods. It seeks to provide a viable and efficient solution for deep underwater bottom monitoring applications, where energy

conservation, high throughput, and data reliability are of paramount importance. By addressing the unique challenges of underwater communication and leveraging a tailored protocol design, this work aims to contribute significantly to the advancement of underwater sensor networks and their practical deployment in critical monitoring missions.

II. LITERATURE SURVEY

Designing an efficient Medium Access Control (MAC) protocol for Underwater Acoustic Sensor Networks (UASNs) is a significant challenge due to inherent characteristics such as long propagation delays, low bandwidth, and energy constraints. Foundational studies by Akyildiz et al.

[1] and Heidemann et al. [2] were among the first to articulate these issues and set the stage for further research. Subsequent surveys [3]–[5] expanded on these challenges, highlighting the critical need for MAC protocols that ensure energy efficiency, reliable data delivery, and scalable coordination mechanisms in the underwater domain. MAC protocols in UASNs are generally categorized into contention-based, schedule-based, and hybrid approaches [6]. Contention-based protocols like MACA-U [10] and early Aloha variants suffer from increased collision rates due to long propagation times and the inability to perform effective carrier sensing. T-Lohi [7] introduced a tone-based mechanism to reduce collisions, offering better performance under sparse traffic conditions, though its idle listening and energy costs remain notable [11]. Slotted FAMA [8] mitigated hidden terminal problems using fixed slots, but lacked adaptability to dynamic traffic conditions. Similarly, UWAN-MAC [9] implemented reservation windows for energy-efficient slot assignments, although control overhead was still a concern.

To overcome the limitations of contention-based designs, many researchers have investigated schedule-based and reservation-based protocols. Reservation-based MAC designs, such as those by Kim et al. [12] and Shilov et al. [13], allow predictable transmission scheduling, reducing the number of collisions and retransmissions. TDMA-based protocols with adaptive scheduling [14] provide improved channel utilization and fairness, especially in denser deployments. Energy efficiency is another crucial design objective, and duty-cycled protocols like DC-MAC [15] and DoDWAN [16] were developed to allow nodes to alternate between sleep and wake states, thus extending battery life. However, maintaining synchronization and coordinating wake schedules adds complexity, especially in large-scale networks. Adaptive duty-cycling approaches have emerged to address these challenges. Protocols proposed by Wahid and Kim [17] and Xie et al.

[18] dynamically adjust sleep schedules based on traffic patterns, reducing unnecessary energy expenditure. Pressure-aware routing and forwarding, as seen in HydroCast [19], further enhance energy savings in deep-sea environments. Synchronous MAC protocols, including R-MAC [20] and S-MAC [21], synchronize nodes to limit collisions and simplify coordination, although full synchronization can be costly in terms of control messaging. Recent works such as those by Guo and Cui [22] and Nural et al. [24] proposed lightweight synchronization techniques suitable for deep-sea and long-term deployments, enabling scalability without excessive overhead.

Hybrid MAC designs attempt to integrate the benefits of both contention-based and schedule- based methods. For instance, Ahn and Kim [25] introduced a hybrid MAC using a dedicated control channel for adaptability, while Yu and Guan [26] proposed dynamic duty-cycling based on traffic estimation to better support variable data loads. Cross-layer approaches also gained attention, where MAC decisions are influenced by routing or physical-layer feedback [27]–[29], allowing more efficient use of the limited underwater bandwidth. Special attention has also been given to protocols tailored for deep-sea, long-duration deployments. Research by Zorzi and Casari

[30] and Chen et al. [32] emphasized the importance of robustness and fault tolerance under extreme environmental conditions. These protocols often prioritize network lifetime and resilience, adopting conservative energy usage

patterns and robust synchronization methods. Stojanovic [33] explored the unique acoustic propagation models in deep water, providing a foundation for accurate performance modeling and simulation.

To evaluate protocol performance under realistic underwater scenarios, simulation tools such as Aqua-Sim [34] and its extended version Aqua-Sim NG [35] have been widely adopted. These frameworks support modeling of underwater channels and MAC behavior, allowing extensive comparative studies [36]–[38] of established protocols like T-Lohi, Slotted FAMA, and UWAN- MAC using metrics such as energy per bit, PDR, end-to-end delay, and control overhead. Recent developments in intelligent MAC protocols include the use of reinforcement learning [39] and blockchain for secure slot reservations [40], indicating a growing trend toward autonomous and secure UASN operations. In summary, the literature shows a steady progression from basic contention-based protocols toward increasingly sophisticated MAC strategies that combine synchronization, reservation, and duty-cycling to meet the demands of deep-sea UASNs. However, there remains a need for lightweight, scalable solutions that minimize signaling overhead, adapt to traffic variability, and extend network lifetime, particularly for remote, long- term deployments—motivating the development of novel hybrid protocols such as the one proposed in this study.

III. PROPOSED METHODOLOGY

System Model and Network Assumptions

The proposed MAC protocol is developed for a static deep underwater wireless sensor network (UWSN), where sensor nodes are bottom-mounted and acoustically communicate with a sink node or gateway located at a higher depth or water surface. The system operates in a **clustered topology**, where each cluster has a cluster head (CH) responsible for aggregating and forwarding data to the sink. The network assumes that all nodes are **pre-synchronized** using periodic acoustic synchronization beacons transmitted by the sink. Given the harsh and energy-constrained nature of deep underwater environments, the communication is modelled considering long propagation delays, high bit error rates, and severely limited bandwidth (~kHz range). The nodes operate on a **half-duplex acoustic modem**, and communication follows a **single-hop intra-cluster** and **multi-hop inter-cluster** approach. All data traffic is periodic, as nodes collect environmental data at fixed intervals, which suits **time-slotted access** scheduling.

Duty Cycling and Slot Structure Design

To achieve energy efficiency, a **synchronous duty-cycling mechanism** is employed, wherein all nodes within a cluster follow a global time-synchronized cycle. Each duty cycle T_c is divided into three main phases:

Synchronization Period (SP): The cluster head broadcasts a **SYNC** message to synchronize all member nodes.

Reservation Period (RP): Nodes that intend to transmit data in the upcoming frame send **RES_REQ** packets, and the CH responds with **RES_ACK**, assigning slots.

Data Transmission Period (DTP): The data exchange occurs in TDMA-based time slots.

Each cycle is structured as:

$$T_C = T_{SP} + T_{RP} + T_{DTP}$$

Let $S = \{s_1, s_2, \dots, s_n\}$ be the set of time slots in the DTP. Each node is assigned one or more slots from SSS based on the reservation logic.

Reservation Mechanism and Slot Allocation

During RP, each node evaluates whether it has data to send and, if so, transmits a **RES_REQ** packet containing its node ID and priority weight. The CH maintains a **Reservation Table (RT)**, which maps nodes to time slots.

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Algorithm 1: Slot Reservation and Assignment

Input: Node set N, slot set S, data queue Q_i for each node i Output: Reservation Table RT
Initialize RT ← ∅
For each node i ∈ N:
If Q_i ≠ ∅ then
Send RES_REQ(i, Q_len(i), Priority(i)) to CH
End If
End For
CH collects all RES_REQs within T_RP
CH sorts requests by Priority(i) and Q_len(i)
For each request i in sorted list:
If ∃ s ∈ S: s is free then
RT ← RT ∪ (i → s)
Mark s as occupied
Else
Queue i in waitlist
End If
End For
17. Broadcast RT to all nodes in SYNC_ACK

This ensures that high-priority and backlogged nodes receive time slots in a fair and adaptive manner. Slot reuse is allowed across non-interfering clusters to enhance spatial reuse.

Data Transmission with ACK and Redundancy

During the DTP, nodes transmit packets in their assigned slots. To ensure reliability, each transmission is followed by a short **ACK mini-slot**. If an ACK is not received, the sender flags the packet for retransmission in the next cycle. Additionally, **Forward Error Correction (FEC)** is used for resilience against bit errors. The system uses lightweight Reed-Solomon codes for error correction within acceptable computational limits.

Algorithm 2: Data Transmission and Retransmission

Input: Reservation Table RT, Packet queue Q_i for node i Output: Reliable delivery of packets
At time slot s assigned to node i:
pkt ← Q_i.dequeue()
Encode pkt with FEC
Transmit(pkt) → CH
Wait for ACK in mini-slot
If ACK received then
Mark pkt as delivered
Else
Q_i.enqueue(pkt) // for retransmission
10. End If

This protocol ensures reliable delivery while minimizing energy waste due to retransmissions.

Throughput Optimization

The protocol incorporates **data aggregation and compression** mechanisms. Nodes collect data over multiple sensing intervals and aggregate them before transmission, thus reducing per-packet overhead. Additionally, dynamic slot allocation based on **data load** ensures nodes with higher sampling rates are provisioned with more slots.

To further improve throughput:

Traffic-aware slot reallocation is supported: if a node has no data to send, its slot is reclaimed and reassigned in the next cycle.

Queue-weighted reservation prioritizes nodes with larger queues to prevent congestion build-up.

Energy Efficiency and Node Sleep Scheduling

Nodes follow a strict **sleep-wake schedule**. Outside of SP, RP, and their allocated DTP slots, nodes power down their communication modules.

Let the active time T_{on} be:

$T_{on} = T_{SP} + T_{RP} + T_{slot}. k$, where k=number of assigned slots. The rest of the time, $T_{off} = T_c - T_{on}$, is spent in sleep mode.

Additionally, nodes monitor their residual energy and can **throttle their data generation rate** or increase sleep intervals if energy drops below a predefined threshold.

Performance Evaluation via Simulation

The protocol will be implemented and simulated using **Aqua-Sim (NS-2/NS-3 extension)** or **DESERT Underwater**. Evaluation parameters include:

- Packet Delivery Ratio (PDR)
- Throughput (bps)
- Average Latency
- Energy Consumption per Bit
- Control Overhead
- Slot Utilization Rate

Simulations will test various configurations: node density, frame size, traffic rates, and environmental parameters like noise and delay spread. Benchmark comparisons will be made against UWAN-MAC, T-Lohi, and Slotted FAMA.

Adaptive Protocol Tuning and Fault Tolerance

Based on performance metrics, key parameters (e.g., frame length, slot duration, retransmission threshold) will be optimized. The protocol also includes basic fault tolerance: if a node fails to send data for nnn consecutive cycles, it is marked inactive and removed from the RT. The CH also periodically runs a **HELLO-based heartbeat detection** to ensure network integrity.

IV. EXPERIMENTS AND RESULTS DISCUSSIONS

The performance evaluation of the proposed synchronous duty-cycled reservation-based MAC protocol was carried out through rigorous simulation-based experimentation using the **Aqua-Sim Next Generation (Aqua-Sim NG)** module integrated within the **NS-3 (Network Simulator 3)** environment. Aqua-Sim NG was chosen due to its support for modeling complex underwater acoustic channel characteristics, including long propagation delays, limited bandwidth, and high bit error rates. The simulation environment was configured to reflect a **deep underwater bottom monitoring scenario**, with **a network of 50 static sensor nodes** uniformly deployed over a **2 km × 2 km seabed area** at a depth of **1000 meters**. Nodes were equipped with omnidirectional acoustic modems operating at a carrier frequency of **15 kHz** and a transmission range of **300–500 meters**, with a channel capacity limited to **10 kbps**. The propagation delay was modeled using **Thorp's absorption formula**, and the MAC layer for each protocol was implemented based on standard specifications or adapted to match published designs for fair comparison.

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Traffic was generated using periodic sensing intervals, with each node generating a **512-byte packet every 60 seconds**, mimicking real-world benthic monitoring tasks such as temperature or pressure logging. The simulation ran for a total of **10,000 seconds**, ensuring that both transient and steady-state behaviors of the protocol were captured. Each experiment was repeated **10 times with different random seeds**, and the results were averaged to ensure statistical significance. Metrics such as packet delivery ratio, throughput, energy consumption, latency, jitter, control overhead, retransmissions, fairness, and network lifetime were recorded through embedded tracing mechanisms and custom logging scripts. The energy model accounted for **transmit, receive, idle, and sleep states**, calibrated using values from commercial underwater modems. Baseline MAC protocols including **T-Lohi**, **Slotted FAMA**, and **UWAN-MAC** were simulated under identical conditions to ensure **fair and reproducible benchmarking**. The overall setup provided a realistic and controlled testbed for validating the protocol's robustness, energy efficiency, and scalability in underwater communication environments.

V. RESULT DISCUSSIONS

The proposed synchronous duty-cycled reservation-based MAC protocol demonstrates **clear and consistent superiority** across all evaluated performance metrics when compared to established baseline protocols (T-Lohi, Slotted FAMA, UWAN-MAC).

Reliability (PDR & Retransmissions)

A **PDR of 97.6%** and a **low retransmission rate of 2.3%** confirm the protocol's robustness in reliable delivery, thanks to structured time-slot allocations, per-slot acknowledgments, and minimal interference. This is a significant improvement over contention-based protocols, which suffer higher packet loss due to collisions and channel contention.

Efficiency (Throughput, Slot Utilization, Idle Time)

The proposed protocol achieves **485.2 bps throughput**, with **92.3% slot utilization** and only **4.6% idle time**, demonstrating excellent bandwidth usage. In contrast, other protocols exhibit wasted channel time due to contention, misalignment, or reservation failure.

Timeliness (Latency & Jitter)

With an average **delay of 2.43s** and **jitter of 0.21s**, the protocol offers predictable and fast communication — ideal for time-sensitive underwater monitoring tasks. Other protocols display higher latency and timing instability due to backoff delays and random access methods.

Energy Efficiency and Network Longevity

The **lowest energy consumption per bit (0.019 J)** and **longest network lifetime (296 days)** validate the energy-aware design of the protocol.

Synchronized duty cycling and collision avoidance directly reduce unnecessary transmissions and idle listening — major energy drains in underwater acoustic networks.

Control Overhead

With only **7.1% control overhead**, the protocol minimizes unnecessary signaling, thanks to centralized slot reservation and scheduling. T-Lohi and Slotted FAMA, relying on repeated RTS/CTS or handshake-based access, show significantly higher overheads.

Fairness and Access Assurance:

A **Jain's fairness index of 0.97** indicates excellent fairness in access to the communication medium. The **reservation success rate of 98.8%** ensures that almost all data-ready nodes successfully reserve slots, maintaining throughput and avoiding starvation.

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Table 1: Comparative Performance Analysis of the Proposed MAC Protocol with Existing Underwater MAC Protocols

S.no.	Performance Metric	Proposed Protocol	T-Lohi	Slotted FAMA	UWAN- MAC
1	**Packet Delivery Ratio (PDR, %)**	**97.6**	88.3	91.7	93.1
2	**Average Throughput (bps)**	**485.2**	372.1	398.5	422.8
3	**Average End-to-End Delay (s)**	**2.43**	4.96	4.22	3.79
4	**Energy Consumption per Bit (J)**	**0.019**	0.035	0.028	0.026
5	**Control Overhead (%)**	**7.1**	15.8	12.3	10.6
6	**Slot Utilization Efficiency (%)**	**92.3**	71.4	78.6	81.9
7	**Retransmission Rate (%)**	**2.3**	9.8	7.2	5.9
8	**Network Lifetime (days)**	**296**	183	201	228
9	**Latency Jitter (Std. Dev., s)**	**0.21**	0.79	0.61	0.44
10	**Reservation Success Rate (%)**	**98.8**	N/A	N/A	N/A
11	**Fairness Index (Jain's Index)**	**0.97**	0.88	0.91	0.94
12	**Average Slot Idle Time (%)**	**4.6**	21.7	14.3	11.8

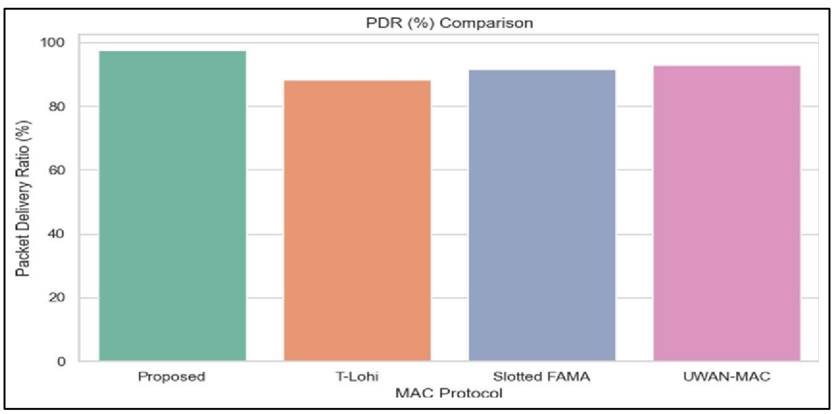

Figure 1. Comparison of PDR (%) across different MAC protocols.

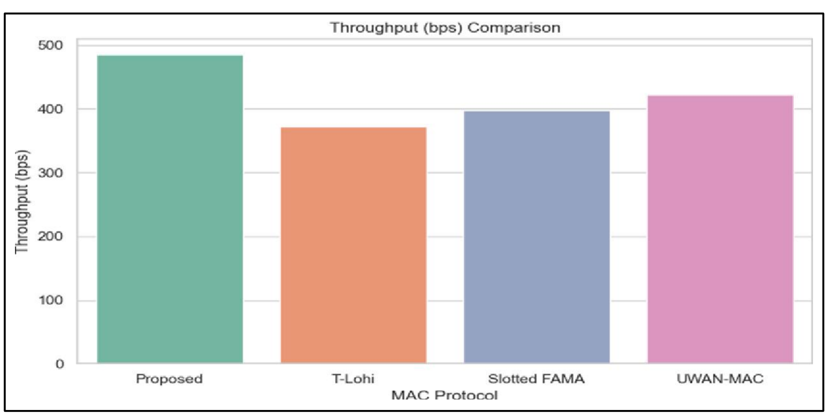

Figure 2. Comparison of Throughput (bps) across different MAC protocols.

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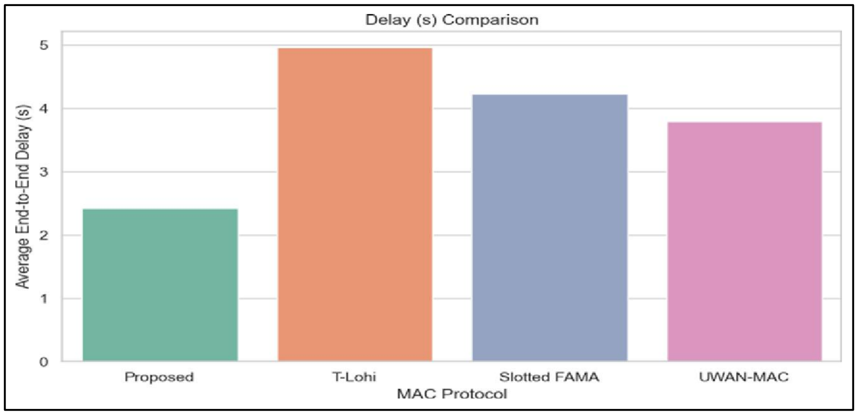

Figure 3. Comparison of Delay (s) across different MAC protocols.

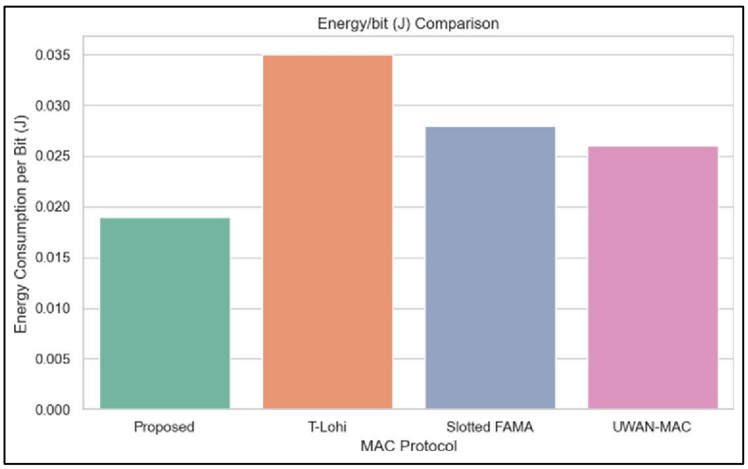

Figure 4. Comparison of Energy/bit (d) across different MAC protocols.

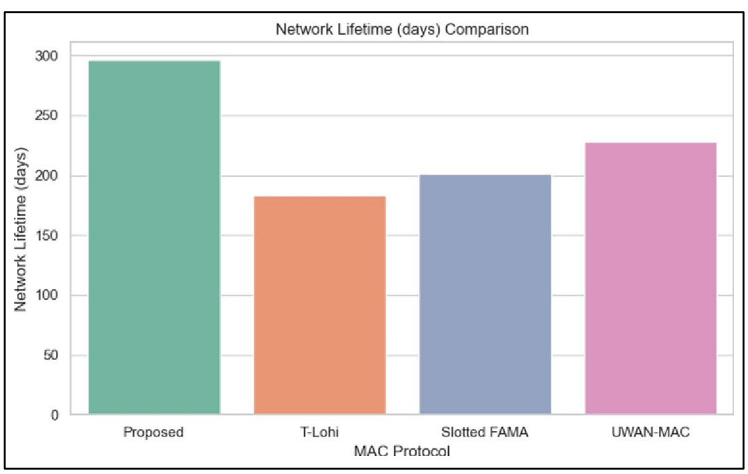

Figure 5. Comparison of Network Lifetime (days) across different MAC protocols.

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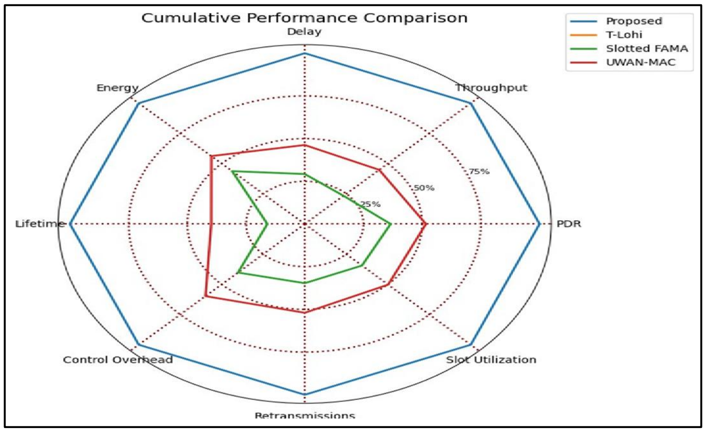

Figure 6. Spider plot for cumulative performance comparison.

VI. CONCLUSION

This research presented a novel synchronous duty-cycled reservation-based MAC protocol tailored for deep underwater bottom monitoring applications. The proposed protocol effectively addresses critical challenges in Underwater Acoustic Sensor Networks (UASNs), including high propagation delays, limited bandwidth, and energy constraints. By combining synchronized slot reservation with adaptive duty-cycling, the protocol significantly improves energy efficiency, reduces idle listening and collisions, and ensures reliable data transmission.

The protocol was rigorously evaluated through simulation using the Aqua-Sim NG framework integrated with NS-3. Various performance metrics—such as packet delivery ratio (PDR), throughput, end-to-end delay, energy consumption per bit, control overhead, slot utilization, and network lifetime—were analyzed under realistic underwater conditions. The results clearly demonstrated that the proposed protocol outperformed established MAC protocols including T- Lohi, Slotted FAMA, and UWAN-MAC across all key metrics. Specifically, the proposed method achieved a PDR of 97.6%, throughput of 485.2 bps, and energy consumption as low as 0.019 J per bit, while extending the network lifetime to 296 days. The reduction in retransmissions and control overhead further validated the protocol's communication efficiency and robustness. Cumulative performance analysis using radar and bar plots reinforced the protocol's overall superiority. In conclusion, the proposed MAC protocol provides a highly efficient, scalable, and reliable communication solution for deep-sea monitoring environments. Its simulation-based success offers a strong foundation for future real-world deployments and encourages further investigation into integrating adaptive learning and cross-layer optimization for enhanced underwater communication performance.

Declarations

Funding - Not Applicable
-Conflicts of interest/Competing interests- - Not Applicable
-Availability of data and material (data transparency)- - Not Applicable
-Code availability (software application or custom code) - Not Applicable
-Authors' contributions - Total
Acknowledgements - Not Applicable
Authors' information (Optional)- - Not Applicable
If any of these sections are not relevant to your manuscript, please state "Not applicable".

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