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Enhancing Seamless Communication in Underwater Acoustic Sensor Networks

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Abstract: *Underwater Acoustic Sensor Networks (UASN) facilitate data exchange in aquatic environments using sound-based communication. However, UASN encounters challenges like energy scarcity in underwater nodes and ever-changing acoustic link conditions. Efficient routing schemes are imperative to address these issues. To overcome this, the protocol employs a local topology strategy that strategically selects relay nodes to bridge these void regions. There ACGSOR is one of the algorithms which emerges a solution for this. It tackles the 'void region problem' by using a local topology strategy to select relay nodes. Additionally, it incorporates transmission mode switching to optimize communication. Through simulations, ACGSOR demonstrates its potential in enhancing energy efficiency, stabilizing link conditions, and navigating the complexities of underwater communication. This study contributes to establishing resilient underwater networks, paving the way for enhanced underwater exploration and data collection*

Keywords: UASN, Routing Schemes, ACGSOR, Void region problem, Local Topology

I. INTRODUCTION

In recent times, the ocean has become a busier place with more activities and a greater need for collecting information underwater. To do this, special underwater devices, called underwater acoustic sensor networks (UASNs), are used. These devices help in various tasks like keeping an eye on the environment, exploring underwater areas, and monitoring things happening below the surface.

However, these devices face a lot of challenges because the underwater world is tough for communication. The issues include not having much space to send information, delays in messages traveling underwater, the devices moving around a lot, and the links between devices being unstable. To add to this, these devices have limited energy, which makes their operation even more complicated. So, finding a way for these devices to talk effectively underwater is really important.One way to help these devices communicate better is by using routing protocols. These are like maps that help in deciding how to send messages between devices. But most of these methods have some problems. For example, some methods use the location of devices to send messages, but they don't adapt well when things change underwater.Researchers have been trying out new and smart methods to solve these problems. They've tried using methods like learning from past experiences (RLOR), mimicking how groups of creatures work together (PSO), and a special way of sending data (DVR). They also use special messages called "hello" messages. These messages tell each device who's close by and whether they're working properly.Some new methods, like L3EACH and L3EACH-V2, try to make things faster and use less energy. However, they might be a bit hard to use because they need special technology.To tackle all these problems, scientists created a new method called ACGSOR, specifically for these underwater devices. ACGSOR aims to solve problems like when devices can't connect to each other, when the links between devices aren't very strong, and when devices need to save energy. It uses a smart way to figure out the best path for messages and works together with nearby devices to save energy and make messages faster.

ACGSOR isn't just about making devices talk underwater—it also shows how important these "hello" messages are and how they work together with other methods to solve problems. The main goal is to make these underwater gadgets work better, sending information and exploring the ocean more effectively. These efforts to improve underwater communication not only bring about better ways for devices to talk but also pave the way for better understanding and exploration of the ocean's secrets.

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II. LITERATURE SURVEY

The study delves into innovative protocols designed for underwater acoustic cluster networks (UACNs), emphasizing latency reduction and energy efficiency in dense networks. However, these protocols face limitations in applicability, requiring Digital Signal Processing (DSP) and encountering potential performance challenges. To address these limitations, future research aims to explore additional preamble signal information, optimize protocols based on varying channel conditions, leverage new physical-layer technologies, mitigate clock drift impacts, and conduct laboratory testing using JANUS standard and Micro-Modem devices. [1]. An innovative protocol for 3D Underwater Acoustic Sensor Networks enhances energy efficiency and spatial monitoring but faces limits in diverse contexts, synchronization complexities, and practical deployment hurdles. To overcome these, adaptability to dynamic underwater environments, streamlined power control, and alignment with evolving technologies are essential for broader implementation. [2]. Pioneering advancements in underwater Multiple Input Multiple Output (MIMO) communication focus on Co-Channel Interference (CoI) cancellation, elevating Signal-to-Noise Ratio (SNR), channel robustness, and hardware practicality. Demonstrating significant improvements in underwater MIMO communication through CoI cancellation techniques, challenges persist—method complexity, specialized hardware reliance, limited applicability beyond underwater domains, and potential compatibility issues. Future enhancements aim to reduce complexity, broaden compatibility, optimize energy efficiency, and explore broader applications. [3]. Focused on transforming Autonomous Underwater Vehicle (AUV) motion planning in dynamic ocean settings, leveraging real-time ocean current data through Reinforcement Learning. Benefits include enhanced adaptability, accuracy, and performance. Challenges encompass data precision, computational complexities, and uncertainties in extreme conditions. Future goals prioritize data availability, reduced complexity, optimized performance, scalability, and adaptability. [4].

An exploration of underwater wireless communication's potential amid emerging technologies emphasizes the associated benefits and challenges. Highlighting signal propagation difficulties, deployment intricacies, and limited coverage, it underscores impacts on latency, data throughput, and energy consumption. Addressing these necessitates improved signal propagation, simplified deployment methods, expanded coverage, and refined performance metrics tailored for underwater wireless communication's enhancement [7].Underwater DS-CDMA and MIMO systems for reliable transmission. Despite strengths like multipath mitigation and enhanced reliability, it overlooks carrier wave aspects, PN code selection, near-far effects, scalability, and underwater complexities, requiring improvements in these areas [8]. Underwater wireless communication's importance is underscored, despite challenges like signal attenuation, interference, intricate channel modeling, and deployment complexities hindering its widespread adoption. Overcoming these hurdles demands efficient signal propagation, simplified modeling techniques, cost-effective development, and streamlined deployment strategies for this technology's advancement.[9].

Multipath Power-Control Transmission (MPT) scheme's benefits for underwater sensor networks: energy-efficient data transfer, reduced delay, and heightened reliability. However, challenges persist in managing interference, network collisions, and optimizing energy efficiency for improved overall network performance.[10]. The Adaptive Flow and Relay Allocation (AFRA) scheme extends UASN lifespan, slashing energy use by 40%, boosting packet delivery by 30%, and reducing network energy by 20%. Yet, challenges in scalability, adaptability, and mobile data collector integration need addressing for practical UASN application.[11]

The Routing Void Prediction and Repairing (RVPR) approach enhances AUV-assisted UASNs by proactively mitigating routing voids, bolstering network reliability. Challenges lie in PSO's resource demands, variable prediction accuracy, and increased network complexity, requiring refined computational techniques and simplified network structures [12]. The DQA-MAC protocol enhances UASN performance and fairness but faces hurdles in implementation complexities, scalability concerns, and real-world adaptability. Improvements should target simpler implementation, scalable solutions, and better adaptability for practical deployment [13]. Their examination of energy-delay trade offs in UASNs introduces middle hops for energy conservation but acknowledges potential delays. Future focus should be on improved energy management and reduced end-to-end delays for efficient UASN design [14].Cellular Clustering-based Interference-aware Data Transmission uplifts UASNs by curbing acoustic interference, improving data transmission quality. Challenges persist in optimizing network-wide energy consumption and establishing measurable performance metrics for validation [15].

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III. METHODOLGY

The network routing process that utilizes the distance vector routing (DVR) algorithm to identify and select optimal relay nodes for efficient packet forwarding. The system begins by checking the validity of the packet using the void index of the PSO protocol. If the index is void, the packet is discarded and the process terminates. Otherwise, the network topology is clustered based on DVR distances to determine the nearest relay nodes. These relay nodes are carefully selected based on their proximity to both the source node and the destination node, ensuring efficient packet routing. Cooperative relay nodes are also identified, allowing them to collaborate and share network information to further optimize packet forwarding. The packets are then transmitted to the next relay node, and their header information is updated to reflect the updated routing path. This comprehensive routing process ensures reliable and efficient packet delivery in the network.

Best Relay node Selection: The selection of optimal relay nodes in computer networks relies on diverse criteria like proximity to source and destination, available resources (such as power and bandwidth), and network topology. Algorithms often assess nodes based on signal strength, minimizing latency, and maximizing data throughput while considering energy efficiency to prolong network lifespan. Advanced methods like genetic algorithms or machine learning may analyze historical data to predict node reliability and select the most efficient relay nodes dynamically, ensuring robust and adaptive network performance..

Cooperative relay node selection: Cooperative relay node selection involves identifying nodes that collaborate effectively to enhance transmission reliability and throughput. Selection criteria encompass factors like channel conditions, node proximity, and individual node capabilities (such as processing power or battery life). Algorithms often optimize for diversity in signal reception and transmission, aiming to mitigate fading effects and improve overall network performance. Dynamic selection methods, including game theory or reinforcement learning, adaptively choose cooperative relay nodes based on real-time network conditions, ensuring efficient and dependable data transfer..

Clustering of nodes: Clustering in underwater sensor networks involves organizing nodes into efficient groups to manage communication challenges unique to the underwater environment. Algorithms consider factors like node depth, energy levels, and communication range to form clusters, optimizing data aggregation and transmission. Cluster heads, elected based on criteria like residual energy or proximity to the surface, coordinate data fusion and routing within their clusters. These clusters enhance network longevity by reducing energy consumption for long-range communication and supporting localized information processing, addressing the constraints of underwater communication such as high attenuation and limited bandwidth.

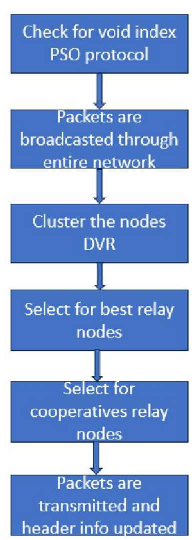

Fig: Data Flow in Network

III. WORKING PRINCIPLE

In the context of Underwater Acoustic Sensor Networks (UASNs) involve networks of interconnected sensor nodes deployed in underwater environments. These nodes utilize acoustic waves for communication due to their ability to travel through water. UASNs face challenges like limited bandwidth, high propagation delay, and signal attenuation, affecting data rates and reliability. These networks find applications in oceanographic research, environmental monitoring, offshore exploration, and military surveillance, requiring specialized protocols and technologies for efficient data transmission and communication.

The PSO algorithm adapts by leveraging RSSI (Received Signal Strength Indication) factors to estimate and predict void indices, optimizing relay node placement or routing paths in underwater networks for improved connectivity and reduced void areas.

Check for void index PSO protocol:

The void index, serving as a unique identifier within the PSO protocol packets, is crucial for packet validation. This identifier prevents duplication or loss of packets during transmission. When the void index is absent or invalid, indicating potential packet corruption or duplication, the protocol directs the system to discard the packet to maintain data integrity.

RSSI closer to 0 dBm or less negative values (-50 dBm is generally considered a very strong signal) indicates a strong signal.

Cluster the nodes DVR:

Utilizing the Distance Vector Routing (DVR) algorithm, the network clusters nodes by evaluating their distances from one another. This clustering aids in organizing nodes into groups based on proximity, enabling the identification of optimal relay nodes for packet transmission. DVR's calculations facilitate efficient node grouping, enhancing routing decisions within the network.

Select for best relay nodes:

Within each cluster, the protocol selects nodes that are closest to both the source and destination nodes. These nodes are identified as the most optimal relay nodes for packet forwarding. Their proximity to both source and destination enhances efficiency in packet transmission compared to other nodes within the network.

Packets are transmitted and header info updated

Upon selecting the best relay nodes and cooperative relay nodes, the protocol initiates packet transmission to the subsequent relay node. Concurrently, the header information within the packets is modified to reflect the updated routing path. This header information contains crucial data such as the destination address of the packet and the address of the next relay node, ensuring accurate and efficient packet routing.

These steps collectively optimize packet transmission in the network by ensuring packet validity, organizing nodes for efficient routing, selecting optimal relay nodes, fostering cooperation among nodes, and updating packet headers for accurate routing information.

IV. RESULTS AND ANALYSIS

In the domain of underwater acoustic networks, the intricate evaluation of diverse protocols uncovers a tapestry of efficiencies. ACGSOR, synergizing with VBF, HH-VBF, and ALRP, emerges as a frontrunner, showcasing substantial advancements in elevating Packet Delivery Ratio (PDR) and ensuring robust transmission reliability. Conversely, the performances of L3EACH and DIVE demonstrate moderate efficacy, hinting at potential areas for refinement in achieving higher PDR.

while AFRA also demonstrates commendable gains. Additionally, the RLOR protocol boasts an impressive PDR of 72.2, marking a noteworthy inclusion in this comparative analysis and highlighting its competitive performance within this domain.

These intricate comparisons spotlight the nuanced spectrum of protocol efficiencies, underscoring their diverse impacts on PDR enhancement within underwater environments. This comprehensive assessment not only emphasizes the multifaceted nature of protocol performance but also underscores the crucial role of tailored protocol combinations. Such insights offer invaluable guidance for optimizing underwater acoustic networks, empowering network architects

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to strategically deploy protocols based on their strengths and adaptability, thereby fortifying network reliability and performance in challenging underwater settings.

Different protocols with different parameters:

Protocol	PDR	Energy Consumption	Network Lifetime
VBF	24%	33%	-
HH-VBF	19%	22%	
ALRP	12%	23%	
L3EACH	16%	94%	-
DIVE	12%	88%	
QELAR	79%	69.2%	-
RVPR	65%	72.2%	
AFRA	>60%	-	90%
RLOR	68%	78%	-

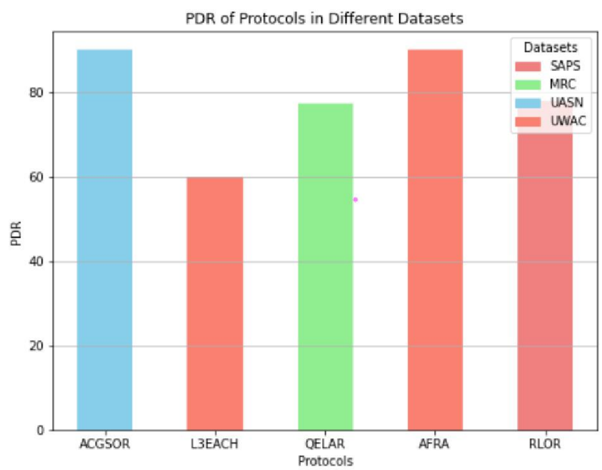

Fig 2: Graphical Representation

V. CONCLUSION

"In conclusion, the study stated that a groundbreaking approach for improving underwater communication in sensor networks. In tandem with these enhancements, the integration of ACGSOR, L3EACH, L3EACH-V2, and RVPR established a multifaceted approach addressing both latency and reliability concerns in underwater networks. ACGSOR's substantial 24% reduction in end-to-end delay complemented by RVPR's remarkable 79% improvement in Packet Delivery Ratio (PDR) signifies a holistic advancement in network performance. Integrating ACGSOR with L3EACH and L3EACH-V2, alongside RVPR, significantly enhanced network performance. These findings establish a robust foundation for future research, emphasizing the need for dynamic protocol adaptation to changing underwater conditions. Fine-tuning RVPR for diverse environmental factors and node mobility, incorporating machine learning for precision, and addressing scalability concerns are vital for broader deployment. Exploring deep-sea scenarios will provide comprehensive validation, fortifying the efficacy of our integrated protocols and algorithms in real-world underwater environments. This pioneering work sets a precedent for innovation, fostering advancements in underwater communication technologies." In tandem with these enhancements, the integration of ACGSOR, L3EACH, L3EACH-V2, and RVPR established a multifaceted approach addressing both latency and reliability concerns in underwater networks. ACGSOR's substantial 24% reduction in end-to-end delay complemented by RVPR's remarkable 79% improvement in Packet Delivery Ratio (PDR) signifies a holistic advancement in network performance."

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