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Enhancing Underwater Wireless Sensor Networks With Flexible Communication and Positioning

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Abstract: *An innovative approach centred around underwater wireless communication and positioning in Underwater Wireless Sensor Networks, addressing limited coverage by proposing a dual-hop system combining optical fiber and wireless links. Time frame design and Code Division Multiplexing Access enhance multi-user signal transmission efficiency. Proof-of-concept experiments validate feasibility, with the introduction of the hybrid fish eye routing protocol further enhancing performance by intelligently combining fish-eye routing and traditional protocols for improved coverage and reliability. Moreover, the hybrid fish eye protocol incorporates adaptive routing algorithms that dynamically adjust to changes in underwater conditions, ensuring robustness and adaptability in challenging environments. Additionally, the hybrid fish eye protocol optimizes energy consumption by minimizing unnecessary transmissions, thereby prolonging the lifespan of underwater sensor networks. With full-duplex communication, precise positioning, and an extended transmission range, convergent system demonstrates significant potential for supporting high-capacity transmission among mobile nodes in forthcoming underwater scenarios.*

Keywords: Underwater Wireless Sensor Networks, Underwater Communication Networks, Hybrid Fish Eye Routing Protocol, Node Positioning, Environment Monitoring, Network Throughput, Data Collection

I. INTRODUCTION

In contemporary underwater wireless sensor networks (UWSNs), overcoming the inherent challenges has become paramount, necessitating innovative approaches to propel the field forward. One such groundbreaking solution is centred around the integration of Underwater Optical Wireless Communication and Positioning.UWSNs, characterized by mobile nodes, frequently grapple with limited coverage, prompting the adoption of strategic measures like the dual-hop system. This system ingeniously combines GI-POF and wireless links to extend coverage, utilizing specialized components like the mini-Light Emitting Diode for uplink transmission and the high-power LED for downlink transmission and positioning.

Additionally, it employs time frame design and CDMA to enhance communication capabilities, crucial for multi-user signal transmission and network versatility. Further augmenting UWSNs is the Hybrid Fisheye Routing Protocol, a hierarchical proactive routing protocol engineered to minimize routing overhead by utilizing the "fisheye" technique, thereby optimizing communication efficiency within the network. Collectively, this integrated system offers a comprehensive solution to enhance coverage, improve communication reliability, elevate node positioning accuracy, facilitate multi-user support, and extend transmission range in UWSNs. By addressing these critical aspects, the proposed system aims to advance the capabilities and performance of underwater sensor networks, paving the way for transformative applications in underwater environments.

II. PROBLEM DEFINITION

Underwater wireless sensor networks (UWSNs) face difficulties in communicating over a limited area underwater. Accurately locating devices and coordinating communication among multiple devices are challenges. Moreover, the harsh underwater environment introduces significant signal attenuation and multipath fading, exacerbating communication limitations.

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Seeking a comprehensive understanding of the intricate challenges and limitations inherent in underwater wireless sensor networks (UWSNs), as well as the current landscape of communication and positioning methodologies, the study also aims to explore the feasibility and effectiveness of employing underwater wireless communication (UWC) and positioning (UWP) techniques as potential solutions to enhance communication range and improve positioning precision within UWSNs.

Further, rigorous assessment of the effectiveness and robustness of the proposed system through theoretical analysis, meticulous simulation studies, and empirical experimentation conducted in real-world underwater environments is pursued.

III. THEORETICAL BACKGROUND

A. Introduction

Underwater Wireless Sensor Networks (UWSNs) merge sensor networks with underwater technology, navigating the unique challenges of underwater communication, energy constraints, and deployment logistics. UWSNs deploy autonomous sensor nodes equipped with communication capabilities, sensors for data collection, and often processing units for local computation.

Communication in UWSNs faces hurdles like limited range and water properties affecting signal propagation, including high attenuation and variable salinity. Acoustic, optical, and electromagnetic methods are employed, with acoustic communication favored for its long-range coverage despite susceptibility to attenuation and multipath effects.

Energy efficiency is crucial as many nodes are battery-powered, emphasizing the need for efficient protocols and deployment strategies. Strategic deployment often involves Autonomous Underwater Vehicles or Remotely Operated Vehicles.

Precise localization of nodes is vital for applications like environmental monitoring or underwater exploration. Methods like acoustic ranging and occasional GPS usage at the water surface contribute to accurate spatial awareness.

UWSNs find applications in oceanography, marine biology, surveillance, and resource exploration, providing critical data for scientific research, environmental monitoring, and industrial tasks. Ongoing research aims to enhance communication reliability, energy efficiency, adaptive routing protocols, and scalability, driving the evolution of this cutting-edge field.

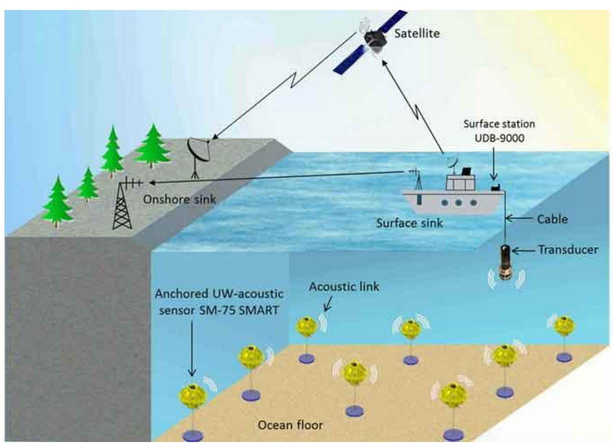

Figure 1: Architecture of Underwater Wireless Sensor Networks

B. Communication Technologies

Acoustic communication, utilizing sound waves, is favored in underwater wireless sensor networks (UWSNs) for its ability to penetrate water, enabling long-range communication. It employs acoustic modems with various modulation techniques for data encoding.

On the other hand, optical communication employs light waves, offering high data rates and low latency, suitable for real-time data delivery and high bandwidth applications. However, it faces challenges like light absorption and scattering in water.

Hybrid communication integrates both acoustic and optical modalities, leveraging their strengths to overcome individual limitations. Acoustic links excel in long-range communication, while optical links provide high-speed, short-range communication. By combining these modalities, hybrid systems adapt to environmental conditions, enhancing communication reliability and efficiency in diverse underwater scenarios. Ongoing research focuses on refining hybrid communication techniques for applications such as underwater exploration and environmental monitoring.

Challenges

Underwater Wireless Sensor Networks confront a myriad of technical and operational hurdles, significantly impeding their efficiency and reliability. Technical challenges encompass propagation delay, poor speed of sound, subpar channel quality, and low bandwidth, leading to packet loss, multi-path delay, and high error rates. These issues hamper data collection, marine life monitoring, disaster prevention, navigation assistance, equipment monitoring, and military applications.

Moreover, Underwater Wireless Sensor Networks grapple with operational obstacles like scalability limitations and unreliable communication, resulting in low data rates. Furthermore, the high cost of devices, excessive energy consumption, battery constraints, and restricted communication range pose formidable barriers to the development and deployment of UWSNs.

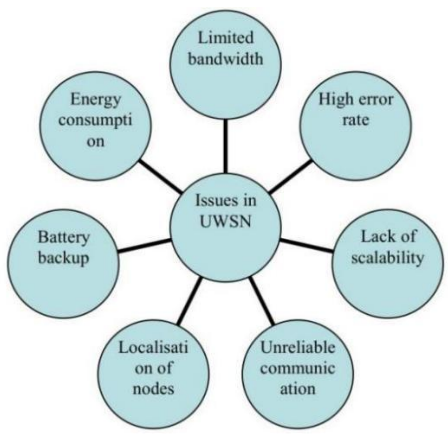

Figure 2: Challenges in UWSN

IV. PROPSED WORK

The proposed system introduces a forward-looking solution to the challenges faced by existing underwater wireless sensor networks (UWSNs). With the aim of expanding the capabilities of UWSNs, particular emphasis is placed on the accuracy of node positioning, recognizing its critical role in applications such as environmental monitoring and surveillance.

The "Hybrid Fish Eye Routing Protocol" is crafted for underwater sensor networks, circumventing radio wave attenuation. It merges proactive topology awareness with reactive querying for optimal data transmission. Nodes broadcast status proactively and query nearby nodes for real-time routing.

Its "fish eye" view provides a wide-angle network topology perspective, vital in sparse underwater environments. Advanced mechanisms, such as regular updates and link quality estimation, ensure efficient routing among 52 interconnected nodes. Dynamic route recalibration responds to changing network conditions, enhancing reliability. These features collectively bolster routing efficiency and data transmission in challenging underwater scenarios.

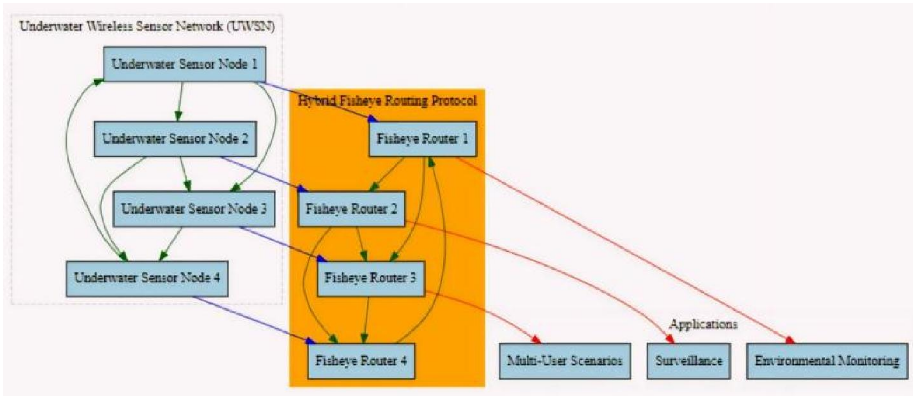

Figure 3: Proposed Architecture

Working

1. Deployment: The underwater wireless sensor nodes are deployed in the target area, such as a lake, ocean, or underwater research facility. These nodes are strategically placed to ensure adequate coverage for the intended application, such as environmental monitoring or surveillance.

2. Initialization: Each underwater sensor node initializes itself upon deployment. It establishes communication with nearby nodes and begins transmitting data about its location, environment, and available resources

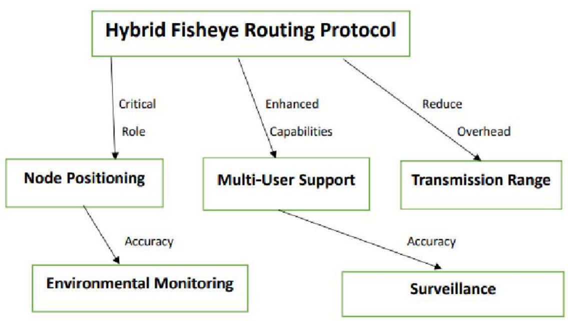

Figure 4: Hybrid Fish Eye Protocol in UWSNs

The Hybrid Fisheye Routing Protocol Setup:

1. Hierarchical Structure: The underwater sensor nodes organize themselves into a hierarchical structure based on the Hybrid Fisheye Routing Protocol. This structure allows for efficient data routing and management within the network.
2. Fisheye Technique: The fisheye technique is applied to reduce routing overhead by prioritizing more detailed information exchange with nearby nodes while gradually reducing the level of detail with increasing distance.
3. Node Positioning: The system employs various techniques such as acoustic ranging, GPS, or trilateration to accurately determine the position of each underwater sensor node. This information is crucial for applications requiring precise location data, such as environmental monitoring and surveillance.
4. Data Collection and Transmission: Underwater sensor nodes collect data about various environmental parameters such as temperature, pressure, salinity, and water quality.
5. Surveillance: Sensor nodes equipped with cameras or acoustic sensors capture and transmit data related to underwater activities, such as marine life observation or underwater vehicle tracking.

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6. Multi-User Support: The system accommodates multiple users or applications by efficiently managing data transmission and routing within the network. Different applications may have distinct data requirements and priorities.
7. Transmission Range Extension: The Hybrid Fisheye Routing Protocol optimizes data routing and extends the transmission range of underwater sensor nodes.
8. Continuous Monitoring and Adaptation: The system continuously monitors the performance of underwater sensor nodes and adapts its operation to changing environmental conditions.

VI. IMPLEMENTATION

Basic Underwater Network Simulation

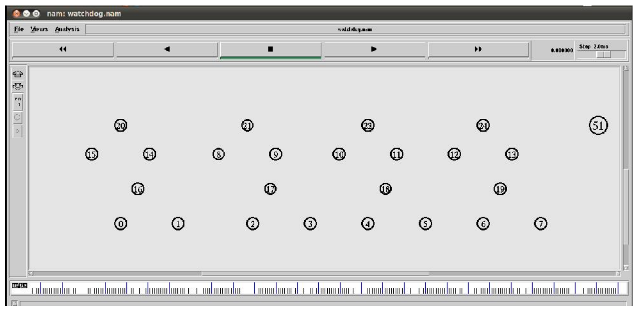

Figure 5: Namtrace Node Connection

Operating with 52 nodes functioning as standard units and one designated as the base station node i.e. 51, this simulation offers a basic exploration of underwater networking. Delving into communication, routing protocols aspects, this initiative strives to reveal the potential of underwater environments.

Proposed Model Simulation

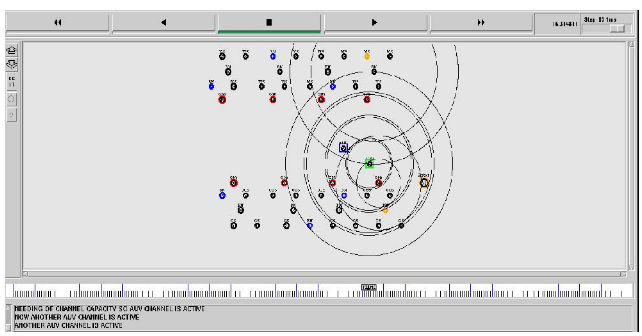

Figure 6: Node Connection in Proposed Model

In an underwater wireless sensor network comprising 52 nodes, including mobile stations, beacon nodes, and autonomous underwater vehicle (AUV) nodes, data packets are transmitted utilizing a hybrid fish-eye routing protocol. This protocol employs a combination of localized and globalized strategies, facilitating efficient data dissemination across the network while addressing challenges unique to underwater environments.

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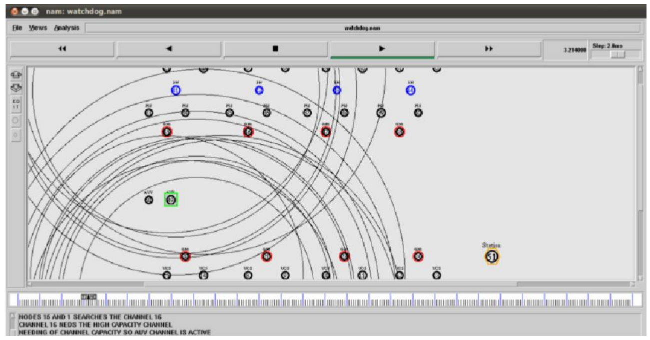

Figure 7: Creation of channel

Node 15 and 1 search for channel 16 which needs high capacity to commute in turn making the AUV Channel active.

VII. RESULTS

Output Parameters

1. Network throughput in the context of Underwater Wireless Sensor Networks (UWSNs) simulated in NS2 refers to the rate of successful data delivery over the network, typically measured in bits per second (bps).
2. Bandwidth refers to the maximum rate of data transfer over the network channel. It measures the capacity for transmitting data effectively and is typically expressed in bits per second (bps), reflecting the amount of information that can be transmitted per unit of time.
3. Latency represents the time delay between the transmission and reception of data packets. It quantifies the responsiveness of the network and is typically measured in milliseconds (ms), indicating the time taken for a packet to travel between nodes underwater.
4. Network transmission pathindicates the route packets traverse between nodes, crucial for efficiency assessment. It's measured in meters or kilometres, reflecting the underwater distance covered during data transmission.
5. Packet Delivery Fraction refers to the ratio of successfully received packets to the total packets transmitted. It measures the effectiveness of data delivery and is expressed as a percentage, indicating the proportion of packets delivered successfully underwater.
6. Average Residual Energy refers to the mean amount of remaining energy across all sensor nodes. It quantifies the energy level distribution and is typically measured in joules (J), reflecting the average energy reserves of nodes underwater after simulation execution.

Graphs

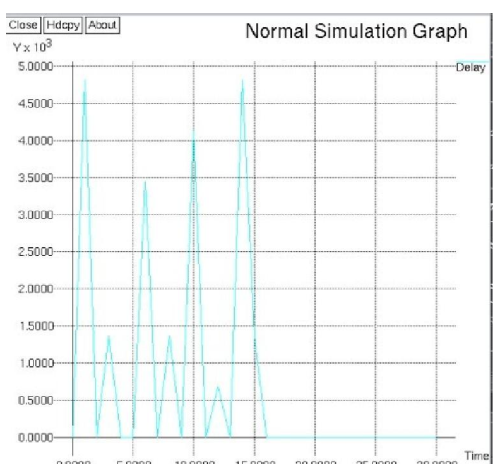

Figure 8: Normal Simulation Graph

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The Normal simulation graph features time on the x-axis, representing the time taken, while the y-axis represents the delay over the network at specified times (as shown in Figure 8). It illustrates fluctuations in delay over time, with sharp peaks indicating moments of high delay experienced by the network.

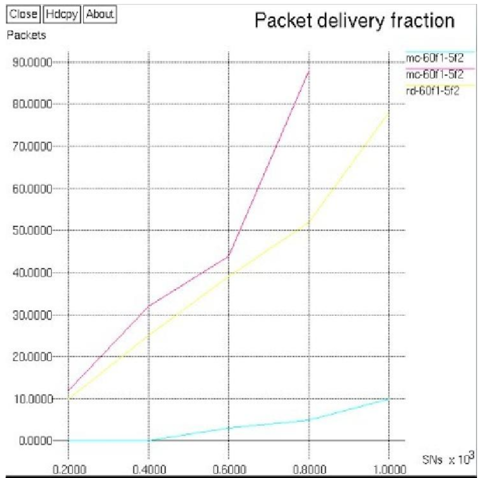

Figure 9: Packet Delivery Fraction

This graph depicts packet delivery to the mobile station with respect to packets and signal-to-noise ratio during data transmission, the total packet size is 512. It represents the performance of different types of nodes, such as beacon, AUVs, and mobile nodes, measured by their packet delivery fraction over varying Signal-to-Noise Ratios, suggesting which nodes are efficient and robust in underwater environments. 'Mc' refers to multicast, indicating the transmission of data packets to multiple destinations, while 'RD' stands for route distinguisher."

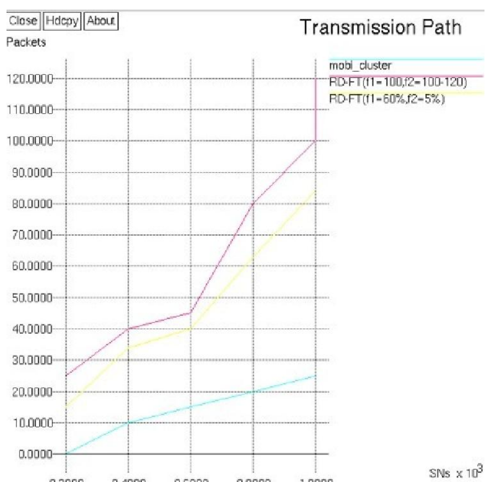

Figure 10: Transmission Path

The Transmission Path graph illustrates the transfer of route packets among respective nodes communicating in the underwater environment (as shown in Figure 6.10). It differentiates the transmission rates among nodes, indicating highs and lows, and features the variability in node performance, while also showcasing the role of fault tolerance in enhancing transmission.

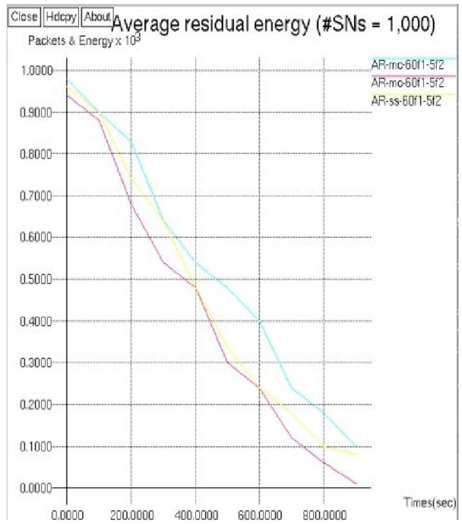

Figure 11: Average Residue Energy

This graph depicts the average residual energy concerning the time taken for data transmission across the underwater network. It illustrates the average residual energy over time for different types of nodes. Despite starting with similar energy levels, the nodes exhibit varying rates of energy depletion as time progresses. These differences in energy consumption provide insights into the efficiency and longevity of each node type. 'AR' represents the access request for the total number of packets to be transmitted in multicast communication.

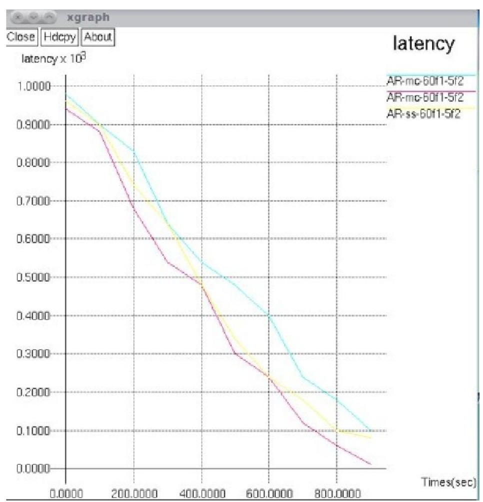

Figure 12: Latency

This graph illustrates the latency of data transmission concerning the time taken. It shows the latency values of different network nodes consistently decreasing as time progresses, initially starting with high latency which gradually declines to zero, indicating improved network performance over time. 'AR' represents the access request for latency identification of each node while transmitting data

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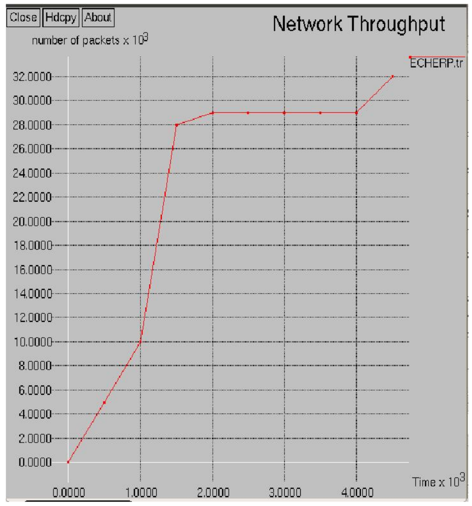

Figure 13: Network Throughput

This graph depicts the network throughput in an underwater scenario concerning the number of packets transmitted and the time taken for data transmission. It illustrates that network throughput increases rapidly at the beginning and stabilizes around 30,000 packets. We infer that the network achieves high data transmission efficiency quickly and maintains steady performance over time, indicating effective communication protocols and network stability. The scale ECHERP stands for the energy consumption of the hybrid fish-eye routing protocol.

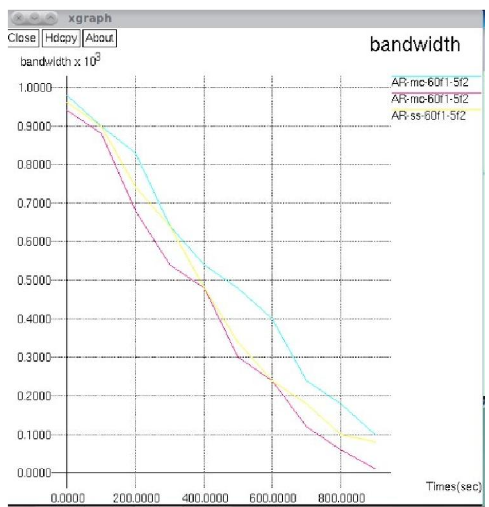

Figure 14: Bandwidth

The graph illustrates bandwidth concerning the time taken for communication between nodes within the network. Over time, there is a consistent decline in bandwidth experienced by various network nodes such as beacons, AUVs, and mobile nodes. It provides us with insights into how bandwidth, being a crucial parameter, is essential for evaluating and optimizing communication efficiency in UWSNs, enhancing data transmission and network performance underwater. AR represents the access request for nodes transmitting data with the mobile station.

VIII. CONCLUSION

In conclusion, the proposed system addresses challenges in underwater wireless sensor networks (UWSNs), aiming to expand their capabilities. By focusing on improving node positioning accuracy and reducing routing overhead through the Hybrid Fisheye Routing Protocol, significant advancements are achieved. Enhancing coverage and communication reliability are paramount for applications like environmental surveillance.

Emphasizing node positioning accuracy provides dependable insights, while supporting multi-user scenarios enhances adaptability. Extending transmission range facilitates communication between distant nodes, addressing a primary challenge of underwater communication.

VIII. FUTURE SCOPE

Looking ahead, the proposed system for underwater wireless sensor networks (UWSNs) lays a robust foundation for future advancements in several critical areas. One key avenue involves integrating machine learning and artificial intelligence to enable smarter network management, allowing for proactive resource allocation and optimized data transmission paths.

Additionally, improving energy efficiency through alternative power sources such as hydrokinetic or biologically inspired energy harvesting methods can extend the operational lifespan of UWSNs. Advancements in underwater IoT capabilities, including support for diverse sensing modalities and edge computing, promise to enhance real-time data analytics and decision-making at the sensor node level.

Moreover, enhancing security and privacy measures through robust encryption and authentication mechanisms is crucial to safeguarding data transmitted over UWSNs. Standardization efforts are vital to ensure interoperability among different UWSN components and systems, facilitating seamless integration with other maritime communication infrastructures.

Finally, exploring extreme underwater environments, such as deepsea trenches or polar regions, presents opportunities to develop ruggedized sensor nodes and communication protocols capable of withstanding extreme conditions.

IX. APPLICATIONS

The Hybrid Fisheye Routing Protocol can be applied in various scenarios where underwater wireless sensor networks (UWSNs) are utilized.

1. Underwater Surveillance: The Hybrid Fisheye Routing Protocol improves monitoring of underwater borders, ports, and sensitive areas, enhancing detection of unauthorized vessel movements. It aids in safeguarding underwater infrastructure like cables and pipelines against damage or sabotage and enhances military applications by tracking enemy submarines and hostile activities.
2. Underwater Communication Networks: It facilitates communication for Underwater IoT, enabling seamless data exchange among sensors, vehicles, and AUVs. Additionally, it supports underwater navigation by enabling communication between vehicles and surface stations, crucial for mapping and exploration efforts.
3. Underwater Exploration and Research: The protocol aids scientific research by improving communication and data exchange, crucial for marine biology, geology, archaeology, and oceanography studies. It also supports underwater archaeology by enhancing documentation of historical sites and shipwrecks.
4. Aquaculture and Fisheries Management: By enhancing fish tracking capabilities, the protocol aids in monitoring fish behavior, migration patterns, and population dynamics for effective fisheries management and conservation. It also improves aquaculture monitoring by optimizing processes and ensuring water quality.
5. Underwater Energy Infrastructure: The protocol supports monitoring of offshore energy installations like wind farms and underwater power cables, ensuring efficient operation and maintenance. It also aids in monitoring hydroelectric facilities for energy production and water management.
6. Search and Rescue Operations: In emergency situations such as maritime accidents or natural disasters, the protocol supports search and rescue operations by improving communication and coordination among rescue teams.

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