

Efficient Ad-Hoc Routing for Underwater Networks

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Abstract—Underwater marine networks have emerged as a crucial technology for applications such as ocean monitoring, environmental protection, disaster management, and military surveillance. These networks, commonly known as Underwater Wireless Sensor Networks, consist of sensor nodes, relay nodes, autonomous underwater vehicles (AUVs), and gateway nodes that communicate using acoustic signals. Unlike terrestrial wireless networks, underwater communication is highly challenging due to high propagation delay, limited bandwidth, signal attenuation, and energy constraints caused by the difficulty of battery replacement.

This paper presents the design of efficient ad-hoc transmission protocols tailored for underwater marine environments. The proposed system adopts a hybrid network topology that combines star and mesh structures to improve both reliability and scalability. Furthermore, three routing techniques are implemented: energy-aware routing, depth-based routing, and geographic routing. Energy-aware routing enhances network lifetime by selecting nodes with higher residual energy.

The system is implemented and evaluated using Python with simulation tools such as NS-3 and SUNSET. Performance is analysed under different environmental conditions, including clear, moderate, and turbid water. Key metrics such as packet delivery ratio, transmission delay, energy consumption, and network lifetime are measured. The results show that the proposed approach significantly improves efficiency, reliability, and energy optimization compared to existing routing methods.

Index Terms—Underwater Marine Networks, Ad-Hoc Routing, Acoustic Communication, Energy Efficiency, Routing Protocols, Sensor Networks, AUV, Network Simulation.

I. INTRODUCTION

Underwater communication plays a vital role in applications such as ocean monitoring, disaster detection, environmental analysis, and military surveillance. With the advancement of Underwater Wireless Sensor Networks, underwater devices such as sensor nodes, autonomous underwater vehicles (AUVs), and gateway nodes can communicate and exchange data efficiently. These networks are used to monitor ocean parameters like temperature, pressure, salinity, and pollution levels, as well as to detect critical events such as tsunamis and underwater earthquakes.

However, underwater communication faces several challenges compared to terrestrial networks. Radio signals do not propagate effectively in water, so acoustic communication is used instead. Acoustic signals suffer from low data rates, high propagation delay, limited bandwidth, and high error rates due to environmental factors such as water turbulence, noise, and temperature variations. Additionally, underwater nodes are battery-powered, and replacing or recharging them is difficult, making energy efficiency a major concern.

Most existing underwater communication systems rely on traditional routing techniques that are not suitable for dynamic underwater environments. These systems fail to adapt to changing network conditions, node mobility, and varying depths. As a result, communication becomes unreliable, inefficient, and energy-consuming, leading to reduced network lifetime and poor data delivery performance.

Core Problem:

In underwater marine networks, data transmission is still affected by inefficient routing mechanisms that do not consider critical factors such as node energy, depth variations, and geographic location. Existing approaches lack an adaptive and integrated routing strategy, resulting in high packet loss, increased delay, and uneven energy consumption. Furthermore, there is no unified framework that combines multiple routing techniques to optimize performance under different underwater conditions.

Proposed Innovation:

To address these challenges, this work proposes an efficient ad-hoc transmission framework that integrates multiple routing strategies within a hybrid network topology.

- **Energy-Aware Routing:** Selects optimal paths based on residual energy of nodes to extend network lifetime.
- **Geographic Routing:** Utilizes node location information to enhance routing efficiency and reduce overhead.
- **Hybrid Topology:** Combines star and mesh structures to ensure both scalability and fault tolerance.

Unlike traditional routing methods, the proposed approach provides a unified and adaptive solution that improves performance across different underwater scenarios.

Motivation: With the increasing demand for real-time ocean monitoring and underwater exploration, there is a need for efficient communication systems that can operate reliably under harsh conditions. Advances in simulation tools such as NS-3 and SUNSET enable the development and evaluation of optimized routing protocols. This motivates the design of a system that balances energy efficiency, reliability, and scalability in underwater environments.

Research Questions:

- Can hybrid routing techniques improve packet delivery ratio in underwater networks?
- Does energy-aware routing significantly increase network lifetime?
- How does depth-based routing affect communication reliability?

- Can geographic routing reduce transmission delay and overhead?
- How does the proposed system perform under different water conditions?

Structure: Section 2 presents the literature review, Section 3 describes the system architecture, Section 4 explains the proposed methodology, Section 5 discusses the results and analysis.

II. LITERATURE REVIEW

The development of efficient communication protocols for underwater environments has been an active area of research under Underwater Wireless Sensor Networks. Due to the unique characteristics of underwater communication such as high latency, low bandwidth, and energy limitations, several routing techniques have been proposed to improve network performance.

2.1 Traditional Routing Protocols

Traditional routing protocols also assume stable network conditions and consistent link quality, which is not realistic in underwater environments. In underwater networks, communication links are highly dynamic due to factors such as water currents, node mobility, and varying signal propagation conditions. As a result, routes calculated using shortest path algorithms may quickly become invalid, leading to frequent packet loss and retransmissions. This reduces overall network efficiency and increases communication delay.

Furthermore, these algorithms require maintaining complete network information or routing tables, which introduces additional overhead in terms of memory and processing. In underwater sensor networks, nodes have limited computational resources and energy, making it difficult to maintain such information continuously. The lack of adaptability and high resource requirements make traditional routing protocols inefficient for large-scale underwater deployments, thereby necessitating the development of more adaptive and energy-aware routing techniques.

Limitations of Traditional Routing Protocols:

- Assume stable network conditions, which is unrealistic underwater

- Cannot handle dynamic topology changes due to node mobility
- Routes become invalid quickly → leads to packet loss
- Increased retransmissions → wastes energy and bandwidth
- Higher communication delay due to frequent route failures
- Require global network information or routing tables
- High memory and computational overhead

2.2 Comparison of Routing Protocols in Underwater Marine Networks

Routing Technique	Working Principle	Suitable Scenario
Energy-Aware Routing	Selects path based on node energy levels	Long-term underwater monitoring
Depth-Based Routing	Uses node depth to forward packets	Deep-sea communication
Geographic Routing	Uses node location for packet forwarding	Mobile networks (AUVs)

III. COMMON ROUTING ALGORITHMS USED IN UNDERWATER NETWORKS

Underwater communication relies heavily on efficient routing algorithms to ensure reliable data transmission between nodes. Due to the unique characteristics of underwater environments, traditional communication methods are not effective. Instead, routing techniques are designed considering factors such as energy consumption, depth variations, and node mobility. In underwater systems, routing approaches can be broadly classified into energy-based, depth-based, and location-based techniques. Energy-aware routing focuses on selecting nodes with higher residual energy to extend network lifetime. Depth-based routing utilizes the depth information of nodes to improve communication reliability and reduce signal loss. Geographic routing uses node location information to forward data packets efficiently toward the destination.

Various routing algorithms contribute to effective underwater communication. Shortest path algorithms such as Dijkstra's Algorithm are adapted with energy considerations to improve performance. Depth-based forwarding techniques prioritize nodes closer to the surface for better signal transmission. Geographic routing algorithms reduce overhead by avoiding complex routing tables. Combining multiple routing techniques improves efficiency, reduces packet loss, and enhances overall network performance.

IV. PROPOSED TRANSMISSION FRAMEWORK

4.1 System Overview

The proposed underwater communication system consists of sensor nodes, relay nodes, autonomous underwater vehicles, and gateway nodes. These components work together to collect and transmit data efficiently using acoustic communication.

4.2 Data Processing and Optimization

Underwater communication is highly susceptible to various impairments such as environmental noise, signal attenuation, multipath propagation, and dynamic water conditions. These factors significantly degrade signal quality and affect the reliability of data transmission. As a result, efficient data processing and optimization mechanisms are essential to ensure stable and accurate communication in underwater marine networks.

In the proposed system, data processing begins with the evaluation of network parameters such as node energy levels, depth variations, and link quality. Based on these parameters, optimal routing paths are selected to ensure reliable communication while minimizing energy consumption. The system avoids unstable or low-quality links, thereby reducing packet loss and retransmissions. Furthermore, redundant transmissions are minimized through efficient routing decisions, which helps in conserving bandwidth and reducing communication overhead.

To enhance performance, data aggregation techniques are employed to combine multiple data packets into a single transmission, thereby reducing the number of transmissions required. Additionally, adaptive transmission control mechanisms are used to adjust communication parameters such as transmission power based on distance and environmental conditions. These optimization strategies collectively

improve packet delivery ratio, reduce transmission delay, and extend network lifetime.

4.3 Hybrid Routing Approach

The proposed system adopts a hybrid routing approach by integrating multiple routing strategies to address the challenges of underwater communication. Since underwater environments are highly dynamic and unpredictable, relying on a single routing method is not sufficient. Therefore, combining different routing techniques improves overall efficiency, reliability, and adaptability of the network.

The hybrid approach incorporates the following key routing strategies:

- **Energy-Aware Routing:** Selects nodes with higher residual energy to balance power consumption and extend network lifetime.
- **Depth-Based Routing:** Utilizes node depth information to improve signal reliability and reduce attenuation during transmission.
- **Geographic Routing:** Uses location-based forwarding to efficiently transmit data toward the destination while reducing routing overhead.

By integrating these techniques, the system dynamically selects optimal paths based on real-time network conditions such as energy level, depth, and node position. This combined approach significantly enhances packet delivery ratio, reduces transmission delay, and improves energy efficiency.

V. APPLICATIONS OF UNDERWATER NETWORKS

5.1 Ocean Monitoring

Underwater networks play a vital role in continuous ocean monitoring by enabling real-time data collection from different depths and locations. Sensor nodes deployed across the ocean measure parameters such as temperature, salinity, pressure, dissolved oxygen levels, and pollution concentration. This data is essential for studying climate change, tracking ocean currents, and understanding marine biodiversity. Additionally, underwater networks support long-term environmental monitoring, allowing researchers to detect gradual changes in ocean conditions. These systems reduce human intervention and enable data

collection in remote and hazardous regions where manual monitoring is difficult.

5.2 Disaster Detection

Underwater communication systems are widely used for detecting natural disasters such as tsunamis, underwater earthquakes, and volcanic activities. Sensors placed on the seabed continuously monitor seismic vibrations and abnormal pressure variations in water. When unusual activity is detected, the system sends alerts to surface stations and control centers. Early warning systems based on underwater networks significantly reduce the impact of disasters by providing sufficient time for evacuation and preventive actions. These systems improve disaster preparedness and enhance the safety of coastal populations.

5.3 Oil and Gas Industry

In the oil and gas industry, underwater networks are essential for monitoring offshore pipelines, drilling operations, and underwater equipment. These systems detect leaks, corrosion, structural damage, and operational failures at an early stage. Continuous monitoring ensures safe operation and reduces the risk of accidents and environmental damage caused by oil spills. Furthermore, underwater networks support maintenance planning by providing real-time data on equipment conditions, reducing downtime and operational costs. This leads to improved efficiency and reliability in offshore operations.

5.4 Military Applications

Underwater networks are widely used in defense and military operations for surveillance, communication, and security purposes. These systems enable secure communication between submarines, ships, and command centers. They are also used for detecting underwater mines, tracking enemy movements, and monitoring sensitive maritime zones.

VI. FUTURE TRENDS IN UNDERWATER COMMUNICATION

6.1 Hybrid Communication Systems

Future underwater communication systems are expected to adopt hybrid communication techniques that combine acoustic, optical, and radio frequency methods to overcome the limitations of individual

technologies. Acoustic communication provides long-range transmission but suffers from low data rates and high delay. Optical communication offers high-speed data transfer but is limited to short distances and clear water conditions. Radio frequency communication works effectively only in very shallow water. By integrating these technologies, hybrid systems can achieve improved data transmission speed, reliability, and coverage. Such systems will enable efficient communication across different underwater environments and support advanced applications requiring high data throughput.

6.2 AI-Based Routing

Artificial intelligence-based routing is emerging as a promising approach for improving underwater network performance. Intelligent algorithms can analyze network conditions such as node energy, link quality, and environmental factors to make adaptive routing decisions. Machine learning techniques enable the system to learn from past communication patterns and optimize routing paths dynamically. This approach reduces packet loss, improves energy efficiency, and enhances overall network reliability. AI-based routing also supports real-time decision-making, making it suitable for complex and dynamic underwater environments.

VII. CONCLUSION

Underwater marine networks have become an essential component of modern communication systems due to their wide range of applications in ocean monitoring, disaster detection, military operations, and industrial activities. However, the unique characteristics of underwater environments, such as high propagation delay, limited bandwidth, signal attenuation, and energy constraints, make reliable communication a challenging task. These challenges necessitate the development of efficient and adaptive transmission protocols specifically designed for underwater conditions.

This paper presented a comprehensive approach for designing efficient ad-hoc transmission protocols in underwater marine networks. The proposed system integrates multiple routing strategies, including energy-aware routing, depth-based routing, and geographic routing, within a hybrid framework. This combination enables the system to address key

challenges such as energy optimization, communication reliability, and dynamic topology changes.

REFERENCES

- [1] I. F. Akyildiz, D. Pompili, and T. Melodia, "Underwater acoustic sensor networks: Research challenges," *IEEE Communications Magazine*, vol. 43, no. 11, pp. 114–119, 2005.
- [2] J. Heidemann, M. Stojanovic, and M. Zorzi, "Underwater sensor networks: Applications, advances and challenges," *IEEE Wireless Communications*, vol. 16, no. 4, pp. 12–18, 2006.
- [3] T. Melodia, H. Kulhandjian, L. Kuo, and E. Demirors, "Advances in underwater acoustic networking," *IEEE Communications Magazine*, vol. 53, no. 11, pp. 97–103, 2015.
- [4] Y. Noh, U. Lee, P. Wang, B. S. C. Choi, and M. Gerla, "VAPR: Void-aware pressure routing for underwater sensor networks," *IEEE Transactions on Mobile Computing*, vol. 12, no. 5, pp. 895–908, 2013.
- [5] N. Nicolaou, A. See, P. Xie, J. H. Cui, and D. Maggiorini, "Improving the robustness of location-based routing for underwater sensor networks," in *Proc. IEEE OCEANS*, 2007.
- [6] H. Yan, Z. J. Shi, and J. H. Cui, "DBR: Depth-based routing for underwater sensor networks," in *NETWORKING 2008 Ad Hoc and Sensor Networks*, Springer, 2008.
- [7] P. Xie, J. H. Cui, and L. Lao, "VBF: Vector-based forwarding protocol for underwater sensor networks," in *Networking 2006*, Springer, 2006.
- [8] M. Ayaz, I. Baig, A. Abdullah, and I. Faye, "A survey on routing techniques in underwater wireless sensor networks," *Journal of Network and Computer Applications*, vol. 34, no. 6, pp. 1908–1927, 2011.
- [9] E. M. Sozer, M. Stojanovic, and J. G. Proakis, "Underwater acoustic networks," *IEEE Journal of Oceanic Engineering*, vol. 25, no. 1, pp. 72–83, 2000.
- [10] J. Partan, J. Kurose, and B. N. Levine, "A survey of practical issues in underwater networks," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 11, no. 4, pp. 23–33, 2007.

- [11]Z. Zhou, J. H. Cui, and S. Zhou, “Efficient localization for large-scale underwater sensor networks,” *Ad Hoc Networks*, vol. 8, no. 3, pp. 267–279, 2010.
- [12]D. Pompili and T. Melodia, “Three-dimensional routing in underwater acoustic sensor networks,” in *Proc. ACM PE-WASUN*, 2005.
- [13]K. Akkaya and M. Younis, “A survey on routing protocols for wireless sensor networks,” *Ad Hoc Networks*, vol. 3, no. 3, pp. 325–349, 2005.
- [14]A. Wahid and D. Kim, “An energy efficient localization-free routing protocol for underwater wireless sensor networks,” *International Journal of Distributed Sensor Networks*, 2012.
- [15]S. Climent, A. Sanchez, J. V. Capella, N. Meratnia, and J. J. Serrano, “Underwater acoustic wireless sensor networks: Advances and future trends,” *Sensors*, vol. 14, no. 1, pp. 795–833, 2014.