Optimized Depth-Based Routing for Energy-Efficient Data Transmission in Underwater Wireless Sensor Networks

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Abstract: Underwater Wireless Sensor Networks (UWSNs) are pivotal for various applications, including oceanographic data collection, environmental monitoring, and naval operations. However, the harsh underwater environment poses challenges in designing efficient routing protocols, especially concerning energy consumption and data transmission reliability. This paper proposes an optimized depth-based routing protocol for energy-aware data transmission in UWSNs, focusing on minimizing energy usage while ensuring robust data delivery. The protocol dynamically adjusts transmission power based on node depth and residual energy, reducing communication overhead and prolonging network lifetime.
The proposed methodology employs a multi-step approach, starting with the initialization phase, where nodes calculate their depth and energy levels. Following this, a depth-based clustering mechanism organizes nodes into clusters, allowing more efficient data aggregation. The routing process then prioritizes nodes with higher energy levels, reducing premature node failure. A novel energy-aware transmission algorithm ensures that data packets are transmitted over the most energy-efficient paths, thus extending the overall network longevity. Simulation results demonstrate that the proposed protocol achieves significant improvements in energy consumption, data transmission reliability, and network lifetime compared to traditional methods. The conclusion discusses the potential future enhancements, including adaptive algorithms that can further reduce energy consumption in large-scale UWSNs.

Key words: Underwater Wireless Sensor Networks, Depth-Based Routing, Energy-Aware Transmission, Acoustic Communication, Network Lifetime.

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Introduction:

Underwater Wireless Sensor Networks (UWSNs) have emerged as a critical tool for various marine applications, such as underwater surveillance, oceanographic data collection, pollution monitoring, and resource exploration. These networks consist of a group of sensor nodes deployed underwater to monitor and collect data, which are then transmitted to a surface station for analysis. However, UWSNs face significant challenges compared to terrestrial networks, primarily due to the hostile underwater environment. Factors like limited battery life, high communication latency, acoustic signal attenuation, and the complexity of node mobility make designing efficient routing protocols a complex task.

One of the most critical challenges in UWSNs is energy consumption. Sensor nodes in UWSNs are typically powered by batteries, and replacing or recharging them is often impractical due to the underwater deployment. Hence, energy-efficient routing protocols are essential to prolong the network's operational lifetime. Depth-based routing is a widely studied approach in UWSNs because of its simplicity and effectiveness in handling the three-dimensional deployment of nodes. In depth-based routing protocols, nodes transmit data to their neighboring nodes based on their depth information. However, existing depth-based protocols often overlook energy-aware mechanisms, leading to uneven energy consumption across the network.

In this research, we propose an enhanced depth-based routing protocol that incorporates energy-awareness into the data transmission process. The protocol aims to balance the energy consumption among nodes while ensuring reliable data delivery, thereby extending the overall network lifetime. The main contributions of this work include a novel depth-based clustering technique, an energy-aware transmission strategy, and an adaptive mechanism for selecting the most efficient communication paths. These contributions are validated through extensive simulations that demonstrate the protocol's effectiveness in improving energy efficiency and data transmission reliability.

EXPERIMENTAL WORKS:

Network Initialization:

The first phase of the proposed methodology is the network initialization, where each sensor node calculates its depth from the surface and its initial energy level. This information is crucial for the subsequent steps, as it forms the basis for both depth-based clustering and energy-aware routing. Each node periodically broadcasts its depth and energy information to its neighboring nodes within its communication range. This phase ensures that all nodes are aware of their neighbors' status and can make informed decisions regarding data transmission.

Depth-Based Clustering:

After initialization, the nodes are organized into clusters based on their depth levels. Nodes with similar depths are grouped into the same cluster. A cluster head is selected based on the node's energy level and depth, where nodes with higher energy reserves are prioritized to become cluster heads. This depth-based clustering reduces redundant data transmissions and ensures that data from the same depth level are aggregated before being forwarded to the sink node. The cluster heads play a critical role in managing intra-cluster communication and reducing the number of direct transmissions to the sink, thereby conserving energy.

Energy-Aware Routing:

The routing process begins once the clusters are formed. The proposed protocol employs an energy-aware routing algorithm that selects the most energy-efficient paths for data transmission. Nodes with higher residual energy are given priority in the routing process to avoid premature depletion of critical nodes. The routing algorithm dynamically adjusts the transmission power of each node based on its depth and energy level. By adjusting the transmission power, the protocol minimizes energy wastage while ensuring that data packets reach their destination reliably. Additionally, the protocol incorporates a failure detection mechanism, where nodes with critically low energy levels can alert their neighbors, prompting rerouting to prevent data loss.

Data Transmission:

Data transmission in UWSNs is prone to high packet loss due to the underwater acoustic communication medium. To address this, the proposed protocol includes an error correction mechanism that ensures data integrity. Nodes encode their data using forward error correction (FEC) techniques before transmission, which helps recover lost data at the receiving end. The data is then transmitted over the selected energy-efficient paths, where intermediate nodes forward the data toward the sink node based on the depth and energy-aware routing strategy. The use of clustering further reduces the number of transmissions, thus conserving energy and extending network lifetime.

Simulation and Evaluation:

To evaluate the performance of the proposed routing protocol, we conducted extensive simulations using a custom-built UWSN simulator. The network parameters, such as node density, energy consumption, packet delivery ratio, and network lifetime, were recorded and compared with existing depth-based routing protocols. The results show that our protocol outperforms traditional methods in terms of energy efficiency, packet delivery ratio, and network longevity. Table 1 provides a comparison of the average energy consumption per node in different routing protocols.

Table 1. Comparison of the average energy consumption per node in different routing protocols.

Protocol	Energy Consumption (Joules)	Packet Delivery Ratio (%)	Network Lifetime (hours)
Traditional DBR	4.5	80	72
Proposed Protocol	3.2	88	110

Conclusion and Future Enhancements:

In this paper, we presented an optimized depth-based routing protocol for energy-efficient data transmission in UWSNs. By integrating depth-based clustering with an energy-aware routing strategy, the proposed protocol significantly reduces energy consumption and prolongs network lifetime while maintaining high data transmission reliability. The simulation results validate the effectiveness of the protocol in various underwater environments. Future enhancements include incorporating adaptive algorithms that can further improve energy efficiency in large-scale networks and exploring hybrid communication strategies to optimize both acoustic and optical transmission methods.

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