Underwater Wireless Sensor Networks (Review)

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Abstract. Underwater wireless sensor networks (UWSNs) are becoming increasingly popular among researchers due to their potential for real-world applications such as marine surveillance, sea monitoring, deep sea archaeology, oil monitoring, and more. With almost 70% of the earth's surface covered in water, it is challenging for humans to gather valuable information from the seabed without advanced technology. In UWSNs, sensor nodes are placed to sense the underwater environment, and the data collected is sent to a sink node, which then transfers the data to a base station for processing. The deployment of sensor nodes in UWSNs is difficult due to the harsh underwater environment, and the routing of data is complicated by the nodes' limited communication range and high energy consumption. This study provides a comprehensive overview of UWSNs, including their applications, deployment methods, and routing algorithms. A comparative analysis of deployment techniques and routing algorithms is presented to help researchers identify research gaps in these areas. The study also reviews some UWSN applications, which offer valuable insights into the approach. The study covers the conventional technologies used in UWSNs and highlights significant research approaches towards UWSNs' applications, deployment techniques, and routing processes. The insights provided in this study will assist researchers in understanding the present state of UWSNs and identifying future research directions in this exciting field.

1 Introduction

Underwater Wireless Sensor Networks (UWSNs) are a novel technology that utilizes wireless devices to collect and transmit data underwater (1). The primary objective of these networks is to develop an efficient and secure monitoring system for marine and river environments, aiding scientists in studying underwater environmental conditions, marine animal movement patterns, and natural phenomena (2). Developing UWSNs presents unique challenges that differ from those encountered in traditional wireless networks. Underwater signals propagate differently from land, necessitating specialized devices and software to facilitate communication between sensors and data collection (3). Underwater sensor networks comprise a cluster of devices distributed throughout the water, connecting with each other to transmit data to the control center. These networks can be used for pollution detection, environmental hazard monitoring, weather and climate research, earthquake prediction, ship movement monitoring, and improving marine exploration and fishing operations (4). Furthermore, UWSNs face technical challenges such as withstanding the marine environment, device energy availability, and communication infrastructure availability. To enhance efficiency and performance in these networks, techniques such as data mining, artificial intelligence, and machine learning are employed (5).

To sum up, the use of underwater wireless sensor networks has the ability to transform the way we monitor marine and river environments, as well as aid in scientific research and environmental conservation efforts. This article covers various aspects of underwater communication, including underwater sensing nodes, their applications, network architectures, deployment techniques, routing algorithms, and future developments. Underwater communication involves transmitting messages, data, or signals through water. This is a complex field of study due to the distinct characteristics of water, such as high attenuation, dispersion, and multipath propagation, all of which can have a significant impact on signal transmission.

2 UNDERWATER COMMUNICATION

There are multiple ways to communicate underwater, including:

I. Acoustic communication, which is the most commonly used method. It involves sending sound waves through the water, which can be audible or inaudible to humans depending on their frequency. This method is used for underwater navigation, remote sensing, and monitoring.[6]

II. Optical communication, which uses light to transmit data through clear water at high speeds. However, this method is limited by the range and turbidity of the water.[7]

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III. Electromagnetic communication, which uses radio waves to transmit signals through water. But, this method is limited by the absorption and scattering of electromagnetic waves in water. [8]

IV. Magnetic induction communication, which uses magnetic fields to transmit signals through water. It is useful for short-range communication, but its range and sensitivity are limited.[9]

Underwater communication is crucial for various applications, such as marine research, offshore oil and gas exploration, and underwater military operations. Ongoing research focuses on enhancing the reliability and efficiency of underwater communication systems.

3 Advantage and Disadvantage of Different Type of Underwater communication

3.1 Acoustic communication

Advantages: Acoustic communication is the most commonly used method of underwater communication. It can transmit signals over long distances, up to thousands of kilometers, depending on the frequency used. [10] It can penetrate through obstacles and is not affected by visibility or turbidity of the water. It can be used for both passive listening and active transmission.[11]

Disadvantages: Acoustic communication can be affected by the background noise of the water, which can make it difficult to distinguish signals from noise. The high attenuation and dispersion of sound waves in water can limit the range and speed of communication.[12] - Acoustic communication can interfere with marine animals and disrupt their natural behavior.[13]

3.2 Optical communication

Advantages: Optical communication can transmit signals at very high speeds, up to several gigabits per second.[14] It is not affected by electromagnetic interference, making it suitable for use in environments with high levels of electromagnetic noise. It can be used for both short and long-range communication.[15]

Disadvantages: Optical communication is limited by the range and turbidity of the water, which can scatter or absorb the light. It requires a clear line of sight between the transmitter and receiver, which can be difficult to maintain in murky or turbulent waters.[16] Optical communication can be affected by marine life, such as algae or plankton, which can attach to the optical fibers and cause attenuation.[17]

3.3 Communication using electromagnetic waves

Advantages: Electromagnetic waves can transmit signals at high frequencies, resulting in high data rates.[18] They are not affected by background noise in water, making them suitable for use in noisy environments. They can also be used for both short and long-range communication.[19]

Disadvantages: However, electromagnetic waves are absorbed and scattered by water, which limits their range and effectiveness. They can also interfere with marine life that uses magnetic fields for navigation.[20] Additionally, they may be susceptible to interference from other sources of electromagnetic radiation, such as ship or submarine radar.[21]

3.4 Communication using magnetic induction

Advantages: Magnetic induction communication is ideal for short-range communication, such as between two submerged vehicles or divers.[22] It is not affected by background noise in water, making it suitable for use in noisy environments. It is also less susceptible to interference from other sources of electromagnetic radiation than electromagnetic communication.[23]

Disadvantages: However, magnetic induction communication has a limited range and is only effective over short distances. It requires specialized equipment to generate and detect magnetic fields, which can be expensive and cumbersome. It is also susceptible to interference from natural magnetic fields, such as those produced by underwater geological formations.[24]

4 Underwater Sensor Nodes

Underwater sensor nodes are devices created to gather information from the underwater surroundings. They are equipped with various sensors, such as temperature, pressure, salinity, and acoustic sensors, that can measure different aspects of the underwater environment.[25] These nodes have many applications, including oceanographic research, environmental monitoring, offshore oil and gas exploration, and defense and security. They are deployed in large numbers and communicate with each other wirelessly to form a network.[26] However, designing underwater sensor nodes poses challenges due to the harsh underwater environment. The environment is highly corrosive, with high pressure, salt water, and biological growth that can damage the sensors and other components. Communication underwater is also limited by low bandwidth and high electromagnetic wave attenuation.[27] To overcome these challenges, underwater sensor nodes often use specialized materials and coatings to protect against corrosion and biological growth, and acoustic communication techniques that can transmit data over long distances in water.[28] They may also use low-power or energy-harvesting technologies to extend their battery life and reduce the need for maintenance. In conclusion, underwater sensor nodes have the potential to provide valuable insights into the underwater environment, but their design and deployment require careful consideration of the unique challenges of the underwater environment.[29][30]

5 Underwater wireless sensor application

An application of underwater wireless sensors involves devices that can gather data on physical, chemical, and biological properties of the underwater environment. This information is then transmitted wirelessly to a central monitoring system where it can be analyzed and utilized to make informed decisions. The use of underwater wireless sensors has various applications, such as in

oceanography, where they can collect data on ocean temperature, salinity, and currents. This information is essential in understanding ocean circulation patterns, climate change, and the impact of human activities on the marine environment.[31][32]

Additionally, underwater wireless sensors can be used for environmental monitoring, where they detect pollution and measure the impact of climate change on marine ecosystems. This data can aid policymakers in making informed decisions about resource management and conservation.[32]

In aquaculture, underwater wireless sensors can monitor water quality and feeding patterns in fish farms, optimizing feeding schedules and preventing disease spread.[32] Furthermore, underwater wireless sensors can be used in offshore oil and gas to monitor the structural integrity of offshore platforms and pipelines, ensuring worker safety and accident prevention.[33]

Lastly, underwater wireless sensors have military and defense applications, where they can be used for underwater surveillance, reconnaissance, and detecting enemy submarines.[34]

Overall, underwater wireless sensors have the potential to revolutionize our understanding of the marine environment and aid in informed decision-making for its management and conservation.[35][32]

6 UWSN architectures

There are different architectures for underwater wireless sensor networks (UWSN) that can be utilized depending on specific application needs and environmental conditions. The following are some of the commonly used UWSN architectures:

Star Topology: This architecture involves all nodes in the network communicating with a central node, which serves as a sink for the data collected by other nodes.[36]

Mesh Topology: This architecture connects nodes in a network through multiple paths, allowing for more dependable and efficient data transmission.[37]

Cluster-Based Topology: In this architecture, nodes are divided into clusters, and each cluster has a cluster head responsible for gathering and forwarding data from the nodes within the cluster.[38]

Hybrid Topology: This architecture combines two or more of the previously mentioned topologies to leverage their strengths and overcome their weaknesses. For instance, a hybrid topology may use a mesh topology for data transmission and a star topology for control and management.[39][40]

The choice of UWSN architecture is determined by various factors such as network size, application type, deployment environment, and power constraints of network nodes.

7 Deployment techniques

The deployment of an underwater wireless sensor network (UWSN) can pose challenges due to the harsh underwater environment. This can result in limited communication range, increased signal attenuation, and noise interference. Nonetheless, there are various deployment methods that can enhance the performance of UWSNs. These techniques include:

I. Optimizing Node Placement: The ideal placement for nodes in an underwater sensor network should prioritize maximizing network coverage while minimizing interference. This can be achieved through careful selection of deployment locations and node orientation.[41][42]

II. Localization and Synchronization: Accurate localization and synchronization of nodes is crucial for effective communication and coordination within the network. Techniques such as time-of-arrival (TOA) and time-difference-of-arrival (TDOA) can be utilized for localization and synchronization.[43]

III. Routing Protocols: Routing protocols determine the path that data takes through the network. A good routing protocol should be able to handle the dynamic topology of the underwater environment while optimizing energy consumption. Examples of routing protocols for UWSNs include geographic routing, opportunistic routing, and data-centric routing.[44][45]

IV. Efficient transmission of data through energy conservation: When deploying UWSNs, it is crucial to consider energy efficiency as underwater nodes are usually powered by batteries. To minimize energy consumption and maximize data transmission, techniques such as adaptive modulation and coding, data aggregation, and duty cycling can be utilized.[46][47]

V. Maintenance of the network: Regular maintenance is necessary to ensure the proper functioning of UWSNs. This includes tasks such as node and battery replacement, as well as software updates. A maintenance plan should be established before deployment to ensure the network's long-term sustainability.[48]

8 Routing algorithms

The efficient and reliable transmission of data in an underwater wireless sensor network (UWSN) heavily depends on routing algorithms. These algorithms must be specifically designed to overcome the unique challenges posed by the underwater environment, such as limited bandwidth, high propagation delays, and harsh and dynamic conditions. Some of the commonly used routing algorithms in UWSN are as follows:

I. Geographic-based routing involves utilizing the geographical location of nodes within a network to route data packets to their intended destination node. This algorithm is made possible by nodes exchanging location information with each other. It can prove to be especially useful in UWSNs where nodes are densely deployed. [49][50]

II. Depth-based routing is an algorithm that utilizes information on the depth of nodes in order to transfer data packets. Nodes with similar depth values are grouped together and data packets are transmitted through these groups. This approach can prove to be highly beneficial in Underwater Sensor Networks (UWSN), where nodes are deployed at varying depths.[51][52]

III. Energy-based routing, on the other hand, focuses on considering the energy levels of nodes in the network. Nodes with higher energy levels are preferred for routing data packets, while the nodes with lower energy levels are avoided. This technique can be particularly useful in UWSN, where the nodes operate on battery power and energy conservation is crucial.[53][54]

IV. Multi-hop routing is another algorithm that involves using multiple nodes to send data packets from the source to the destination. The nodes relay the data packets to neighboring nodes until they finally reach the destination node. This approach is helpful in UWSN, where the distance between the source and the destination nodes is too great for direct communication.[55][56]

V. Hybrid routing is a combination of multiple routing techniques that help optimize the performance of UWSN. For example, a hybrid routing algorithm could make use of geographic-based routing and depth-based routing to produce a more efficient and reliable routing system.[57][58]

The choice of which routing algorithm to use in a UWSN deployment is determined by its unique characteristics and requirements. When selecting a routing algorithm, factors like network topology, sensor type, data rate, and energy restrictions should be taken into account.

9 Conclusion and Future work

In conclusion, the use of underwater wireless sensor networks (UWSNs) presents exciting opportunities for underwater exploration, surveillance, and other applications. However, the underwater environment and current technology have limitations that require further research and development. The future focus of UWSNs should be on enhancing energy efficiency, expanding communication protocols and technologies that can overcome challenges in the underwater environment, and exploring new opportunities for underwater wireless power transfer. Additionally, interdisciplinary collaborations between oceanographers, engineers, and computer scientists can lead to a better understanding of the underwater environment and the development of more effective and efficient sensor networks. With continued research and development, UWSNs have the potential to transform our understanding and exploration of the underwater world and its crucial role in our planet's ecosystem.

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