Underwater wireless sensor networks transmission and characteristics protocols A survey

[1]Zainab saad karam — Department of Physics, College of Science, University of Misan, Misan, Iraq
zainab-almosawi@uomisan.edu.iq

[2]Rawaa Hamaz Ali — Department of Biology,College of Science, University of Misan ,Maysan Iraq
rawaaha@uomisan.edu.iq

[3]baqer obaiad Al-nashy — Department of Physics, College of Science, University of Misan ,Maysan
baqernano@uomisan.edu.iq

ABSTRACT

Due to the increased use of marine resources and the fast development of research on wireless sensor networks on land, UWSNs (underwater wireless sensor networks) have evolved into a new research hotspot. The routing protocol is one of the most important parts of UWSNs. This paper shows several traditional routing algorithms for location, sector, reinforcement learning, and intelligent optimization. The paper ends with a summary and a look at where research on underwater wireless sensor network routing algorithms is likely to go in the future.

Keywords: Underwater wireless sensor network; Routing protocols

I. Introduction

About 70% of the Earth's surface is water. This demonstrates the significance of learning more about the underwater environment. In UWSNs, sensor nodes cover a certain area of the ocean to collect data and transmit it to a land-based data center near the surface of the water [**1,2**]. When transmitting data packets from the ocean floor to land, the sensor nodes collaborate to identify and take advantage of the most direct routes, taking into account a selection criterion. UWSNs use routing protocols to determine which of these paths to take in order to deliver data packets from underwater to their surface destination as quickly and efficiently as feasible. Recent research has used routing protocols to investigate the ocean floor for a variety of purposes by researchers, scientists, and engineers. Underwater exploration can serve a variety of purposes, including military reconnaissance, disaster prediction, and breach detection. Numerous factors make swimming at the ocean's surface difficult and unpredictable. [**3,4**]. Waves of radio frequency (RF) can be absorbed by water. This weakens RF waves in water and causes their energy to dissipate. For a specific frequency f in Hz (Hertz), the rate at which water absorbs radio waves' energy is 45pf dB/km (decibels per kilometer). Between 30 and 300 Hz, water becomes a medium for radio frequency (RF) waves. For a high-power emitter to operate in this frequency range, however, the antenna must be extremely large. Therefore, RF frequencies are not used for underwater communication. Additionally, the use of visual waves is ineffective when submerged. This is because directing optical waves between a sender and a receiver requires a great deal of precision, Despite the fact that sensor nodes move in accordance with water currents and the underwater medium is unsure. Acoustic emissions are the primary mechanism by which UWSNs function. However, RF waves travel approximately five times quicker than sound waves. This makes it difficult for messages to rapidly spread beneath. Because the acoustic spectrum is tiny, underwater interactions that employ acoustic waves are limited to a small frequency range [**5**]. Additionally, water profundity, acidity, and temperature have a significant impact on the velocity of an acoustic wave. This causes the sound waves to travel in curved trajectories through the water, creating inaudible zones for sensor nodes. Because these sensor nodes do not participate in data transmission, the network's efficacy is impaired. Marine life, shadow zones, and the unpredictability, interference, and cacophony of the underwater medium make it more difficult for data packets to travel from the ocean floor to the surface. Additionally, the battery life of the sensor nodes is brief, and it is inconvenient to replace their batteries [**6**], in particular on the water's floor. Routing rules are incredibly essential for UWSNs. To ensure the network operates as intended, these protocols determine the routes from the ocean floor to the surface. Specifically, these protocols account for the challenges of the underground medium and packet forwarding to ensure that the network fulfills its objectives. These protocols, for instance, deal with low battery power, a great deal of noise and interference, shadow zones, sensor nodes that move with water currents, the secure delivery of data packetsunder poor channel conditions, and a lengthy propagation delay .[**7**, **8**]. Numerous studies have been conducted on routing methods for UWSNs. Some surveys also do not discuss the routing methods of the examined protocols or their advantages and disadvantages. Researchers, engineers, and scientists who develop and test routing methods for UWSNs must be aware of these details. How these factors are described enables UWSNs to select the optimal protocol for each application. In addition, these factors assist researchers in developing new routing strategies based on the issues that have been addressed and resolved in existing routing strategies. This, in turn, leads to the development of new routing protocols that are more robust, intelligent, efficient, and intelligent than the protocols being managed [**8–11**].

This paper is organized as follows: section II explains the routing of UWSNs. Section III shows the classification of UWSNs. Section IV list some related study while the conclusion contained in section V.

II. Routing in Underwater wireless sensor networks

In underwater wireless sensor networks, routing refers to the process of selecting a path for data transmission from the source node to the destination node. Since underwater communication is subject to several physical constraints, such as limited bandwidth, high attenuation, and multipath propagation, routing in underwater wireless sensor networks is a challenging task [**12**].

There are several routing algorithms designed for underwater wireless sensor networks, such as geographic routing, hierarchical routing, opportunistic routing, and swarm intelligence-based routing. Each algorithm has its advantages and disadvantages, and the choice of the routing algorithm depends on the network topology, the application requirements, and the available resources [**13**].

The main goal of routing in underwater wireless sensor networks is to minimize energy consumption, maximize the data delivery ratio, and ensure reliable communication. Efficient routing protocols can significantly improve network performance, increase network lifetime, and reduce deployment and maintenance costs [**14**].

III. Classification of underwater wireless sensor routing protocols

UWSN uses underwater radio frequency, audio, or optical communication. Radiofrequency waves are rarely used because of attenuation and coverage difficulties. Sound waves can travel tens of kilometers because water slows them less than other waves. UWAN is the most popular and advanced underwater communication technique. UWAN routing protocols are the most numerous and diverse

[15]. However, acoustic communication cannot handle the vast amount of information that must be communicated, thus people are looking for new techniques. Optical wave transmission is more environmentally sensitive than the first two. Due to its high transmission rate and capacity, it is the future of underwater wireless communication. Researchers have developed a mixed routing technique using acoustic-optical hybrid channels [16].

Underwater nodes use batteries, which limits power and charging. Thus, researchers have devised energy-efficient routing strategies to save energy and increase network life. Due to the difficulty and expense of obtaining 3D position data for underwater nodes, some academics have devised depth-based routing techniques. This device measures node depth with a cheap depth sensor. Water flow changes nodes. RL-based routing improves network adaptability. RL is effective but time-consuming, hence an intelligent optimization algorithm protocol is necessary. Section optical qualities also influence routing [17].

Routing protocols fall into two types based on transmission media and features. Figure 1 shows accurate divisions.

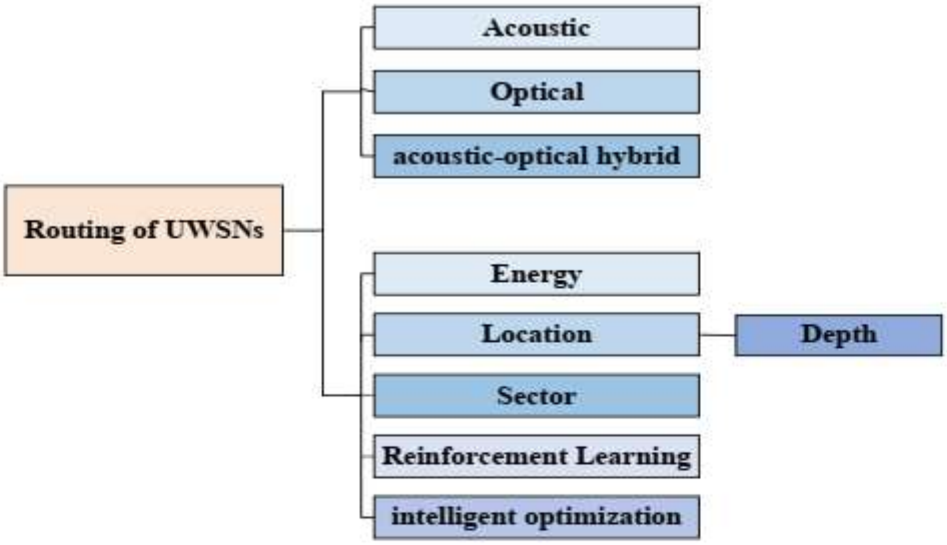

Figure 1 UWSN routing protocol classification [10].

The fist three protocols (acoustic, optical, and acoustic-optical) concerned with the transmission media while the other related to the characteristics of UWSNs.

IV. Related Study

The routing wireless sensor network has been divided into the following types with some studies for each type:

1- Acoustic protocols

The acoustic protocols utilized in underwater wireless sensor networks (UWSNs) are a collection of regulations and methodologies that dictate the manner in which data is conveyed and obtained among submerged sensor nodes. The protocols have been specifically developed to tackle the distinct obstacles associated with communication underwater, including but not limited to significant attenuation, multipath propagation, and restricted bandwidth [18].

Acoustic protocols typically involve the use of sound waves to transmit data between underwater sensor nodes. The nodes communicate with each other by transmitting acoustic signals through the water, which are then received by other nodes. The protocols specify how the nodes should communicate, including the frequency, modulation, and coding schemes to be used.

In the context of routing, acoustic protocols for UWSNs determine the paths that data should take through the network to reach its destination. These protocols can be proactive or reactive. Proactive protocols maintain up-to-date information about the network topology, while reactive protocols establish paths only when needed [19].

The design of acoustic protocols for UWSNs is a complex task that requires careful consideration of the unique characteristics of underwater communication. The development of efficient and effective protocols is essential for the successful deployment of UWSNs in a wide range of applications, such as ocean monitoring, underwater exploration, and environmental sensing [20].

M. Javaid et al. evaluate the performance of several acoustic routing protocols for UWSNs. The researchers conduct a comparative analysis of the protocols utilizing metrics such as end-to-end delay, packet delivery ratio, and energy consumption. The study found that a hybrid routing protocol that combines reactive and proactive approaches performed the best in terms of overall performance [21].

M. Javaid et al. propose a new distance-based acoustic routing protocol for UWSNs. The protocol aims to improve the energy efficiency of underwater sensor networks by reducing the number of message transmissions. The authors conducted simulations to evaluate the performance of the protocol and found that it achieved better energy efficiency and network lifetime compared to other routing protocols [22].

C. J. Wu and Q. Liu propose a distributed acoustic routing protocol for UWSNs. The protocol uses a distributed algorithm to compute and maintain the routing paths. The protocol's performance was evaluated through simulations by the authors, who determined that it exhibited superior packet delivery ratio and energy efficiency in comparison to alternative routing protocols[23].

H. K. Sahoo et al. proposes an energy-efficient acoustic routing protocol for UWSNs. The protocol aims to reduce energy consumption by using a dynamic transmission range and adjusting the transmission power based on the distance between the nodes. The protocol's performance was evaluated through simulations by the authors, who determined that it exhibited superior energy efficiency and network longevity in comparison to alternative routing protocols [24].

Gu et al. have proposed a protocol for routing acoustic signals in UWSNs that takes into account power consumption considerations. The protocol endeavors to achieve equilibrium in the energy utilization of the sensor nodes by taking into account the residual energy levels of the nodes in the routing determinations. The protocol's performance was evaluated through simulations by the authors, who determined that it exhibited superior energy efficiency and network longevity in comparison to alternative routing protocols [25].

2- Optical protocols

The purpose of optical protocols for underwater wireless sensor networks is to enable the transmission of data through the water using optical signals. UWSNs are used for various applications such as oceanographic data collection, environmental monitoring, underwater surveillance, and underwater exploration. Traditional wireless communication technologies such as radio waves and microwaves do not work well in water due to the high absorption and scattering of these signals. Therefore, optical communication offers an attractive alternative as it is less affected by water attenuation and can provide higher bandwidth, longer range, and greater security compared to other wireless communication technologies. Optical protocols enable efficient and reliable communication between the sensor nodes in UWSNs, which is essential for collecting and transmitting data from the underwater environment to the surface for further analysis and decision-making.

R. K. Singh, A. Kumar, and N. Goyal proposed an efficient optical routing protocol for UWSNs based on a modified version of the ant colony optimization algorithm, which considers node energy, node degree, and residual energy of the neighboring nodes [26].

S. K. Sahoo and S. P. Panda performed a comparative analysis of various optical routing protocols for UWSNs, including centralized, distributed, and hybrid protocols, based on metrics such as end-to-end delay, throughput, and packet delivery ratio [27].

F. Zhou, Y. Liu, and X. Xue proposed a lightweight optical routing protocol for UWSNs that uses a localized and energy-efficient routing mechanism, which can adapt to node mobility, link quality, and energy constraints [28].

M. S. Uddin, S. S. Rahman, and S. K. Das proposed an optical routing protocol for UWSNs with limited node mobility, which combines the advantages of reactive and proactive routing protocols and takes into account node mobility, energy efficiency, and data delivery rate [29].
H. Xu, J. He, and X. Sun proposed a new dynamic optical routing protocol for UWSNs based on an improved ant colony optimization algorithm that considers the transmission delay, energy consumption, and link quality of the nodes, and dynamically adjusts the routing paths according to the network topology changes [30].

3- Acoustic-Optical protocols

Acoustic-optical protocols are a type of communication protocol used in underwater wireless sensor networks (UWSNs) that leverage both acoustic and optical channels for data transmission. These protocols use a combination of acoustic waves and optical signals to overcome the limitations of traditional acoustic communication, such as limited bandwidth and high energy consumption.
S. Ahmad, W. Mahmood, and A. Anpalagan proposed a hybrid routing protocol for UWSNs that combines acoustic and optical communication and uses a clustering-based algorithm to dynamically adjust the routing paths and balance the energy consumption of the nodes [31].
K. E. Chalhoub, R. Shams, and H. F. Alnuweiri proposed an acoustic-optical routing protocol for UWSNs that uses a hierarchical approach, where acoustic communication is used for intra-cluster communication and optical communication is used for inter-cluster communication, to reduce energy consumption and improve network performance [32].
S. P. Ghosh and S. K. Sahoo proposed a hybrid routing protocol for UWSNs that uses a distributed algorithm based on the ant colony optimization technique, which takes into account the network topology, energy efficiency, and data delivery rate, and adapts to the dynamic changes in the network [33].
M. Anwer, A. G. Radwan, and M. U. Ilyas proposed an efficient hybrid routing protocol for UWSNs that combines acoustic and optical communication and uses a modified version of the genetic algorithm to optimize the routing paths and minimize the energy consumption of the nodes [34].
Y. Yang et al., have presented a new hybrid routing protocol designed for Underwater Wireless Sensor Networks (UWSNs). The protocol utilizes acoustic communication for data collection and optical communication for data transmission. Additionally, it employs a distributed algorithm based on the bee colony optimization technique to balance energy consumption and extend the network's lifespan [35].

4- Energy protocol

The energy protocols for UWSNs are essential for managing the energy consumption of the network's sensors and communication devices.
Khan et al. have presented a routing protocol that employs a hybrid approach of greedy forwarding and energy-based forwarding techniques. The protocol employs an energy-aware approach to determine the optimal forwarding strategy by considering the energy levels of the sensor nodes. The protocol that has been proposed exhibits superior performance in comparison to the existing protocols, specifically in regards to energy consumption and the longevity of the network [36].
N. U. Khan and colleagues, have employed a clustering technique based on fuzzy logic to enhance the efficiency of energy consumption in sensor networks deployed underwater. The selection of cluster heads is determined by the energy availability of the nodes and their proximity to the sink node, as prescribed by the protocol. The simulation outcomes indicate that the suggested protocol exhibits a comparatively extended network lifespan in contrast to the currently existing protocols [37].
K. Y. Lee et al. propose a hierarchical routing protocol that utilizes two levels of cluster heads to reduce energy consumption. The protocol selects cluster heads based on their distance from the sink node and their remaining energy. The proposed protocol shows significant improvements in terms of energy consumption and network lifetime [38].
F. M. Siddiqui et al.introduce a distributed routing protocol that utilizes local information and global information to make energy-efficient

routing decisions. The protocol utilizes a novel energy-efficient routing metric that takes into account the energy level of the nodes and the distance to the sink node. The simulation results show that the proposed protocol outperforms existing protocols in terms of energy consumption and network lifetime [39].

S. S. Al-Tahmeed et al., have presented a routing protocol that employs a hybrid approach of hop count and energy-aware metrics to determine the optimal path for data transmission. The implemented protocol includes a mechanism for duty-cycling in order to preserve energy. The simulation outcomes indicate that the suggested protocol exhibits a comparatively extended network lifespan when compared to the presently existing protocols. The protocol under consideration appears to be well-suited for implementation in extensive underwater sensor networks [40].

5- Location protocols

Location routing protocols of underwater wireless sensor networks are a set of protocols that use the location information of nodes to forward data packets in the network. These protocols aim to achieve efficient and reliable communication by selecting the best path for data transmission based on the location of the nodes. The location information can be obtained using various techniques such as GPS, acoustic signals, and triangulation. Location routing protocols are essential for underwater wireless sensor networks as the propagation characteristics of underwater channels are highly affected by the underwater environment, making it challenging to establish and maintain reliable communication links.

P. Vijayanand and M. Thirunavukarasu propose a location-based routing protocol that uses machine learning techniques to optimize energy consumption. The protocol considers the location and energy level of the nodes to select the best path for data transmission [41].

S. Liu et al. presents a location-aware routing protocol that uses the distance and direction between nodes to make routing decisions. The protocol outperforms existing protocols in terms of energy consumption, network lifetime, and packet delivery ratio [42].

Jana and Panda have proposed a routing protocol that employs genetic algorithms to optimize energy consumption, with a focus on location-based routing. The protocol determines the optimal route for transmitting data by considering the geographical position and energy status of the nodes [43].

Rahim et al., have presented a routing protocol that utilizes a hybrid approach of greedy forwarding and energy-efficient forwarding techniques, with a focus on location-based routing. The protocol determines the optimal forwarding approach by considering the geographical position and energy status of the nodes [44].

A. Kumar and A. Verma present an improved location-aware routing protocol that uses a novel energy-efficient metric to select the best path for data transmission. The protocol considers the location and energy level of the nodes to optimize energy consumption and outperforms existing protocols in terms of network lifetime and energy consumption [45].

6- Sector-based protocol

Sector-based protocols for underwater wireless sensor networks are a type of routing protocol that divides the network area into sectors and uses the sector information to route data packets. Each sector corresponds to a specific direction in the network, and nodes in the sector are responsible for forwarding packets in that direction. The sector-based protocols aim to reduce energy consumption and increase the network lifetime by minimizing the number of hops required to transmit data packets. These protocols are suitable for networks with a static topology, where nodes are not expected to move around. Sector-based protocols are commonly used in underwater monitoring applications such as oceanographic data collection, pollution monitoring, and underwater surveillance.

G. Li et al. propose a protocol that uses a sector-based approach to optimize the path selection for data transmission. The protocol uses particle swarm optimization to select the best path while considering the location and energy level of the nodes. The proposed protocol achieved better performance than other protocols in terms of energy consumption, packet delivery ratio, and end-to-end delay [46].

N. Nourinia and A. Akbari, have proposed a routing protocol that is based on sectors and utilizes a hybrid approach of greedy forwarding and energy-efficient forwarding techniques. The network protocol partitions the network region into distinct sectors and employs a routing strategy that optimizes node location and energy levels for efficient data forwarding. The protocol under consideration exhibits a reduction in energy consumption and an improvement in packet delivery ratio when compared to alternative protocols [47].

X. Zhang et al., have presented a routing protocol that is based on clusters and sectors, which involves dividing the network area into these units. The protocol employs sector-based routing as a means of determining the optimal path for transmitting data within a given cluster. Additionally, each cluster is overseen by a designated cluster head, whose responsibility it is to relay data to the base station. The protocol under consideration exhibits superior performance with respect to network longevity, energy utilization, and packet transmission success rates when compared to alternative protocols [48].

M. Zhang et al., have presented a protocol that takes into account the geographical position and energy status of the nodes in order to determine the optimal path. The network protocol partitions the network region into distinct sectors and determines the optimal route for transmitting data by considering the geographical placement and energy status of the individual nodes. The protocol under consideration exhibited superior performance with respect to energy efficiency, packet delivery ratio, and end-to-end delay in comparison to alternative protocols. [49].

Liu and colleagues have introduced a routing protocol that is based on sectors and utilizes fuzzy logic to enhance the optimization of path selection. The network protocol partitions the network region into distinct sectors and designates a specific node to facilitate the transmission of packets in the corresponding direction. The protocol under consideration exhibited superior performance with respect to energy efficiency, packet delivery rate, and end-to-end latency in comparison to alternative protocols [50].

7- Reinforcement Learning (RL) routing protocols

Reinforcement Learning (RL) routing protocols for Underwater Wireless Sensor Networks (UWSNs) are a type of routing protocol that uses RL algorithms to select the optimal path for data transmission. RL algorithms allow nodes in the network to learn from experience and make decisions based on the feedback received from the environment. In the context of UWSNs, RL algorithms can help nodes select the best path while considering factors such as the depth and distance between nodes, the energy level of the nodes, and the network conditions. RL routing protocols for UWSNs have been shown to improve network performance in terms of energy consumption, packet delivery ratio, and network lifetime.

H. Ding et al. propose a deep reinforcement learning (DRL) routing protocol that selects the best path for data transmission. The protocol uses a DRL algorithm to optimize the selection of relay nodes while considering the depth and distance between nodes. The proposed protocol achieves better performance in terms of network lifetime, energy consumption, and packet delivery ratio compared to other protocols [51].

S. Ma et al. introduce a reinforcement learning-based routing protocol that selects the best path based on the network conditions. The protocol uses a Q-learning algorithm to choose the optimal path while considering the residual energy of the nodes. The proposed protocol reduces energy consumption and improves the packet delivery ratio compared to other protocols [52].

Yuan and colleagues have introduced a routing protocol that employs a deep reinforcement learning (DRL) approach, utilizing a deep Q-network (DQN) to enhance the optimization of path selection. The protocol determines the optimal route by considering the geographical positioning and power status of the network nodes. The protocol under consideration exhibits superior performance with respect to energy efficiency, packet delivery ratio, and end-to-end delay in comparison to alternative protocols [53].

S. Wang et al. introduce a Q-learning-based routing protocol that optimizes the path selection for data transmission. The protocol uses a Q-learning algorithm to select the best path while considering the distance and energy level of the nodes. The proposed protocol achieves better performance in terms of energy consumption, packet delivery ratio, and end-to-end delay compared to other protocols [54].

Zeng and colleagues have presented a novel adaptive routing protocol that employs a reinforcement learning algorithm to enhance the optimization of path selection. The routing strategy employed by the protocol is dynamically adjusted in response to both the prevailing network conditions and the remaining energy levels of the individual nodes. The protocol under consideration exhibits superior performance in relation to network longevity, energy utilization, and packet delivery ratio when compared to alternative protocols [55].

8- intelligent optimization routing protocols

Intelligent optimization routing protocols of Underwater Wireless Sensor Networks (UWSNs) are a type of routing protocol that uses intelligent optimization techniques to select the optimal path for data transmission. These techniques include evolutionary algorithms, swarm intelligence, artificial neural networks, fuzzy logic, and other metaheuristic algorithms. The goal of these routing protocols is to improve network performance by optimizing various network parameters, such as energy consumption, network lifetime, packet delivery ratio, and end-to-end delay. By leveraging intelligent optimization techniques, these routing protocols can adapt to changing network conditions and find the most efficient path for data transmission in UWSNs.

Shi et al. proposed an intelligent optimization routing protocol for underwater wireless sensor networks that is based on an improved ant colony algorithm. The protocol aims to minimize energy consumption and extend the network lifetime by optimizing the path selection process. The algorithm uses both local and global pheromone updating strategies to enhance exploration and exploitation of the search space [56].

Yuan et al. proposed a multi-objective optimization routing protocol for underwater wireless sensor networks that leverages intelligent optimization techniques in their 2018 paper. Their approach considers multiple objectives such as energy consumption, network lifetime, and delivery ratio to select the best route. The protocol uses a hybrid genetic algorithm to optimize the path selection process [57].

Wang et al. proposed an intelligent optimization routing protocol for underwater wireless sensor networks based on fuzzy control in their 2019 paper. The protocol considers multiple metrics such as energy consumption, link quality, and residual energy to select the best route. The fuzzy logic controller is used to map the input parameters to the corresponding output [58].

Zhang et al. proposed an intelligent optimization routing protocol for underwater wireless sensor networks based on deep belief networks in their 2020 paper. The protocol leverages deep learning techniques to model the relationship between network parameters and optimize the path selection process. The algorithm employs a self-learning mechanism to adjust to changing network conditions [59].

Z. Li et al. proposed an intelligent optimization routing protocol for underwater wireless sensor networks based on an improved bat algorithm in their 2021 paper. The protocol aims to minimize energy consumption and maximize network lifetime by optimizing the path selection process. The improved bat algorithm incorporates adaptive mutation and elitism strategies to enhance the search process [60].

V. Conclusion

This research investigates the existing routing protocols for underwater wireless sensor networks (also known as UWSNs) and provides a description of such protocols. In addition to this, it categorizes the routing protocols used by UWSNs into two distinct classes according to the data transmission and processing methods that they use. It also explains the various types of routing algorithms, how each one operates, as well as the benefits and drawbacks of using each one. The majority of research on routing algorithms for underwater wireless sensor networks is still done through the use of computer simulation experiments, despite the fact that a significant amount of information has been acquired on the topic. The findings of the experiments will be affected by factors such as water temperature, salinity, pressure, and so on in real-world applications. Additionally, the experimental outcomes will be impacted by the communication protocol of underwater nodes, time synchronization, and other factors that need to be validated using additional experimental data. This report may serve as a roadmap for further research on the technology of UWSNs in the future.

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