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A Survey of DBR Protocols in Underwater Wireless Sensor Networks

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Abstract - *Underwater Wireless Sensor Networks (UWSNs) have become very important for handling all kinds of tasks underwater. It is somewhat cumbersome to implement terrestrial wireless sensor network routing protocols due to large propagation delays, packet delays, and energy consumption. Routing in underwater sensor nodes is one of the challenging problems in UWSNs because of the need to forward data packets with minimal energy consumption and high packet delivery rate. Therefore, this issue has received great attention from researchers with the intention of improving the performance of UWSNs.*

Researchers have performed surveys about routing protocols in underwater wireless sensor networks. This paper focuses on studying the routing protocols associated with the depth-based routing (DBR) protocol. We survey the different routing protocols available so far for routing data in UWSNs. These protocols classified into two main categories: Intelligent Algorithm-Based Routing Protocols and Intelligent Algorithm-Free Routing Protocols. In addition, important aspects of the protocols are discussed and analyzed. The comparison of protocols is also presented on the basis of various characteristics such as factors used in data routing, protocol problem, solution method, advantages and disadvantages.

Key Words: Underwater wireless sensor networks (UWSNs), Routing protocol, Depth-based routing protocol, Intelligent algorithm-based routing protocols, Intelligent algorithm-free routing protocol, Routing Strategy.

1. INTRODUCTION

Underwater Wireless Sensor Networks are a modern wireless technology in which small size sensors are deployed at different depths where these nodes have limited power, memory and bandwidth. Sink nodes are placed on the surface of the water as shown in Figure (1). Major applications of underwater wireless sensor networks include earthquake monitoring, tactical monitoring, pollution monitoring, assisted navigation, and oil and gas leak monitoring. These applications need to deploy underwater sensors that will sense and collect data. Underwater wireless sensor networks are very different from terrestrial sensor networks in that radio waves cannot be used in underwater wireless sensor networks. Acoustic channels are used to communicate in deep sea water. Acoustic signals have many limitations, such as limited bandwidth, network path loss, higher end-to-end delay, and dynamic topology. These limitations lead to higher energy consumption with fewer packets being delivered, the main goal nowadays it is to increase energy efficiency and operate sensor nodes that contain a smaller battery for a longer time in the network.

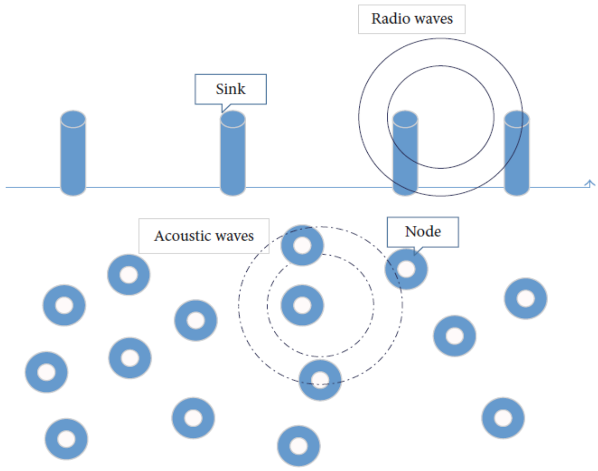

Fig -1: Underwater sensor network architecture [1]

In UWSN, an important area of research is routing protocol design. The routing protocol ensures reliable and efficient transmission of data from the source node to the destination node. Considering the differences between the terrestrial and underwater environment, the design of the UWSN routing protocol is more difficult and limiting than that of the WSN [2].

There are several surveys of routing protocols for UWSNs in the literature [1-5].
However, these surveys either do not focus too much on routing protocols or do not take into account modern routing protocols for UWSNs. In addition, some surveys do not address parameters such as the routing strategies or their advantages and disadvantages. Describing these parameters is essential for researchers, engineers, and scientists who design and test routing algorithms for UWSNs. The description of these parameters helps in choosing the appropriate protocol for the correct application in UWSNs. Moreover, these parameters also help researchers to design new routing strategies based on the disadvantages addressed in the routing schemes. This, in turn, leads to the establishment of new routing protocols that are more powerful, efficient, and intelligent compared to traditional routing protocols.

The following contributions of this paper:

- Presentation of a survey of DBR protocols in UWSN networks. Compared to existing surveys, this survey takes into account all protocols associated with the Depth-Based Routing (DBR) protocol.
- Protocols are classified into two categories: Intelligent Algorithm-Based Routing Protocols and Intelligent Algorithm-Free Routing Protocols. This classification is useful and effective for researchers to understand the design of each protocol.
- Unlike current surveys, the survey focuses specifically on routing strategies, the protocol problem it has solved, the solution, the advantages and disadvantages of the protocols. The description of routing strategies helps researchers understand the routing process for the protocols that have been processed. Describing the advantages of each protocol facilitates its choice by researchers for a particular application. The description of protocol disadvantages is useful in designing new routing protocols for more efficient UWSNs. This is because new protocols can be designed keeping in mind the disadvantages of existing protocols. In this way, more robust, efficient, and intelligent protocols can be designed.

The paper is organized as follows: Section 2 discusses the DBR routing protocol, its routing mechanism and its problems. Section 3 discusses the classification of routing protocols, all the protocols based on intelligent algorithms and the protocols that are free from intelligent algorithms, and makes a comparison between the protocols. Finally, Section 4 concludes the paper.

2. DEPTH-BASED ROUTING PROTOCOL

DBR is a Depth-Based Routing protocol [6] that uses the Greedy Algorithm to route a packet from the source node to the sink node. This protocol does not require the complete location information for the sensor nodes but rather only the local depth data. Each node uses its own depth information, as the sensor node is equipped with inexpensive depth devices to calculate depth pressure locally.

2.1 Routing Mechanism

In this protocol, in order to define the next forwarding nodes, the sensor node tries to find the best neighboring nodes in terms of depth information for forwarding the packet. In other words, adjacent nodes of depth less than the transmitter would be candidates for forwarding the packet. After receiving the packets, the adjacent node compares its depth with the depth of the transmitter included in the packet. This node will be a candidate for forwarding the packet if its local depth is less than that of the transmitter. Otherwise, the node directly ignores the packet. Then the forwarder node broadcast the packet including its depth.

Figure (2) shows n1, n2 and n3 are sensor nodes adjacent to the sensor node S and the circuit line represents the transmission range. S node broadcasts a packet to neighboring n1, n2 and n3 nodes in the transmission range. Node n1 and n2 are a forwarder nodes, while n1 is defined as a perfect forwarding due to its depth is less than the sender node and n3 is more depth than the node sender node S, so it ignores the packet. When receiving data packets, the neighboring node calculates its depth across compression devices and compares it to the depth in the data packet. If the node depth is less than the packet depth, then the packets are forwarded to the next node, otherwise the packets are discarded. In other words, adjacent nodes of lower depth than the sender would be candidates for routing the packets.

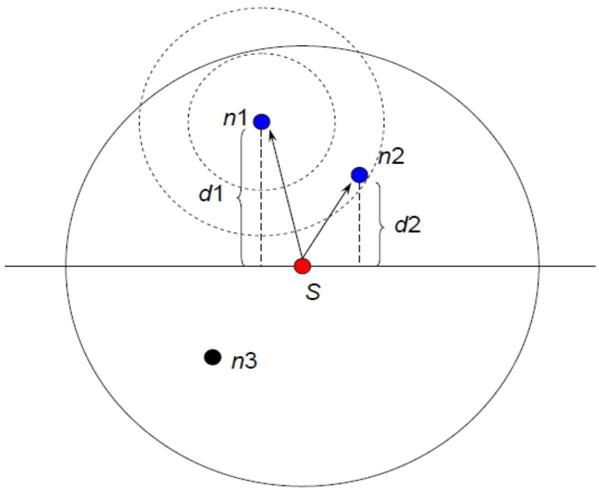

Fig -2: Forwarding node selection [6]

2.2 Disadvantages of Depth-Based Routing Protocol

1. High end-to-end delay in dense network. [5]
2. Connection problems in sparse area due to Greedy Algorithm.[5]
3. The data packet is forwarded in the broadcast method, so that a number of duplicate packets are forwarded, which reduces network performance. [5]
4. Due to the large area and density, the complexity increases which leads to more energy consumption, packets and inefficient use of memory.[5]
5. Rapid energy consumption of medium-depth nodes results in large energy holes in the network.
6. Sensor nodes quickly expire due to unnecessary data forwarding and high load on low depth nodes.

3. CLASSIFICATION OF ROUTING PROTOCOLS

In this section, we will present the protocols related to the depth-based routing protocol, as shown in Figure (3):

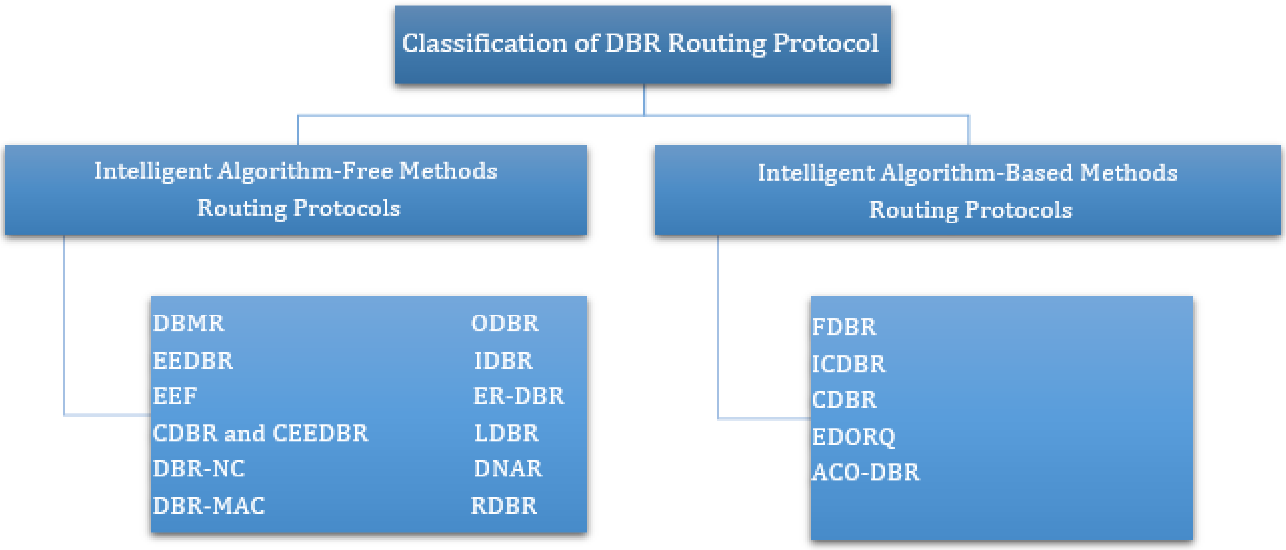

Fig -3: Classification of DBR Routing Protocol

3.1 Intelligent Algorithm-Free Routing Protocols

In this category of protocols, a set of parameters are used to improve routing performance. We will review previous studies of intelligent algorithm-free routing protocols, as shown in table (1):

3.1.1 DBMR

The Depth-Based Multi-hop Routing (DBMR) protocol is proposed in [7]. This routing protocol only needs depth information, as it optimizes DBR and saves energy. By using the multi-hop mode for each node to send the packets instead of the flood approach, thus reducing the communication cost. DBMR protocol consists of two phases: the route discovery and send packets. After all nodes deployed in the water, they will start to detect their underwater depth and start the route discovery process to choose their next hop nodes. Finally, packets from the source node are sent to the sink node through multi-hop.

3.1.2 EEDBR

The Energy-Efficient Depth-Based Routing (EEDBR) protocol [8] utilizes the depth of sensor nodes for forwarding data packets. Furthermore, the residual energy of sensor nodes is also taken into account in order to improve the network lifetime. EEDBR consists of two phases: the knowledge acquisition phase and the data forwarding phase. During the knowledge acquisition phase, sensor nodes share their depth and residual energy information among their neighbors. In the data forwarding phase, data packets are sent from the sensor nodes to the sink node.

3.1.3 EEF

The Energy Efficient Fitness based routing (EEF) protocol [9] takes into account residual energy, depth and distance from the source node to the sink node to route a packet from source to the destination node. The source node calculates its fitness factor, embeds the fitness value and its position in the data packet and broadcasts it. The one-hop adjacent nodes that receive the packet calculate their own fitness, which determines whether they forward or discard the packet. The forwarding node compares its fitness with the sending node's fitness included in the packet after receiving it. If the forwarding node's fitness is higher than the sender node's, the packet is forwarded; otherwise, it is discarded. In this process, more nodes may take part in forwarding packet; In order to prevent more nodes to forward the same packet.

3.1.4 CDBR and CEEDBR

The Constraint Depth-based Routing (CDBR) protocol and Energy Efficient Constraint Depth-based Routing (EECDBR). The main idea of CDBR and CEEDBR is to limit the number of data forwarding nodes, so that the energy consumption can be reduced [10]. In a CDBR between a groups of nodes, a node with a lower depth for forwarding data is optimal forwarder node. In the case of CEEDBR from among a set of nodes, the weight is assigned to the nodes based on depth and residual energy. A node will have the maximum weight if it has the lowest depth and highest energy remaining between adjacent nodes. The node with maximum weight is a candidate for data forwarding. It is also important to check whether the node is alive or not.

3.1.5 DBR-NC

The Depth-Based Routing protocol with Network Coding (DBR-NC) [11] improves the reliability of the DBR protocol and the problem of low data delivery rate using network coding**.** Besides the encapsulated payload data, packet header of DBR-NC contains three fields: generation ID, coefficient vector and depth information. Generation ID is a unique sequence number. Only packets with the same generation ID are encoded and decoded together. Coefficient vector field is constituted by K different bytes and K is the generation size. While considering the encoding complexity, generation size is generally less than 5. Depth field records the depth value of the sensor where the packet was generated [11].

3.1.6 DBR-MAC

In depth-based routing protocols working with broadcast Medium Access Control (DBR-MAC) [12], low-depth nodes with high overhead access to the channel are prioritized. The node angle, depth, and overhead of adjacent nodes of lower depth are considered to make them reach the channel with greater preference than the rest of the nodes. This leads to improvement in energy consumption, throughput and delay. DBR-MAC also reduces the possibility of collisions by using the local information (i.e. depth information and node angle information) that better attempts to reduce the number of forward hops for all packets.

3.1.7 ODBR

The Optimized Depth-based Routing (ODBR) protocol [13] which addresses the problem of irregular energy consumption, which leads to the creation of energy holes, meaning dead nodes whose energy is zero. ODBR addresses this problem by allocating more primary energy to the nodes near the sink and increasing the traffic load and dividing the grid area into three equal regions. The nodes in region 1 have the maximum traffic load as they have to receive and send data packets from all other nodes along with their data packets to the sink in order to consume maximum energy. The maximum initial energy is set to ensure that the maximum nodes belonging to region 2 share a lower traffic load than that belonging to region 1. Therefore, nodes in region 2 are assigned a relatively lower primary energy. The nodes belonging to Region 3 are provided with the least amount of primary energy as they have to send only their data packets and thus use the least amount of energy.

3.1.8 IDBR

Intelligent depth-based routing (IDBR) protocol [14] to solve the energy hole problem by allocating primary energy to the nodes in proportion to their distance from the sink node. This work is an extended version of the previous study in which it used the idea of optimal energy allocation to improve network life. This idea was improved to make energy allocation more intelligent by working on the EEDBR protocol that takes into account the remaining energy.

3.1.9 ER-DBR

Energy-Efficient and Reliable Depth-Based Routing (ER-DBR) protocol [15] improving DBR protocol performance by presenting a new solution using three metrics (packet reception probability, signal-to-noise ratio, and link quality indication) used to determine the next forwarder node of reliability, which in turn reduces routing cost, , reduces energy consumption, and increases link quality. ER-DBR operates in different Phases, which are the link quality metrics phase, neighbors knowledge collection phase and data forwarding phase.

3.1.10 LDBR

The Light-weight Depth-Based Routing (LDBR) protocol [16] takes into account the energy consumption and residual energy by the sensor node. Node compares its current depth with the previous depth that is embedded into the packet. It will hold packet for a certain time in Q1. It will check if the node energy is high and its current depth is less than its previous depth (Dc <Dp) than it will broadcast the packet to the next-hop/nearest neighbor, if the next-hop/nearest neighbor is closer to the water surface forward the packet to surface sink. If the node energy is low it will simply discard the packet [16].

3.1.11 DNAR

The Depth and Noise Aware Routing (DNAR) protocol [17] to solve the problem of death of nodes near the sink nodes due to its frequent use in routing data. The DNAR scheme is done in two stages: relay node detection and data forwarding. In the DNAR protocol more energy is allocated to the sensor nodes having a depth level ≤150 m. Therefore the sensor nodes deployed nearby to the sink node have more capability of transmission and will not die quickly, also defines which forwarder candidate has the lowest depth and minimum channel noise.

3.1.12 RDBR

The Robust Depth-Based Routing (RDBR) protocol [18] addresses the problem of higher end to end delay and energy consumption between data forwarders. RBBR employs balanced energy consumption by proper forwarder selection through variation in d_{th} and T_{tx} that provide the stability period of remaining nodes. Increase in stability period also confirms reduction in redundant transmissions. Variations in d_{th} and T_{tx} improve load balancing in middle and low depth region by controlling the eligible neighbor node.

3.2 Intelligent Algorithm-Based Routing Protocols

Intelligent algorithm-based methods for routing protocol design are still a new research area for underwater wireless sensor networks. In recent years, many researchers have devoted their efforts to combine the traditional design method using parameters and intelligent algorithms together to find an effective approach to routing protocol design. We will review the previous studies of intelligent algorithm-based routing protocols, as shown in table (2):

3.2.1 FDBR

The Fuzzy Depth-based Routing (FDBR) protocol [19] modified the DBR protocol by making routing decisions based on fuzzy logic depend on the residual energy of the receiver node with the depth difference of the receiver node, the previous forwarder node, and the number of hops traveled by the received packet. The input fuzzy variables are: remaining energy of receiver node, depth difference of receiver node and previous forwarder node and the number of hops traveled by the received packet. The rules for fuzzy inference system are made on the basis of the inputs depth, hop-count and the energy. There is a single output fuzzy variable, namely delay, the defuzzified value of which determines the value of holding time [19].

3.2.2 ICDBR

Improve Clustering Depth-based Routing (ICDBR) protocol [20] which is an improved version of the DBR protocol. The routing process is based on the clustering. The division of the network is performed into groups, the nodes organize themselves into these groups. Where the head of the cluster is determined by the node with the largest amount of energy, then the other nodes send their data in one step to the head of the cluster. The cluster headers process the collected data and send it with the help of the header of other groups and through a multi-step approach to the sink node.

3.2.3 CDBR

In Clustering Depth-based Routing (CDBR) protocol [21], cluster based approach is used. In order to minimize the energy consumption, load among all the nodes are distributed equally. The energy consumption of each node is equally utilized as each node has equal probability to be selected as a Cluster Head (CH). In CDBR also does not require full dimensional location information of nodes. It takes into account depth and residual energy of nodes.

3.2.4 EDORQ

The Energy-Efficient Depth-based Opportunistic Routing algorithm with Q-learning [22]. It combines the respective advantages of Q-learning technique and opportunistic routing (OR) algorithm without the full-dimensional location information to improve the network performance in terms of energy consumption, average network overhead and packet delivery ratio. In addition, a simple and scalable void node recovery mode is proposed for the selection of candidate set so as to rescue packets that are stuck in void nodes unfortunately. Furthermore, designed a novel method to set the holding time for the schedule of packet forwarding base on Q-value so as to alleviate the packet collision and redundant transmission [22].

3.2.5 ACO-DBR

Ant Colony Optimization Depth-based Routing (ACO-DBR) protocol [23] to improve energy efficiency and reduce consumption in the DBR protocol. ACO-DBR protocol uses depth, distance, residual energy of nodes and number of hops, ACO-DBR consists of two phases, namely, path discovery and selection phase and data forwarding phase. In the phase of discovering and selecting the path, the ant colony optimization algorithm was used and improved upon by entering the energy factor as describe in the data forwarding phase, in order the choose the next hop based on distance and energy. The data is forwarded through the chosen path. All nodes within this path have a depth less than the depth of the sending node.

Table -1: The state-of-the-art intelligent algorithm-free routing protocols

Protocol	Metrics	Problem Addressed	Routing Strategy	Advantages	Disadvantages	Year
DBR [6]	1. Depth.	Solves problems related to localization.	Use the pressure sensor to select the lowest depth node.	• It does not require full dimensional location information of nodes. • Uses multiple sinks to reduce battery loss. • High packet delivery ratio.	○ Use only one parameter (depth information) ○ Reducing network lifetime (by using the same node multiple times as the forwarder node). ○ High energy consumption (sending redundant packets). ○ High delay. ○ Energy holes.	2008
DMBR [7]	1. Depth	Energy consumption.	Use of multi-hop approach for each node to send packets instead of flooding approach.	• Reducing the cost of communication. • Reducing energy consumption (using the best single path). • Reducing collisions. • High packet delivery ratio.	○ Low throughput.	2010

Table -1: Continued

Protocol	Metrics	Problem Addressed	Routing Strategy	Advantages	Disadvantages	Year
EEDBR [8]	1. Depth. 2. Residual energy. 3. Priority value.	▪ Redundant transmissions. ▪ Energy imbalance. ▪ Death of low-depth nodes.	Only a node with high residual energy forwards the packet.	• No extra packet transmission occurs due to the use of the priority value. • Low energy consumption. • Improving network lifetime.	o High delay. o Energy holes. o Low packet delivery ratio. o Low reliability.	2012
EEF [9]	1. Depth. 2. Distance. 3. Residual energy.	The forwarder node makes the decision to forward the packet based only on depth.	Add fitness value.	• Improving network lifetime. • Reducing delay. • Low energy consumption	o Low packet delivery ratio.	2013
CDBR/ CEEDBR [10]	1. Depth. 2. Residual energy.	▪ Energy imbalance. ▪ Redundant transmissions.	Limiting the number of forwarding nodes.	• Energy efficient. • Fewer forwarders. • Improving network lifetime.	o Unbalanced energy consumption. o Drop more data packets. o High delay.	2014
DBR-NC [11]	1. Depth.	Low data delivery in the sparse network.	Use network coding.	• High throughput. • High packet delivery ratio. • High reliability.	o Energy consumption. o High delay.	2016
DBR-MAC [12]	1. Depth. 2. Information angle.	▪ Collisions and traffic in major nodes.	Use the main priority nodes using depth information and angle and reduce hops.	• High throughput. • Time efficiency.	o Unbalanced energy consumption as nodes near the water surface are selected frequently.	2016
ODBR [13]	1. Depth.	▪ Energy imbalance. ▪ Early death of a nodes closer to the surface of the water.	Allocate more energy to nodes near the surface of the water.	• Avoid energy holes. • Improving throughput. • Improving network lifetime. • Balanced energy consumption.	o Drop more data packets. o Reducing network reliability.	2016
IDBR [14]	1. Depth.	Energy holes.	Allocate more energy to nodes near the surface of the water.	• Improving network lifetime. • High throughput. • Drop fewer data packets. • Improving energy consumption.	o It does not work in the deep water area where the lower nodes must have sufficient sensor energy.	2017

Table -1: Continued

Protocol	Metrics	Problem Addressed	Routing Strategy	Advantages	Disadvantages	Year
ER-DBR [15]	Triangular metric: 1. Packet reception probability 2. Signal to noise ratio 3. Link quality indication.	▪ Link quality. ▪ Route guidance based on depth-based routing techniques.	Triple routing based on link quality metrics used to determine the next reliable forwarding node.	• Low Energy consumption. • Improving network lifetime. • Reducing the cost of the route. • Low delay. • High packet delivery ratio.	○ Energy holes. ○ Dead nodes are formed during the routing process.	2018
LDBR [16]	1. Depth. 2. Residual energy.	Energy consumption.	The remaining energy node and take the shortest route to minimize the connection time.	• Low energy consumption. • Improving network lifetime	○ Early death of a nodes closer to the surface of the water.	2018
DNAR [17]	1. Depth. 2. Noise.	Early death of a nodes closer to the surface of the water.	1. Allocate more energy to the sensor node which has a depth level ≤150m. 2. Determine which forwarder node has the lowest depth and lowest channel noise.	• High packet delivery ratio. • Low energy consumption. • Improving network lifetime. • The protocol avoids high noise and identifies the forwarder node which has the lowest noise at the receiver and the lowest depth.	○ High delay due to the repeated examination of the state of the channel.	2019
RDBR [18]	1. Variation in depth threshold 2. Variation transmission range. 3. Holding time of sensor nodes.	It addresses the problem of higher end to end and energy consumption between data forwarders in time critical application.	Use variation in depth threshold, variation transmission range, and holding time of sensor nodes for the selection of the optimal forwarding nodes.	• Low energy consumption. • Improving network lifetime. • Low delay.	○ Low throughput. ○ Low packet delivery ratio.	2020

Table -2: The state-of-the-art intelligent algorithm-based routing protocols

Protocol	Metrics	Problem Addressed	Routing Strategy	Advantages	Disadvantages	Year
FDBR [19]	1. Depth. 2. Residual energy. 3. Number of hops.	▪ Use DBR protocol depth as the only metric for path selection ▪ Energy consumption ▪ High delay. ▪ Calculating adaptive values for holding time in the DBR protocol.	Use fuzzy logic.	• Low energy consumption. • High packet delivery ratio. • Low delay.	○ Energy holes.	2015
ICDBR [20]	1. Depth.	Energy consumption.	Clustering approach.	• Improving energy efficiency. • Improving network lifetime. • Reducing the number of node receiving packets.	○ Overload on the head nodes.	2016
CDBR [21]	1. Depth. 2. Residual energy	▪ Death of the nodes near the sink node.	Clustering approach	• Reliable packet transmission. • Improved network lifetime, • Increasing the stability period of the network. • High throughput.	○ High energy consumption.	2016
EDORQ [22]	1. Depth.	▪ Energy consumption due to Energy holes. ▪ Redundant transmissions.	Combining the advantages of the OR algorithm and the Q-learning technique.	• Detecting and bypassing dead nodes in advance. • Reducing collision of packets. • Reducing energy consumption. • High packet delivery ratio.	○ High delay due to the use of the Q value as each packet needs to wait before being forwarded.	2020
ACO-DBR [23]	1. Depth. 2. Remaining energy. 3. Distance. 4. Number of hops.	▪ Energy consumption.	Improved ant colony Routing algorithm.	• Finding the optimal path that reduces the total energy. • Cut off a path to the sink node, there will be another path. • Reducing energy consumption. • Increasing the stability period and lifetime of the network.	○ High delay.	2021

4. CONCLUSIONS

In this article, modern UWSN routing protocols are analyzed and described in details. A survey of current and recent routing protocols related to the depth-based routing protocol. Routing protocols are also classified into two categories: Intelligent Algorithm-Based Routing Protocols and Intelligent Algorithm-Free Routing Protocols. The first on requires the use of one of the artificial intelligence algorithms, whether fuzzy logic or clustering algorithms, as well as q-learning technology with the OR algorithm and other algorithms. The second classification does not require the use of an intelligent algorithm but rather the use of parameters such as residual energy, depth, distance, noise, number of hops. Each protocol is described in terms of its routing strategy, the problem it solved, and the advantages and disadvantages. This description of protocols is useful for researchers, as routing strategies help in understanding the process of routing protocols. The disadvantages of proposer protocols lead to the design of new protocols more efficient and effective, while the advantages help in selecting the appropriate protocol for the suitable underwater application.

In this paper is to encourage new research on routing protocol to improve underwater wireless sensor networks and to improve many applications in this field. In the future, by using these routing protocols, we hope design a multi-layers model to improve energy efficiency, maintain security and also use these protocols to improve the network lifetime of the underwater wireless sensor network.

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