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Comprehensive overview of underwater wireless sensor routing protocols

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Abstract: Underwater wireless sensor networks (UWSNs) have become the seat of researchers' attention recently due to its proficiency to explore underwater areas and finding different applications for offshore exploration and ocean monitoring. One of the main objectives of each deployed underwater network is discovering the optimized path over sensor nodes to transmit the monitored data to onshore station. Although there exist a large number of routing protocols in terrestrial networks but they are not corresponding to the unique characteristics of underwater environment. In this paper we intend to highlight advantages and limitations of the proposed routing protocol.
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1. Introduction

The concept of UWSNs was first introduced by the AOSN plan, which was developed by the American Institute of Marine research and MIT (Soreide, Woody et al. 2001). Underwater acoustic networks are beginning to revolutionize our knowledge of the oceanic world by providing fine sampling of the underwater environment. The ability to monitor the aquatic environment and dynamic changes by small devices such as sensors will bring new opportunities to provide significant benefits to mankind. The threat of climate changes and increasing activities related to water may have great influence on human life and ecosystems (Ayaz, Baig et al. 2011) so UWSNs have received growing interest recently (Proakis, Sozer et al. 2001, Akyildiz, Pompili et al. 2004, Cui, Kong et al. 2006).

An underwater acoustic sensor network is a collaborative network composed of a large number of sensor nodes and vehicles is deployed inside the phenomenon (underwater) randomly, to accomplish a common task for the required application. To fulfill the application goals, underwater sensor nodes and vehicles must provide self-configuration capabilities, i.e., they must be able to coordinate their operations by exchanging configuration, location and movement information, to disseminate sensed data over the network to reach to an onshore station (Pompili, Melodia et al. 2006).

As sensor network applications require long transmission distance, radio waves propagate at long distance through the conductive sea water at extra low frequencies (30-300HZ) which requires large antennae and high transmission power and due to the scattering properties of optical waves in water use of radio waves and optical waves are inefficient so it is widely recognized, acoustic communications are the best choice for the communicate medium in underwater networks (Pompili, Melodia et al. 2006).

Before a network can be used it must be possible to transfer sensed data from source to destination node, moreover due to the circumstances of water like 1. Water salinity, temperature and contaminants in water: the possibility of nodal failure caused by erosive is high. 2. The limitation of each node's transmitted range that are received by a same sink through a network of nodes, appropriate routing algorithms are necessary to direct data in an optimized way, but various priorities are determined to design an algorithm based on the application's requirements.

Specific characteristics of an underwater environment require special concern on algorithms and protocols designed for an autonomous underwater wireless sensor network.

2. Existing routing protocol

In recent years, a variety of routing protocols are designed to transmit sensed data from sources (sensor nodes) to destinations (surface sink or station) via intermediate node's protocol according to the requirement of each application. In this paper we focus on three types of routing protocols such as: location-based routing protocol, flat-based routing protocol, hierarchical routing (Ayaz, Baig et al. 2011).

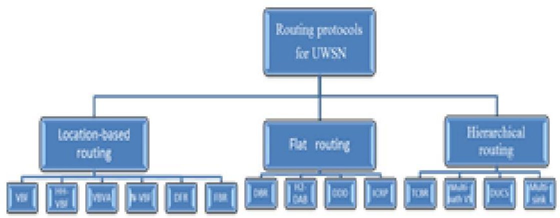

Figure 1: Routing protocol in UWSNs

2.1 Vector-based forwarding (VBF-2006)

Vector based forwarding (VBF) is a routing protocol which designed for mobile underwater sensor network and proposed in (Xie, Cui et al. 2006). Indeed VBF is a geographic routing approach that assumes every sensor node knows its location, and each data packet containing the location of the source, destination, forwarding nodes and also a range field which is used for mobility concept. A small number of nodes participate in data forwarding and the state information is not required for each sensor node, figure. 1 presents a basic view of VBF for UWSN.

VBF is a location based routing approach; it represents a trajectory with a "routing vector" from the source to the sink, so VBF is robust against the problem of packet losses and node failure. Whenever a node receive a data packet, computes its distance to the forwarder using the distance to the forwarder and the angle of arrival (AOA) of the signal (VBF assumes that each node is equipped with the hardware required to measure the distance and the AOA of the signal).All involved nodes compute their positions recursively, to determine if computed distance is less than a pre-controlled distance threshold, it is close enough to the routing vector so it updates packet forwarder position and continue forwarding the packet; otherwise it discards data packet .It establishes a "routing pipe" that only the nodes along forwarding path are involved in packet forwarding, thus the energy of the network is saved.

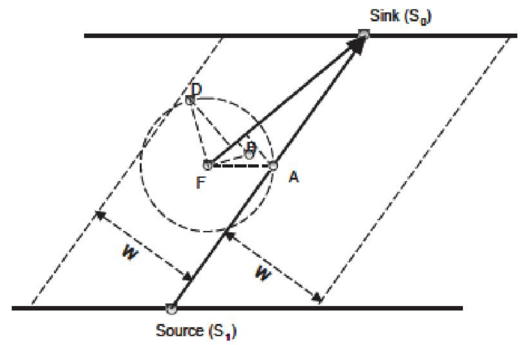

Figure 2: The forwarding selection in VBF protocol

The performance of VBF evaluates based on three metrics: packet delivery ratio, energy consumption, and end-to-end delay through simulation in NS-2.

2.2 Multi Path Virtual Sink architecture (2006)

To deploy a network in underwater environment that insure these requirement energy efficiency, a reliable network, robust against constraints and sufficient redundancy, an organized network topology is really vital. By considering mentioned criteria (Seah and Tan 2006), present a robust routing protocol that causes the whole network to perform well even if a failure happen in one part of the network. According their methodology each underwater network consists of clusters of nodes and each cluster has its own aggregation point. As you can see in figure aggregation point locate in mesh networks which connect through high speed links to local sink.

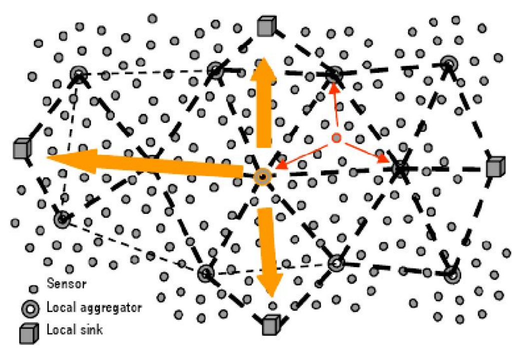

Figure 3 Overview of Multi-path VS protocol

To forward data, each aggregation point gathers its sensed data from local clusters and transmits them to local sink; all these local sinks configure a virtual sink. Sensor nodes forward data through multiple paths to sinks, these multiple path forms in an initialization phase. In this phase each sink node propagates a hop count packet to its local sensors then upon receiving this data packet, each sensor save transmitter sink node information. Finally sensor nodes increment the hop count packet and retransmit packet to other nodes.

2.3 Hop-by-Hop Vector-Based Forwarding (HH-VBF-2007)

Hop-by-Hop Vector-Based Forwarding (HH-VBF) is proposed in (Nicolaou, See et al. 2007) for sparse networks, the basic concept of routing vector in HH-VBF is similar to VBF however it forms the routing pipe in a hop-by-hop method from each intermediate forwarding node to the sink. Because of no use of single virtual pipe each node forwards packets based on its current location.

As we show in the figure. 2 when a node receives a packet, it first holds the packet for some time, to compute desirableness factor like VBF then the node with the smallest desirableness factor will send the packet. HH-VBF allows each node overhearing the duplicate packet transmissions to control the forwarding of this packet to the sink. By doing this, even in sparse networks; HH-VBF can find a data delivery path as long as there is an available node in the forwarding path.

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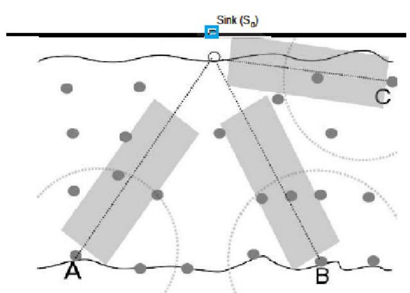

Figure 4: An overview of the forwarding path in HH-VBF

Since each node forms a new routing pipe, this mechanism is not too sensitive to predefined routing pipe radius and the maximum pipe radius is the transmission range and the packet delivery ratio enhances significantly. HH-VBF was simulated in

2.4 Distributed Underwater Clustering Scheme (DUCS – 2007)

As the battery energy of each sensor node is limited and it cannot be replaced or recharged, energy consumption is a major issue in designing routing protocols. (Domingo and Prior 2007) Propose a cluster based protocol to save more energy in the network. Distributed Underwater Clustering Scheme is using a distributed algorithm to divide the underwater network into local clusters. DUCS has two phases to be completed. In the first (setup phase) each local cluster has a cluster head which receives the data packet from the other nodes in a local cluster. This cluster head is selected randomly among the other nodes in a certain cluster. In network operation phase, when data transmitting is finished, each head cluster starts to process collected data, and send processing data to the sink through the other head clusters.

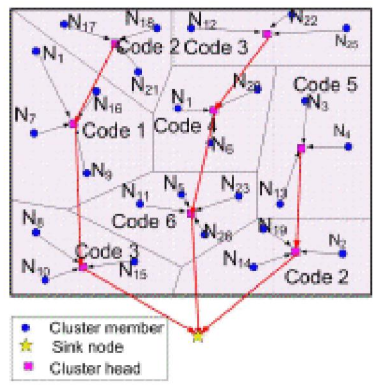

Figure 5: Network architecture in DUCS The packet delivery

Ratio is really high in this method, simultaneously the simulation result depicts that the average routing overhead is decreasing too, the last metric that evaluated the DUCS is the number of active sensor nodes that is required in each successful packet delivery. They use NS-2 to evaluate the performance of presenting protocol. Although the network throughput improves significantly, but there is a number of drawbacks in DUCS like: the mobility of sensor nodes influence the efficiency of cluster since their structure is variable. As a consequence the lifetime of each node cluster is declining relative. On the other hand each cluster head recognizes its adjacent cluster head and transmit its data towards these nodes so when the configuration of the network is changing it cannot its path to forward the data to the sink.

2.5 Information-Carrying Routing Protocol (ICRP- 2007)

A new routing protocol that carried control packets in the data packet is presented (Liang, Yu et al. 2007), this novel protocol is suitable for time critical and energy saving applications. The state of the sensor nodes is not required and a limited number of nodes are participating in routing collected data. Upon receiving a data packet, sensor node will check the path if the path is free it will send the data that contains the discovering massage to find its path, recursively each node that takes this data packet will forward it the other and find the appropriate path. At the end when this data packet reaches the target node, the path is determined so destination utilizes the same path to send acknowledgment packet to the source node. Each discovered path has a predetermined lifetime that can be used to route or be idle, after passing this limited time, this routing time is useless and is not valid any more. Consequently the nodes that are using this routing path should detect another one, if they want to broadcast data again.

This routing protocol validates by simulation and has implemented practical in the real world. The deployment results are not realistic since network size was in small scale, just three sensor node. There are other disadvantages in ICRP, on one hand if a source does not know its target, sending data packet is useless and increase overall energy consumption of network. On the other hand the sensor node life is depending on a predefined threshold that decreases the lifetime of network if this threshold time expires.

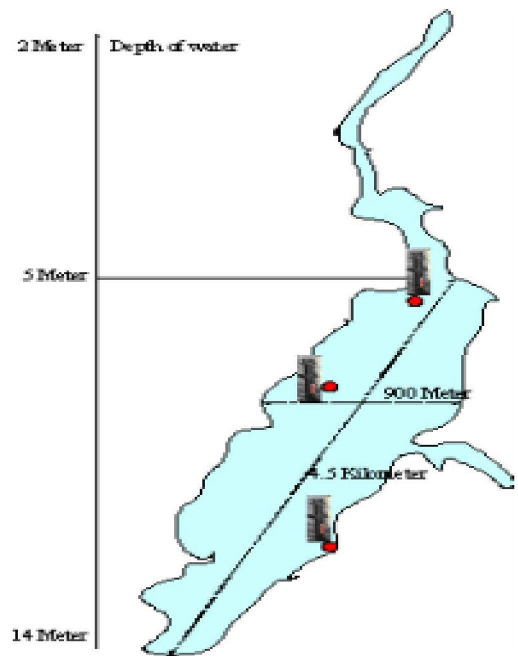

Figure 6: Implementation scenario in ICRP

Due to the unique characteristics of acoustic channel more energy consumers in underwater networks. Consequently designing energy efficient protocols is more critical than in terrestrial sensor networks. Based on mentioned facts (Liang, Yu et al. 2007) states Mobile Delay Tolerant algorithm for delay tolerant network. DDD uses dolphins (mobile nodes) to collect monitoring data from static nodes. In this method whenever a dolphin locates near stationary nodes, each node starts to send its data packet to collector dolphin. The ordinary nodes are placed in the ocean bottom and dolphins are mobile, these nodes have two states: idle and wake up. The stationary nodes wake up at interval time and transmit their data to dolphins. Dolphin sensors use beacons to announce their presence to the other nodes and they move in a random path with the speed of v. After collecting data from dolphin nods, collected data is received at the main station at the surface water.

The remarkable issue with this protocol is that the dolphin cannot cover the entire stationary node as their moving path is random and the numbers of dolphins are limited. As every node has specified memory storage, if dolphins cannot visit node its buffer become full and the data will discard on the other hand additional dolphins mean higher expense's network**.**

2.7 Focused Beam Routing (FBR-2008)

Focused Beam Routing (Montana, Stojanovic et al. 2008) protocol considers a specific number of energy levels ranging from P1 to PN that each level is matched with a transmission radius den. For the first RTS packet, the power level will set as the lowest level (P1), which can increase if no node respond the packet, then every node that receive this RTS will measure the distance between its location and line AB. After calculation, nodes that located in a cone of angle⁄emanating from the transmitter towards the final destination are selected as the next hop candidates to forward the data.

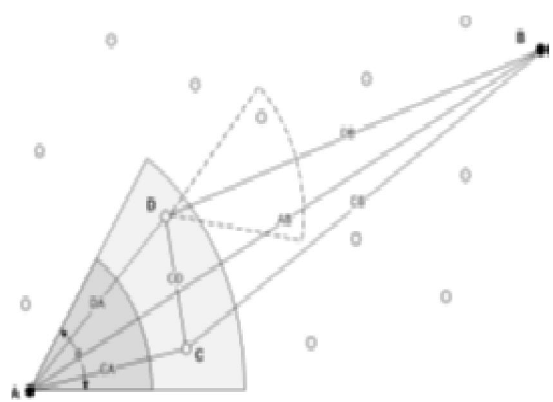
Figure 7: Routing protocol procedure in FBR

In order to validate the performance of FBR we have used a discrete event underwater acoustic network simulator implemented in standard Python and the following metrics were considered: energy per bit consumption energy per bit consumption, and number of collisions.

However, every routing protocol has its limitation, for example in FBR the location of nodes will change due to water current in the underwater environment so it is feasible that no node remain in that forwarding cone of an angel, so to find a candidate node, RST packet should be sent again and again which raise the communication overhead and decrease the data delivery ratio in such sparse areas. So the mobility of sensors in underwater environment should take into consideration.

2.8 Directional Flooding-Based Routing (DFR-2008)

(Hwang and Kim 2008) Proposes Directional flooding-based routing (DFR) which is a packet flooding technique to increase the reliability. The DFR is another routing protocol with the assumption of the localization of sensor nodes and is efficient whenever links are more prone to packet loss. The numbers of involving nodes are limited to prevent flooding of packet over the whole network. As it is observed in the figure 4 the flooding area is specified in terms of the angle between FS and FD where F is the forwarder node which receives a packet, S and D are the source and final destination, respectively.

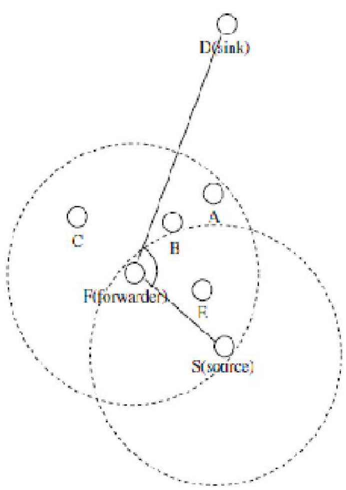

Figure 8: A top view of packet transmission in DFR

When a data packet receives, F determines dynamically to forward the packet by comparing SFD with a criterion angle (called BASE ANGLE) that is included in the received packet). Base angle is adjusted in a hop-by-hop way according to link quality hence specified flooding zone has two advantages: the better link quality and the smaller flooding zone.

Void avoidance is addressed well by selecting at least one node to participate in packet forwarding in DFR, whilst in cases that the link quality is not good enough, several nodes will forward the same data; so more nodes will involve forwarding process, which increase the consumption of energy in network dramatically. The simulation results of this work are evaluated according to three metrics: Packet delivery ratio, Communication Overhead, Average End-to-End Delay.

2.9 Depth Based Routing (DBR-2008)

Localization is essential information for location-based routing protocol hence the location information of all nodes is required in this kind of protocols. Depth Based Routing (Yan, Shi et al. 2008) presents a novel idea to address the localization problem in UWSN. Depth information is enough to route a path through sensor nodes in this study. Each sensor anchored to the bottom of the ocean bed and a depth sensor is inside the sensor node to acquire depth information. Data packet forward through the nodes that have the lower depth priority to multiple surface sinks. The depth information is carried by data packet, upon receiving a data, each node calculate its depth if it is lower it will forward the data otherwise it discard the data.

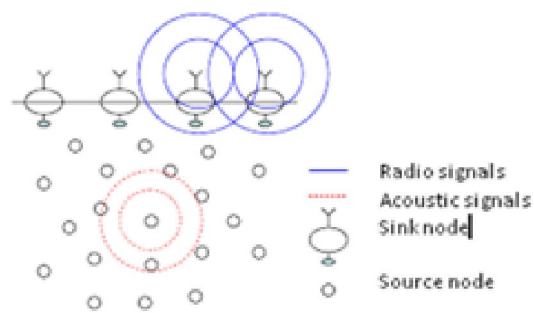

Figure 9: DBR network topology: Multiple-sink underwater sensor network architecture

This routing protocol is not efficient in sparse networks because of employing the greedy method, which decrease packet delivery in sinks. Also in density network deployment, calculating sensor depth one by one is complicated that waste the residual energy of a node and at the same time as the sensor memory is limited it causes data packet losses.

2.10 Multi-sink opportunistic routing protocol (2008)

A new protocol presented by (Li 2008) a multi-sink protocol to achieve high data packet reception in a mesh deployment network. It takes quasi-stationary 2D underwater wireless sensor network architecture into consideration and the coverage area is just shallow water near to the coastal area. They assume that the deployment architecture is a 2-tiered network topology in which the ordinary sensors act as sensing, computational, and communication device located on the lower tier and configure as a backbone network that require data forwarding from sensor nodes to the onshore station. Mentioned backbone is consisting of mesh nodes to (that are rechargeable and has large memory) and multiple underwater sinks. This mesh network deployed at the bottom of the ocean and the underwater sinks connects surface buoy by a wire. The connection medium between the buoys and the main station is WIMAX technology.

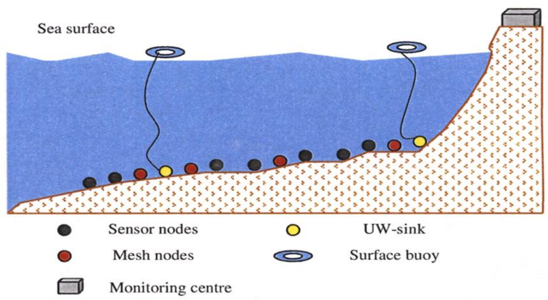

Figure 10: The 2D- quasi-stationary architecture in Multi-sink opportunistic protocol

The procedure of forwarding data is as follows: when an event detects, the source node sends its monitored data to the closest mesh node. Each mesh node aggregates all received data and broadcast received data by means of acoustic signal to the underwater sinks in mesh networks. In the last step, aggregated data are transmitted to the surface buoy by underwater sinks and then the onshore station delivers data packet finally.

Despite the high data packet delivery ratio, there are many limitations in this work. The proposed architecture is 2D and a quasi-stationary that is not similar to the real deployment of sensor networks in underwater environments. Also they assume mesh nodes have information about the location of all the sensor nodes, and the sinks and mesh nodes are static that means located in a specified position in a mesh network, this topology is not able to support node mobility in underwater environments. Data overhead and packet redundancy is really high in this work since forwarding data is performed in terms of multi-path and redundant paths in the network.

2.11 Hop-by-Hop Dynamic Based Routing (H2-DAB-2009)

The major difference between Hop-by-Hop Dynamic Based Routing (Ayaz and Abdullah 2009) and some existing protocols is that there is no assumption about the node localization. Localization is a main challenge in underwater network so different protocol uses different techniques such as equipped sensor with such device that can measure depth, pressure, distance and it's or supposes the nodes are static, but H2-DAB is trying to find a solution for node mobility and movement in the real world. The node dynamic address is utilized to solve this problem, so at different depth intervals every node will receive its new address according to its new location. Some specific sensor nodes are anchored at the ocean bottom and the others are located in different depth ROM the surface and bottom of water, different surface buoys are deployed on surface to gather the data packet from the nodes. As it is shown in figure the address of nodes increase as their depth is going down towards the bottom. Assigning a dynamic address to sensors and data forwarding according to these addresses are the major phases of the H2-DAB procedure. Data forwarding starts with a hello packet that is sent by surface sinks and then each sensor node tries to send packets in a greedy way to the sinks.

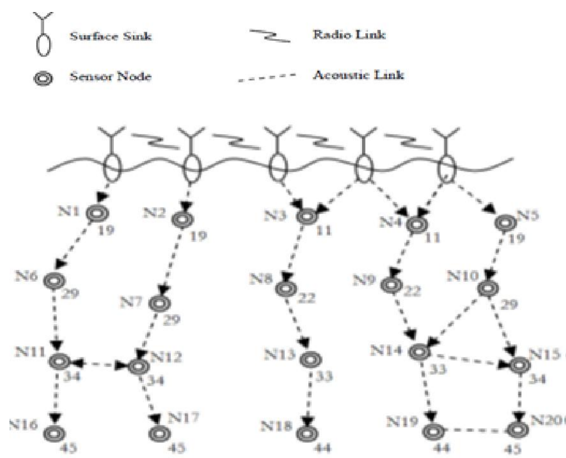

Figure 11: Assigning HopID's with the help of Hello packets

Although there is no need to use any additional device and no network location information but the multi hop routing issue is still available and happen for the nodes that are close to the sink in this routing protocol.

2.12 Temporary Cluster Based Routing (TCBR-2010)

(Ayaz, Abdullah et al. 2010) proposes Temporary Cluster Based Routing to solve the multi-hop routing problem. The mentioned problem occurs when the routing protocols select the nodes near to the sink again and again, so their energy consumption increase it causes these node die sooner than the other nodes. In this proposed protocol multiple sinks are located in a different position on the surface and two types of sensor nodes: ordinary sensor nodes and courier sensor nodes are deployed in underwater.

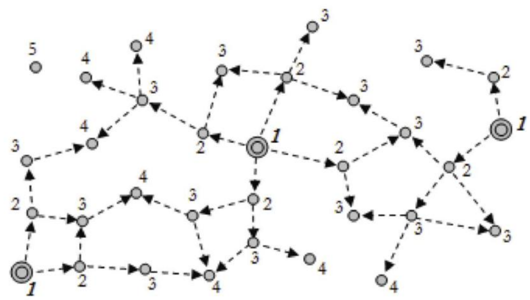

Figure 12: Assigning the HopIDs with the help of Hello packets

The sensor nodes in the data and send monitored data to courier nodes. Then these special nodes sensed received data to the surface sinks. The number of courier sensors is very small in comparison ordinary sensor nodes; a mechanical module resides in courier sensor while they can act as an ordinary sensor too. This module is used to adjust the nodes in different depth and brings them out or inside of the water. When they place at a predefined location, they send a hello packet to their adjacent nodes, by this packet the other nodes are aware of courier presence and begin to send motor data to them. This hello packet forwards only to four hopes so if a node receives a hello packet from two couriers, it will pass it to the other nodes.

Since all the nodes should collect monitoring data and store them in a limited buffer till receiving a courier node, their buffer become full and may miss some new sensed data so this routing protocol in not appropriate for long term application and cause failure in sensing data packet.

3. Conclusion

In this paper routing protocol for underwater sensor network is a major research issue, so three categories of routing protocols for underwater sensor networks are highlighted. After presenting the overview of each routing protocol we mention weakness and advantages of each routing protocol.

The best part that characterized this paper is that fully supported in finding correct routing protocol for underwater sensor network projects and some challenging research projects which should be useful for entire underwater sensor network system.

As a general conclusion we could notice that all of them are energy efficient and scalable, they can handle dynamic networks and most of them require full dimensional localization of the source, the destination and the intermediate nodes.

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