Classification of Routing Algorithms in Volatile Environment of Underwater Wireless Sensor Networks

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***Abstract*:** The planet earth is basically a planet of water with less than 30% land mass available for humans to live on. However, the areas covered with water are important to mankind for the various resources which have been proven to be valuable. Such resources are gas, oil, marine products which can be used as food, and other minerals. In view of the vast area in which these resources can be found, a network of sensors is necessary so that they can be explored. However, sensor networks may not be helpful in the exploration of these resources if they do not have a sufficiently good routing mechanism. Over the past few decades, several methods for routing have been suggested to address the volatile environment in underwater communications. These continue researches; have enhanced the performance along with time. Meanwhile, there are still challenges to deal with for a better and efficient routing of data packets. Large end-to-end delays, high error channel rates, limited bandwidth, and the consumption of energy in sensor network are some such challenges. A comprehensive survey of the various routing methods for the partially connected underwater communication environment are presented in this paper.

***Keywords*:** Underwater Communication, Propagation delays, UWSN, Routing algorithms, Volatile environment.

1. Introduction

Throughout the history of mankind, humans have been influenced either indirectly or directly by the oceans. Applications that make use of wireless underwater sensor networks are gaining popularity in the exploration of areas involving oceans that possess resources, such as gas, oil, products used as food, and other minerals. Underwater wireless sensor networks (UWSNs) are also utilised for the prevention of catastrophic accidents in the ocean, such as pollution on a disastrous level and tsunami warnings. Although UWSNs are similar to wireless sensor networks on land, the UWSNs possess some characteristics that are quite different from the common wired and other land used sensor networks [1, 2]. The first difference is the energy consumption in both types of networks. In the UWSN, not only there shall be no possibility to recharge the battery, it is also not trivially replaceable. Moreover, in underwater transmissions, underwater applications consume more energy than applications that are wire-based [3]. The next difference is that UWSN is normally utilised to rectify some typical issues instead of being used by individual users. The importance is placed on maximising throughput instead of providing fairness among the nodes. The third difference is that for an underwater wireless sensor network, the primary concern is regarding the distance between the links and number of hops, and also the reliability of the network. In concerns to energy, it is preferred to have short term communication rather than long term communication, and it has been proven to be more energy efficient when used in underwater networks applications [4]. Finally, in many situations, UWSNs must be implemented using the existing standards for the economic factors related to operating cost.

The limitations mentioned above mean the protocols for terrestrial ad hoc networks are unsuitable for UWSNs. It is well known that the terrestrial network routing protocols are not good for UWSN. There is a need for a new specifically designed protocol for UWSNs. The unique characteristics of underwater communication conditions have many researchers focusing on creating new designs for routing protocols.
The planning of the rest of the article is as follows. Section 2 presents the brief introduction of basic acoustic communication. The comparison between Terrestrial Wireless Sensor Network (TWSN), Underwater Acoustic Network (UAN) and Underwater Wireless Sensor Network (UWSN) is given in section 3. The classification of routing algorithms is described in sections 4. The comparison of the routing protocols is presented in section 5. Finally, the conclusion and current issues are presented in section 6.

2. Basic Of Acoustic Communication

An acoustic signal is considered as the only feasible medium that works satisfactorily in underwater environments. Although we have a couple of more options in the form of electromagnetic and optical waves, but underwater characteristics and sensor communication requirements have ruled them out. Considering electromagnetic wave, at high frequencies it has very limited communication range due to high attenuation and absorption effect, as measured less than 1 meter in fresh water [5] . Though propagation is acceptable with low frequencies, but at the cost of high transmission power and long antenna size. Recently, electromagnetic modems for underwater communication have been developed, however available technical details are vague [6]. It has been shown that, the absorption of electromagnetic signal in sea water is about $45\times\sqrt{f}$ dB/km, where f is frequency in Hertz [7]. While, the absorption of acoustic signal with the frequencies commonly used for underwater is lesser by three orders of magnitude.

Optical link, even though it is good for point to point communication especially in very clean water, but it is not good enough for distributed network structure due to its short range (less than 5m) [8]. Not only this, also a precise positioning is required for narrow beam optical transmitters. In short, it is not considered as a good choice for long distance underwater communications, particularly when the water is not so clean like shallow water.

On the other hand, acoustic signal is the only reliable and most suitable medium for low cast, ad hoc and densely deployed underwater sensor network. It provides the facility of omnidirectional transmission and distributed channel access with acceptable signal attenuation. Despite all the attractions (relative to electromagnetic and optical waves), underwater acoustic signal introduces a set of new communication challenge. The erroneous acoustic channel faces the problem of temporary path losses, high bit error rate, small bandwidth and large propagation delays. Path losses are not only due to transmission distance, but also depend on signal frequency. Severely limited bandwidth leads to low data rates, which again depend on both the communication range and frequency [9, 10]. Long range systems that operate over kilometers cannot exceed the bandwidth of more than few kHz. On the other hand, a short range system operating over tens of meters can communicate with a bandwidth of more than a hundred kHz. Although, acoustic communications are classified in different categories in terms of range and bandwidth, but it can hardly exceed 40kb/sec at a range of 1 km.

Although the speed of sound is assumed to be constant in most of the situations, but actually it depends on water properties like temperature, salinity and pressure. Normally, the speed of sound is around 1500 m/s near the ocean surface which is 4 times faster than the speed of sound in air, but five orders of magnitude slower than the speed of light [11]. However, the speed of sound increases with the increase in any of these factors including temperature, depth and practical salinity unit (PSU). Approximately, temperature rise of 1°C, depth increase of every 1 km and increase of 1 PSU results to increase the speed of sound by 4 m/sec, 17 m/sec and 1.4 m/sec respectively. The routing schemes that consider these variations are expected to provide better results compared to those which assume uniform speed. The comparison of mediums is given in table 1.

3. Comparison Between Three Types Of Wireless Sensor Networks

The existing routing protocols developed for terrestrial sensor networks are usually divided into two categories, Proactive and Reactive. However, both of these extremes have some problems like, Proactive or Table Driven protocols provoke a large signalling overhead in order to establish the routs, especially for the first time and every time when the topology is modified. So, due to the continuous node's movements, topology changes continuously. Then, if we talk about the Reactive scheme, it's no doubt that protocols belong to this category are more suitable for the dynamic environments, but they incur large delays and also require source initiated flooding of control packets in order to establish the paths. Plus, experiments show that, they give better results when links are symmetrical throughout the network. But for underwater environments, we know that, propagation delays are already high and mostly the links are asymmetrical, so the protocols of the both of these types are not suitable for the underwater networks.

Table1. Comparison of Optical, EM and acoustic waves in seawater environments

	Optical	**Electromagnetic**	**Acoustic**
Bandwidth	~ 10-150 MHz	~ MHz	~ kHz
Frequency band	~1014-1015 Hz	~ MHz	~ kHz
Nominal speed (m/s)	~ 33,333,333	~ 33,333,333	~ 1,500
Effective range	~ 10-100 m	~ 10 m	~ km
Transmission range	~ 1m-100m	~ 1m-100m	~ 50m-5km
Data rate	up to 1Gbps	up to 10 Mbps	up to 100 kbps
Antenna size	~ 0.1 m	~ 0.5 m	~ 0.1 m
Antenna complexity	Medium	High	Medium
Power Loss	∞ turbidity	~28 dB/1km/100MHz	> 0.1 dB/m/Hz

Geographical Routing, where typically routes are not stored, is another promising option for the ground sensor networks. The protocols, use this approach to establish the paths from source to destination by leveraging the localized information of the neighbors. Here each node decides about the next hope based on the information of its neighbor's location and the location of the destination. Its no doubt, in future this technique has much potential, but only for ground based WSN where GPS easily available, because these protocols required accurate localized information, but for underwater networks, it's not easily possible. In fact, GPS uses the waves of 1.5 GHz band and the waves of this range can't propagate in the water environments.

For the wired networks, the routing problems are not complex, as the topology is static, nodes are stationary as well as links are stable. Then, for the ad hoc networks nodes are mobile and links are not stable. An ad hoc or MANET can experience continues and random topological change due to the relative movement of the nodes. Forwarding data across such type of network is not an easy task. Further, a detailed comparison of different characteristics of the terrestrial, underwater acoustic and underwater wireless sensor networks is provided in table 2.

Table 2. Comparison between terrestrial, Underwater Acoustic and underwater WSN

Features	TWSNs	UANs	UWSNs
Architecture	Most of the time 2D	Most of the time 3D	Most of the time 3D
Topology	The topology is static or low dynamic	Topology is dynamic due to movement of nodes by water current	Topology is high dynamic due to continual movement of nodes by water currents
Communication media	Radio waves [4]	Acoustic waves for underwater environment and radio waves for water surface [1, 3]	Acoustic waves for underwater environment and radio waves for water surface [1, 5]
Deployment	Dense deployment due to cheap node price and small area which affects the network performance [2, 7]	It can be dense due to the small size of the network, but depend on the available number of nodes	Sparse deployment due to expensive underwater equipment and the vast area [9]
Position information	Available by GPS	Unavailable by GPS	Unavailable by GPS, because GPS uses high frequency waves which are rapidly absorbed in water [5]
Network components	Terrestrial ordinary nodes, sinks, actors, and base station	Underwater ordinary nodes, sinks, AUV or ROV, and onshore base station	Underwater ordinary nodes, sinks, AUV or ROV, and onshore base station
Frequency	High frequency (MHz, GHz)	Low frequency (Hz, KHz) because high frequency is quickly absorbed in water [10]	Low frequency (Hz, KHz) because high frequency is quickly absorbed in water [10]
Bandwidth	Not only it uses high bandwidth and high data rate, but also bandwidth is fixed in different distances	Bandwidth and data rate are low and they are dependent on distance; short distances have higher bandwidth [21]	Bandwidth and data rate are low and they are dependent on distance; short distances have higher bandwidth [21]
Range	Usually used in small areas	Usually used in small scale areas of water	Usually used in vast areas
Speed of medium	The speed of radio frequency in the air is (3×10^8 m/s) [28]	Acoustic velocity in water is about 1500 m/s [24]	Acoustic velocity in water is about 1500 m/s [24]
Price	Cheap	Cost depends on the size of sensor node and purpose of used	Too expensive, for example, an ordinary sensor costs more than 100USD [2, 25]
Propagation delay	Propagation delay is too low due to employing high speed radio waves as a communication medium	Propagation delay is medium due to the small scale of communication area	Propagation delay is high due to employing low speed acoustic waves as well as large communication area
Path loss	Low path loss	Average path loss	High path loss
Energy consumption	Energy consumption for sending and receiving is low and equal	Energy consumption is medium due to the little bit stability of the water environment	Energy consumption for sending and receiving is too high and energy for sending is bigger than receiving [27]
Wave movement	Disk shape	Spherical in deep water, but cylindrical in shallow water.	Spherical in deep water, but cylindrical in shallow water.
Simulator	Many simulators available such as NS2 [28], OMNeT++ [29], and OPNET [31].	Same as in UWSN	There is not any standard simulator for UWASNs
Sinks position	Everywhere of network and it is always fixed	Located on water surface and it can be fixed	Located on water surface and it usually moves by water current
Routing	Since the nodes are almost stationary, the end-to-end routing is employed	Due to very little movement of nodes, both end-to-end and hop-by-hop can be employed	Due to high movement of nodes in water current, greedy hop-by-hop routing is employed [33]
Prone to error	Links and nodes are low prone to error	Links and nodes are highly prone to error due to high propagation delay	Links and nodes are highly prone to error due to high propagation delay of acoustic waves and corrosion, respectively, [34]
Sensors size	Small size	Medium size	Large size [36]
Hull	Usually made up of plastic	Usually made up of materials such as composite, aluminium	Usually made up of materials such as composite, aluminium, and titanium [38]
Energy scavenging	Usually by solar energy	Same as in UWSN but sometimes it can replace	Usually by Kinetic energy

4. Classification Of Routing Algorithms For UWSNS

The surveyed protocols are classified based on their performance and their specific goals such as delivery ratios, energy efficiency, reliability, mobility, delay tolerance and localisation approaches. This survey also describes the advantages and the limitations of the protocols for each category. Figure 1 shows the classification of the routing methods that are based on these categories. The most cited and the recently proposed protocols are the basis for the selection of these routing methods. This article can provide the new directions for researchers and it can also help to choose the best routing methods for the specific applications. It is important to note that protocols possessing multiple characteristics have been described once in one of the defined categories.

4.1 Protocols Based On Energy Efficiency

Nodes are powered by batteries which have a specific capacity. This means that for UWSNs, a big challenge is the saving of energy. Energy savings are important as it is very difficult to recharge or replace the batteries in this type of environment. Nodes in UWSNs consume more energy than other kinds of wireless sensor networks because of the unpredictable conditions in the underwater environment. Protocols have been described in this section in detail as relate to the issue of energy in UWSNs.

4.1.1 Location-Based Clustering Algorithm for Data Gathering (LCAD)

The primary source of energy usage in communication in underwater situations is the transmission of data packets. The distance between the sender and the receivers is the depending factor for how much energy is consumed. The consumption of energy can be increased as a result of the sensor nodes near the sink generating a huge volume of data. In [12], the authors proposed a solution for these problems in the form of cluster based methods for 3-D UWSNs. The deployment of the sensors is performed at a fixed depth among the nodes throughout the entire network. Multiple cluster heads are used to manage the nodes which are in clusters. The cluster head within the cluster in the network is chosen by using the selection algorithm. The communication type used from cluster to cluster is the horizontal link communication. For the conservation of energy, 500m is used as the maximum transmission range from cluster to cluster. The performance of the acoustic link can be increased by this range of communication. The entire network is divided into 3-D grids in this protocol. Each grid has an area of approximately 30m x 40m x 500m. In order to complete the communication process, there are three necessary phases. The first is the configuration phase; the cluster head is chosen at this time. The second phase is the gathering of data which is forwarded by the nodes within the cluster to the cluster head.

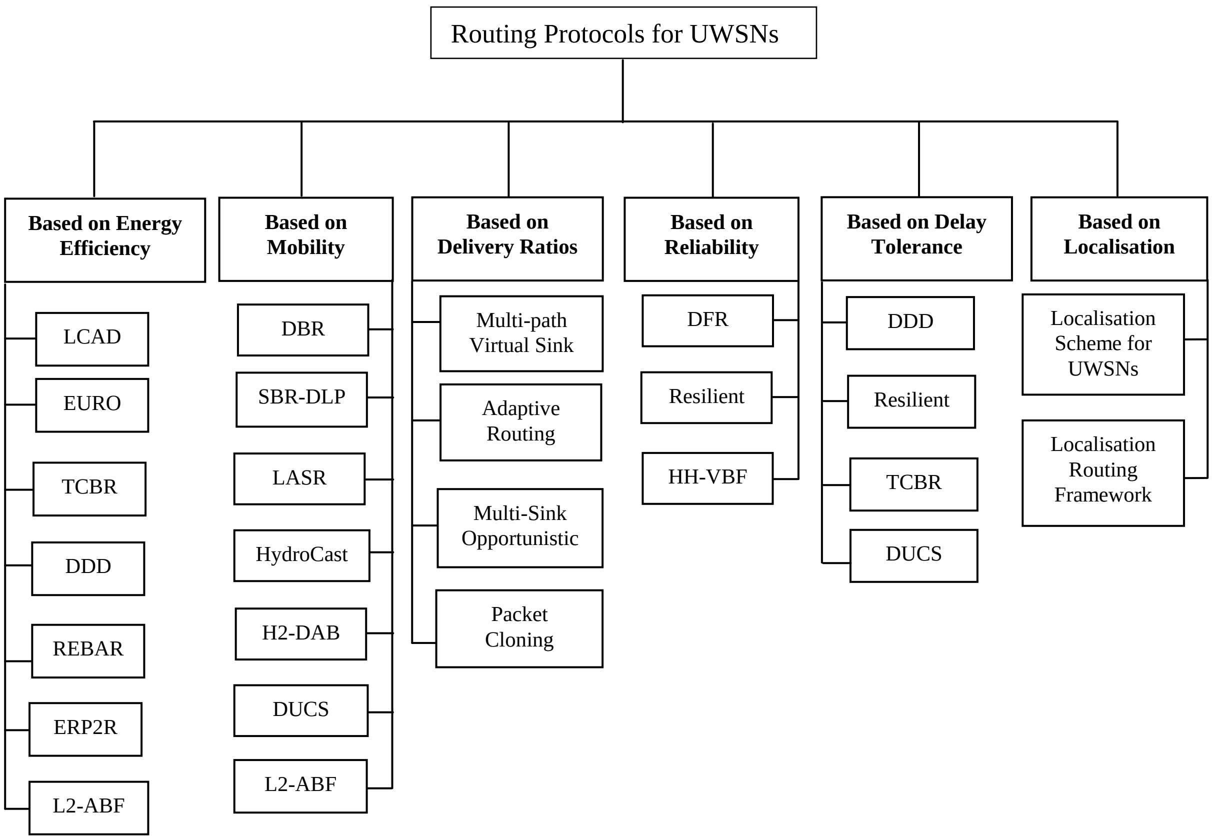

Figure 1. Classification of the major routing protocols for UWSNs

The third phase is the transmission; the data that has been gathered in the cluster heads are transmitted to the base stations on the surface of the water. This is accomplished using Autonomous Underwater Vehicles (AUVs) [17]. No node can take part in choosing cluster heads when additional resources are not available. Therefore, having multiple cluster heads will improve reliability. Moreover, an increased load on the network can be handled. The cluster head is typically situated in the centre of a grid so that communication with other sensor nodes can be achieved. The grids are organised in the same way as the cells in a cellular network. Instead of being able to gather data packets from every node in the network, AUVs can only gather them from cluster heads. This has provided proof that an acoustic link is unsuitable for use at a distance that is greater than 500m. The average depth of the ocean is the depending factor on the number of tiers used. It was suggested by the author that node deployment according to lower tiers and higher tiers is vital to achieve the highest performance.

Some serious performance issues have been noted with the proposed protocol. The manner in which the LCAD performs is dependent on the grid structure, more specifically on the ch-node's position inside it. Considering such a type of structure in the terrestrial sensor networks is not difficult. However, when the environment is underwater, the nodes move frequently making the assumption of such a grid structure difficult as the nodes enter and leave various grids often. In order to analyse the performance of LCAD, it is checked in terms of network lifetime; no information about the movement of the nodes is provided.

4.1.2 Energy-Efficient Routing Protocol (EUROP)

Power efficiency is a critical issue for underwater environments as the underwater sensor nodes are powered by batteries which cannot be replaced easily if at all. In addition, the collapse of the traditional terrestrial routing protocols could result from extremely long delays for acoustic communications because of a limited response waiting time. In [13], an energy efficient routing protocol called EUROP was designed in order to deal with these issues. In their protocol, the authors attempted to decrease a large amount of energy usage by lowering the number of Hello messages that were broadcast.

In the proposed architecture, a pressure sensor was suggested to be used as a significant indicator for each sensor node to get its depth position. This depth sensor would get rid of the need for sending hello messages for purposes of control. This could help to increase energy efficiency. Deployment of these sensor nodes would take place at various depths so that the events happening at various locations of the network could be observed. In addition, each node would be affixed to the bottom of the ocean and fitted with a floating module that could be by a pump. This electronic module would reside on the node and help to push the node up towards the surface of the water and then back down into position underwater. The depth of the sensor node could be controlled by shortening or lengthening the wire connecting the anchor to the sensor. All of the sensor nodes at the various depths would form layers and the number of layers would depend on the depth of the sensors. The sink on the surface would only be able to communicate with the sensors residing in the shallow water. The sensor nodes on each of the layers would communicate by way of an acoustic channel. This communication would take place only after the decision had been made as to which layer the nodes belonged to; this would be achieved by detecting the value of the pressure. RREQ and RREP packets would be used by the sensor nodes so that they could communicate with each other. The next-hop could be determined by the rule of going from deep to shallow and so on.

In terms of communication, EUROP appears to be simple, as many of the control packets are removed when a depth sensor is introduced inside the sensor node. However, it is not just a depth sensor that is required, but an electronic module is also needed for each node so that it can be pushed up towards the upper layer and then pushed back down into its original position. It is not so simple to use the depth sensor and electronic module together. Not only will the cost per node increase, but these two together will also be a burden on the critical energy of the node. This will ultimately reduce the lifetime of the sensor node.

4.1.3 Energy-Efficient Routing Protocol (EUROP)

It is known that water currents result in more difficulty when attempting to communicate underwater. However, in [14], the authors attempted to justify the movement of the nodes as a positive sign in communication underwater. They suggested that it could be supportive in dealing with the energy issue in the network. The reason they provided was that when nodes start to adjust their position around the sink, it would result in a savings of the power of nodes. This would cause the overall energy usage in the entire network to be effected. In this method, the authors presented the solution for controlling the partitioning of the network with the concept of altering the position of the nodes. The nodes that are nearest to the sinks are more likely to die earlier as a result of their frequent participation in the process of communication. A greater amount of energy usage is likely to be caused by wide broadcasting on the network; because of this issue, with the help of a geographic system, nodes in REBAR only transmit data within the specific domain of the source and its destination. This is presented in Figure. 2. Specifically, the communication radii vary for various nodes in regards to the distance between the nodes and the destination. So that the number of chances of being involved in the communication can be controlled, smaller values are used for nodes nearer to the sink. This can help to manage the issue of energy between the nodes. We have come to the conclusion, through the process of analysis, that the concept of altering the position of the nodes in PEBAR possesses some issues. Firstly, they believed that the movement of the nodes is a positive characteristic in communication in underwater environments. It is obvious from the simulation results that with static nodes, the delivery ratios are smaller; they begin to increase as the nodes begin moving.

Secondly, some assumptions are made that each node has knowledge of its own current location as well as the location of its final destination. The result from the simulation showed that they used the movements of the nodes that were fixed from 0 to 4 m/s. This data described that the delivery ratios should be increased continuously as the movements of the nodes increased more than 4m/s.

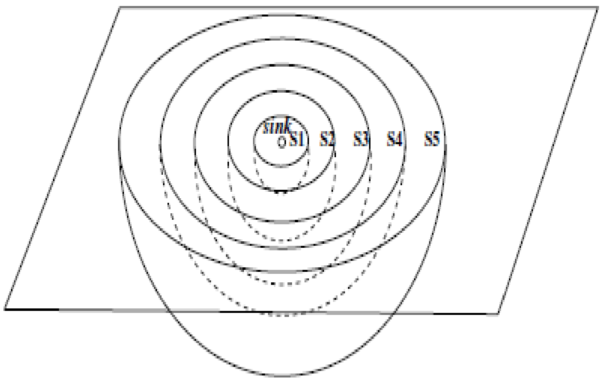

Figure 2. The sphere energy depletion model

4.1.4 Energy-efficient Routing Protocol based on Physical distance and Residual energy (ERP2R)

In [15], the ERP2R protocol (Energy-efficient Routing Protocol based on Physical distance and Residual energy) was proposed on the basis of the physical distance between the nodes going towards the sink. It was assumed that by using the ToA (Time of Arrival), each of the sensor nodes could compute the distances to their neighbours. The same communication range is possessed by each of the sensor nodes in order to complete its task. The task of ERP2R is completed in two stages. The establishment of cost is the first stage. During this stage, a cost is allotted to each sensor node; this cost is defined as its distance towards the sink node. The steps taken are as follows: each sink transmits a Hello packet. Each node that receives the Hello packet computes its distance towards the sink node through the ToA. In this way, each node that receives the message is allotted a cost which is its physical distance towards the sink node. Each sensor node must be allotted a cost because the cost value is used by ERP2R as a metric for forwarding the packet. The Hello packet must be retransmitted, so that each node in the network can be allotted a cost. Therefore, the Hello packet is retransmitted by the nodes. The residual energy and the node's cost are included in the Hello packet of each sensor node. The second stage involves the data packet forwarding. Once the cost establishment has been performed, the node that sent the data packet chooses the forwarding nodes. This can be accomplished because each node has knowledge of the physical distance towards its neighbours and their residual energy. This step is performed as follows. The sender transmits the data packet which includes an ordered list of its neighbours' IDs. Only the IDs of those neighbours having a lower cost than its own cost are included by the sender. Nodes possessing a smaller cost can be considered as being closer to the sink node. Therefore, the transmission of the packet to the nodes with a lower cost result in the packet advancing towards the sink node.

There remain some performance issues with ERP2R although it is simple and energy efficient. One issue is that when the Hello packets are retransmitted over and over again in order to calculate the cost of nodes, it becomes a burden on the network; this results in more energy being used up. Another issue is that the frequent use of the nodes with the lowest physical distances will cause these nodes to die earlier.

4.1.5 Layer by layer Angle Based Flooding (L2-ABF)

A Layer by Layer Angle-Based Flooding (L2-ABF) method has been proposed by the author in [16]. In this proposed routing protocol, the angle-based flooding method is used. This mechanism for routing is not based on data regarding the location of the sensor node. It has, however, been designed for delay and energy-efficient multi-layer communication in underwater acoustic networks. There is no need in this routing mechanism for the sender node to have knowledge of its own location or the location of the final destination (Sink) before broadcasting the data packets. The sensed data are flooded towards the surface sinks by the anchor nodes by way of the upper layer nodes by using the initial base angle of θ=90 ±10K. The K has a finite set of values K {1, 2…..8}. If there is no ACK from the nodes receiving the packets, then the value of K in the initial angle is increased so that its flooding zone is increased until the basic condition is met ($0 < \Theta < \pi$) using the power level P1. The values of K will be chosen by the nodes according to the movement of the nodes.

If there is no ACK from any receiving node after completing one angle incremental round at power level P1, the node will use its power level P2 to increase the length of the flooding cone and the same procedure will then be repeated. P = P1, P2……Pn-1 are the maximum power levels. In this case, "n" is the variable that has a finite set of values which is 100.

It is claimed by the author that this scheme is better for handling the end-to-end delays as well as obtaining a good result in the consumption of energy; however, the calculation of the flooding cone repeatedly to determine the next forwarder of the data packets can result in greater energy consumption. As a result, the entire network can be affected in terms of its performance.

4.2 Protocols Based On Energy Efficiency

This section describes the protocols which consider mobility as a task that is quite challenging. In UWSNs, the mobility of the nodes is quite a challenge for routing protocols to deal with. Because of the movement of the nodes, the network topology is continually being altered. This can result in various kinds of delays, long data routing paths and greater consumption of energy. In these routing methods, the authors attempt to deal with the movement of the nodes using various concepts and methods. Some of them consider mobility as a positive sign. These protocols are presented as follows.

4.2.1 Depth-Based Routing (DBR)

In [17], the DBR (depth-based routing) protocol has been proposed. It is based on a specific kind of hardware. At times it uses assumptions to perform its task. With DBR, comes the introduction of the flooding-based architecture. The data regarding the depth of the nodes that have been deployed are used to carry out the flooding process so that the data packets can be forwarded. A special sensor that is intricate to the node is used to calculate the depth information of that node. The proposed method does not require localization, which is quite expensive for UWSNs. The depth sensors are applied for gathering the data regarding the depth of the sensor nodes.

The nodes calculate their own depth information in DBR and then forward this information in the data packet. The node that receives the data packet only transmits it if its depth is not greater than the depth of the sender without using the entire localised data. Only the local depth information is needed by the protocol. This depth information is not difficult to obtain. This is because the authors suggested that each node be equipped with a low cost depth sensor. The results of the simulation show that DBR can achieve high packet delivery for dense networks at a low cost.
DBR possesses several advantages because it has no need for full dimensional location data. One advantage is that the movement of the nodes caused by the water currents is dealt with in an efficient manner. Moreover, the multiple sink architecture has taken advantage of. However, there remain serious issues to be solved. The first issue is that DBR possesses only a greedy mode. This greedy node by itself cannot achieve delivery ratios that are very high in sparse areas. In areas such as these, the situation may be that there will not be any node suitable to be a forwarding node as a result of the nodes having a greater depth as compared to the transmitting node. Therefore, more and more attempts will be made by the current node. While a few nodes, which could send packets towards the data sink successfully, may be available at higher depths, no mechanism is available for dealing with situations such as these. As a result, the protocol may not perform as well in sparse areas. The second issue is that using a broadcast fashion to forward the data packets can cause the network to suffer from a performance that is decreased. Some authors have even introduced a mechanism that will allow two or more nodes to be nominees for the transmitting the same data packet further; however, the question remains as to which node will be suitable for this. Yet, because of these transmissions, continually, more nodes will get the data packets. Because of the packets being received, the nodes must calculate their depth each time; therefore, the limited energy available is used inefficiently. To be concise, areas of high densities and areas that are very sparse are both challenging issues in DBR. When the densities increase, they not only cause an increase in the usage of the energy, but also result in complexities that can cause the memory to be used inefficiently.

4.2.2 Sector-based Routing with Destination Location Prediction (SBR-DLP)

The proposed SBR-DLP protocol (sector-based routing with destination location prediction) uses the flooding-based architecture [18]. The network topology in this protocol is divided into sectors. The flooding only takes place inside the sectors. Sectors are selected based on how close the sectors are to the target. This is presented in Figure 3. SBR-DLP uses a mobile sink node while each of the other sensor nodes has knowledge of the movements of the sink node, which have been planned ahead of time. Each time the mobile sink nodes attempt to move in a way that deviates from their planned route, the mobile sink nodes transmit notification packets to their one hop neighbours. The decisions in SBR-DLP are made based on the sender nodes as to which of them will become the next transmitter of the received data. If the pre-planned movement of the nodes is assumed, SBR-DLP has some advantages on the destination mobility. However, some serious problems can be produced when this assumption is made. One such problem is that the flexibility of the network is lost. Another such problem is that the location of the destination nodes can be altered as a result of the movement of the water current.

4.2.3 Location-Aware Source Routing (LASR)

UWSNs vary in many ways from the technology of land-based sensors, which has been previously discussed. One way they vary is that radio communications are unsuitable for use in deep water environments; therefore, they must be exchanged with acoustic communication. Acoustic communication in water possesses a data rate that is very low, but has high latency as compared to a radio channel. Higher bandwidths are required by these protocols for routing, which causes large end-to-end delays. Moreover, they are unsuitable for such underwater environments. Another way they are different is that sensor nodes are thought to be static most of the time; however, sensor nodes used underwater can move up to 1-3 m/Sec as a result of various activities underwater [19].
These major variations in the two environments have brought about questions concerning the performance of acoustic network when using protocols created for land-based networks.

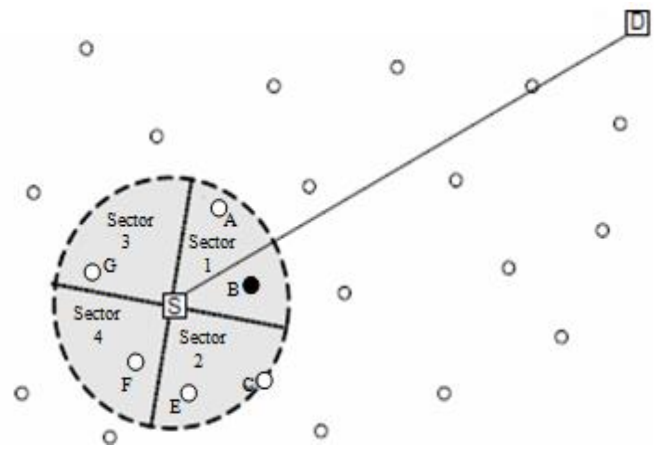

Figure 3. Forwarder selection at the sender

A well-known routing protocol, DSR (Dynamic Source Routing), [20] was initially intended for MANET; however, it has the disadvantage of possessing high latency when used in the acoustic underwater environment. In such situations, the rate of the change of the topology is very high as compared to the acoustic latency. As a result, there is a continuous alteration of the topology at a rate faster than DSR can adapt to. [21] proposed LASR, a modification of DSR, so that this issue could be solved without losing the

DSR experience. LASR implements two methods to deal with the acoustic channel's high latency. A link quality metric is the first method and location awareness is the second method. DSR is dependent on the shortest path metric only; in highly mobile networks this causes the performance to be poor. This shortest path metric is replaced in LASR with an expected transmission count (ETX). With EXT, more informed decisions are ultimately provided by the link quality metric. This provides improved pathways through the network. The incoming transmissions provide for the location awareness which helps to estimate the topology of the local network. A tracking system is used in topology prediction so that the current position of other vehicles in the network can be predicted on the basis of range only and one way measurements. All of the detailed data of the network are transferred through the protocol header. This data encompasses the data about the topology and the routes.

LASR remains dependent on the source routing method that is inherited from DSR even though it has been through all these modifications. Hence, the packet header gets bigger with the increase in the hop count between the source and the destination. As a result of the increased header size, there is overhead for the acoustic communication that possesses a narrow bandwidth.

4.2.4 Pressure Routing for Underwater Sensor Networks (HydroCast)

Geographic methods are more desirable for use in UWSNs. Their stateless characteristics make them so. However, they are dependent on the distributed localisation of their mobility. This can be quite expensive in regards to the consumption of energy. It can also cause problems for convergence. The author in [22] proposed the HydroCast (hydraulic pressure-based any cast) routing protocol to provide a geographic routing solution alternative. It works, with the clustering of the nodes, on the basis of the depth data of the sensor nodes. During the process of the formation of the clusters, the selected clusters do not need to hide the terminal nodes. The mechanism in [23] was introduced as the local-maximum recovery. Only restricted flooding can be performed by the node in the local maximum. Only nodes existing on the surface of the local maximum are able to take part in the process of data flooding. A tetrahedralization approach is used to determine the presence of nodes on the surface area of the local maximum. The tetrahedralization approach describes that a node surrounded by its neighbours is a non-surface node; all other nodes are considered surface nodes. After locating the surface nodes, the packet is forwarded from one surface node to another surface node and then to another until, after some number of iterations, the data packets have been transmitted to the node where there is restoration of the greedy mode. HydroCast has successfully removed the issue of the void regions in DBR. While the results of the simulation have demonstrated that a high data delivery ratio is produced by HydroCast with only a small amount of end-to-end delay, there is no data regarding the consumption of energy in the clustering of the processing nodes in order to determine the pressure depth.

4.2.5 Hop-by-Hop Dynamic Addressing-Based

The H2-DAB (hop-by-hop dynamic addressing-based) protocol with multiple sinks was proposed by the authors in [24]. It makes use of the flooding-based method with the notion of using special Courier nodes and the distinctive IDs of the sensor nodes. Each sensor node in H2-DAB possesses an assigned ID. Calculation of the distance (number of hop counts) from the surface to the bottom is performed using the hop ID.

The proposed algorithm begins to work by transmitting hello packets. All of the sink nodes perform this action. The nodes receive their hop IDs when the hello packets are received. Numbers of two digits are contained in the hop ID. Figure 4 shows this. The distance (in terms of the number of hops) between the nodes and the sinks is represented by the first digit. The number of hops from other sink nodes is represented by the second digit. Only the record of two sink nodes is contained in each sensing node. Initially, the source node transmits a packet of inquiry; then, it sends out the data packets. When this inquiry is received by all of the neighbouring nodes, they reply to it. There are two kinds of addresses provided by the reply to these inquiry packets. The hop ID is the first and the neighbour's node address is the second. Data packets can only be transmitted by the nodes with the smallest hop ID. In concern for the saving of energy, the nodes shut down their transceivers after the data packet has been transmitted and go into the resting mode [25]. The procedure is the same for the next try at transmitting the data. With each transmission, the nodes receive new IDs using the inquiry packets. These IDs are given in relation to the new positions. The author states that this approach is more tolerant in dealing with the mobility of the nodes. Moreover, there is a good result in the consumption of energy. However, by retransmitting the hello packets over and over again, the performance of entire networks can be affected.

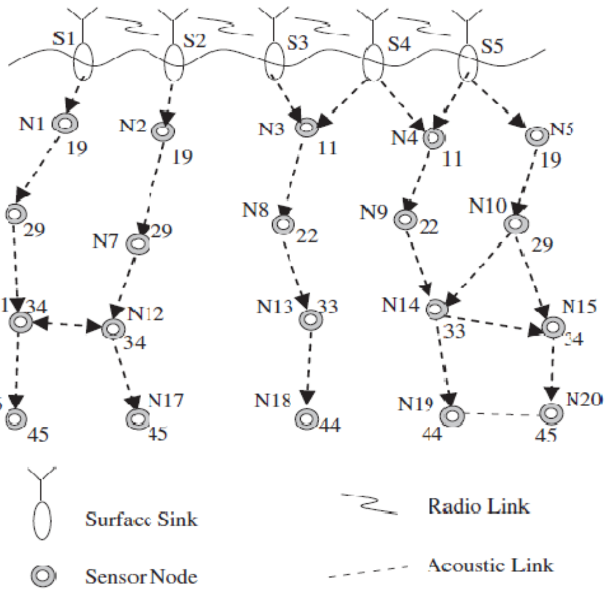

Figure 4. Assigning Hop ID's using Hello packets [24]

4.2.6 Distributed Underwater Clustering Scheme

A major concern for UWSNs is the efficient use of energy. Batteries with a limited amount of power are used by the sensor nodes. These batteries are both difficult to recharge and replace in environments such as these. Designing a scalable and energy efficient routing protocol for these types of networks is an underlying problem. A distributed energy aware and random node mobility supported routing protocol was presented in [26]. It was named the Distributed Underwater Clustering Scheme (DUCS) and was developed for applications that are long term and non-time critical

The entire network is separated into clusters using a distributed algorithm in DUCS which is an adaptive protocol that is self-organising. Local clusters contain organised sets of sensor nodes with one node being chosen as a cluster head for each cluster. The data packets are transmitted to the respective cluster heads by all of the nodes that are not cluster heads. Only a single hop must be used for this transmission. The cluster head carries out a signal processing function, like aggregation, on the data it has received in the data packets from each of the cluster members. Then, it forwards this data towards the sink by making use of multi-hop routing by way of other cluster heads. The cluster heads have the responsibility of not only coordinating transmission among the members of their clusters (intra-cluster coordination) but also communicating with each other (inter-cluster communication). The cluster head is selected by using a randomised rotation among the various nodes of the cluster so that draining the battery of a specific sensor node too quickly is avoided. Two rounds are utilised to complete the DUCS's operation. The *set-up* is the first round. In this round, the network is separated into clusters. The *network operation* is the second round. In this round, the transfer of the data packets is completed. In this second round, several frames are sent to each cluster head. Each of the frames consists of a series of data messages that are sent by the regular sensor nodes to the cluster head following a schedule. It has been found, in the results of the simulation, that DUCS achieved a high packet delivery ratio and considerably decreased the network overhead. Consequently, throughput also increased continually.

DUCS is easy to implement and energy efficient; however, there are a few problems with its performance. Firstly, the cluster life is ultimately decreased by the movement of the nodes with the movement of the water currents which have an effect on the clusters' structures. Sectors being divided frequently pose a burden on the network because the *set-up* round is repeated again and again. Secondly, in the round of the *network operation*, a cluster head can only broadcast the data that it has collected towards another cluster head. Water currents are again the problem as they can cause two cluster heads to move away from each other so that they have no direct communication; although, there could be a number of non-cluster head nodes available between them.

4.3 Protocols Based On Delivery Ratios

In order to increase the reliability of any kind of network, the packet delivery ratio is an extremely important factor. In UWSNs, the delivery ratios are more exaggerated because of the mobility of the nodes and the network's dynamic topology. In most situations, nodes are thought to be static; however, in reality, nodes can move as much as 1-3m/Sec as a result of the moving water currents. These currents can cause rapid changes in the topology of a network. The protocols which have been created to improve the delivery ratios for real time situations and specific task oriented applications are presented in this section.

4.3.1 Multipath Virtual Sink Architecture

The topology of a network is vital in order to determine the capacity, energy usage and reliability of the network. The network must possess enough robustness and redundancy so that there is an assurance that it will not fail to work even in a situation where quite a bit of the network is not functioning correctly. Based on these facts, Multipath Virtual Sink architecture was proposed so that a robust network could be developed [27]. The entire network in the proposed architecture is separated into clusters of sensor nodes. Each cluster has either one or more local aggregation points. A small mesh network is built from these aggregation points. The network joins with local sinks. This network is presented in Figure 5. The assumption, in this situation, is that local sinks are joined by way of high speed links (e.g., RF communications) to a network that contains more than enough resources to take care of the communication requirements of various applications. This architecture was developed with the main goal being the assurance that any one or more of these local sinks, which collectively form a virtual sink, have received data packets.

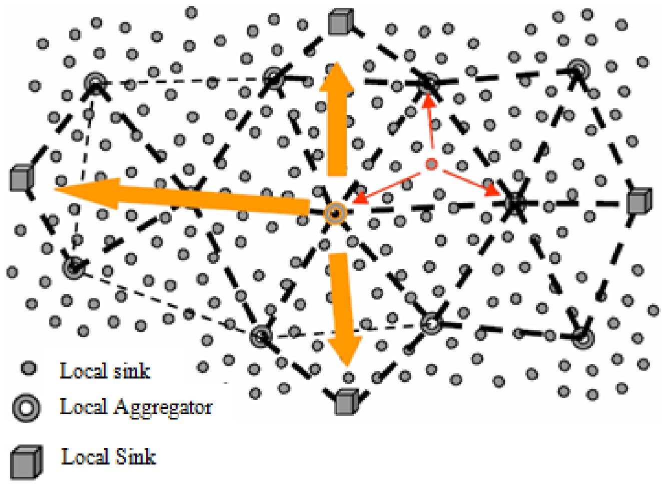

Figure 5. Proposed underwater network topology for the Multipath Virtual Sink architecture

The acoustic channel is sporadic, in regards to connectivity, and only small bandwidths are available; therefore, sensor nodes are better off if they cache their sensed data. They can then send the data when the conditions of the channel have more suitable rather than tried to send the data over and over again. Rather than using the caching method, the system will try to transmit delay sensitive data packets through several routes which increase the probability of the data being delivered successfully. The local aggregation points create a wireless mesh network, which possesses several routes that can reach the various local sinks. Each sink transmits a hop count message so that it can identify itself. Each of the sensor nodes, upon receiving this message, will update its hop count value. Then, it will retransmit the message after increasing is valued by an increment of one. A sensor node, wanting to send a data packet, can transmit the packet towards any local sink that is connected to it by way of the previous hop. It does this repeatedly.

4.3.2 Adaptive Routing

UWSNs are easily divided because of the continuous mobility and the sparse deployment of the nodes. This results in a constant path from a source to a destination being unavailable. As a result, UWSNs can be seen as Intermittently Connected Networks (ICNs) or Delay/Disruption Tolerant Networks (DTNs). Traditional routing methods are typically unsuitable for ICNs and DTNs because data packets will be dropped if there is no route available. In addition, a USN is often necessary for distinguished packets to be delivered according to varying application requirements. Hence, designing a smart routing method, which is able to handle various application requirements in an adaptive manner, is desirable.

To accomplish this, a new routing method named Adaptive routing for underwater Delay/Disruption Tolerant Sensor Networks was proposed in [28]. In this method, decisions regarding routing are considered according to the features of the data packets and the conditions of the network. This protocol is aimed at satisfying various application prerequisites as well as achieving a suitable trade-off among the end-to-end delays, delivery ratios and consumption of energy for every data packet. The packet emergency level and packet age, as well as the density of the neighbours around a node and the node's battery level are all used to calculate the packet priorities. The various numbers of message copies are generated according to the features of the network and the data packets; this is the novelty of their work. All of the elements in the data are variable except for the emergency level. In this way, the protocol can be made flexible according to the conditions it is under. The entire routing spectrum is divided into four states. The routing is performed according to the results that have been calculated. The results of the simulation show that a strategy like this can satisfy various application prerequisites. Examples of such prerequisites are the average end-to-end delay, delivery ratio and consumption of energy. However, these priorities are calculated separately by the proposed approach for each of the data packets after they are received. These kinds of calculations necessitate highly frequent communication with the neighbour nodes. This can become a burden on the energy of the node; on the other hand, it can aid in the enhancement of end-to-end delays.

4.3.3 Multi-Sink Opportunistic Routing Protocol

A Multi-Sink Opportunistic routing protocol for underwater mesh networks was proposed in [29]. A tiered architecture was defined in the deployment of the USNs. An acoustic mesh network is positioned between the central monitoring system and the underwater network. It behaves as the sensor nodes' backbone network. For shallow-water coastal areas, a quasi-stationary 2-dimensional UWSN architecture has been considered. Five kinds of elements make up this architecture. These elements encompass an ordinary regular sensor node, a mesh node, a UW-sink, a surface buoy and a centre used for monitoring. Among these, the surface buoy is situated on the surface of the ocean while the mesh node, sensor node and UW-sink are affixed to the sea bed. In addition, the surface sink and the UW-sink are joined by a wire. The central monitoring system used is situated onshore and is hooked up to the internet. A mesh node is more sophisticated in comparison with an ordinary sensor node in that it has a larger memory capacity, a longer range of transmission and greater processing power. An underwater man controlled vehicle is utilised so that these mesh nodes can be recharged helping the network last for a longer period.

Each sensor node sends the data it has sensed to the nearest mesh node upon observation of the occurred phenomena. First, the mesh nodes aggregate the data they have received. Then, they transmit the data to the UW-sinks through a multi-hop acoustic channel. Finally, after the packets have been aggregated, they get sent to the sinks at the surface; from there, they are sent to the onshore monitoring system by the buoys on the surface of the water. The proposed approach is known as a best effort protocol; it transmits data packets along redundant and interleaved routes. The source node broadcasts the data packets at the same time, but not in order, over several UW-sinks situated at various locations. This protocol is unlike the opportunistic routing as it takes advantage of the duplicated packets to enhance the ratio of the packet delivery.

Nevertheless, there are some serious issues related to performance with the proposed routing protocol. Firstly, the assumption is that each mesh node has data regarding its neighbours as well as all of the UW-sinks. The data are, such as the IDs and geographic locations of the nodes. Secondly, a quasi-stationary network was considered by the authors, not an entire mobile network. For this reason, they assumed that the mesh nodes as well as their neighbours were almost static; however, in all practicality, the situation can be quite different. Furthermore, redundant and interleaved routes are used to transmit the packets. In this way, several copies of the same packet can be created and the number of these copies will continue to increase with the increase in the number of hops along the route.

4.3.4 Packet Cloning

It is possible, in mobile sensor networks, that multiple routes can be present going from a sensor node to the final destination. These routes can be either joint or disjoint. Routing over these multiple routes has been seen to aid in the enhancement of the ratios of data delivery as well as the achievement of quick deliveries. As these routes begin to meet up at the destination, there is the chance that contention will also begin to increase. However, this contention that comes about among the nodes which are close to each other can be seen in a positive way. In order to take advantage of the closeness of the nodes, a Packet Cloning method was proposed [30]. This method aids in the enhancement of the ratios of the data delivery. The proposed method makes use of this concept to clone data packets, selectively, during the process of forwarding the packets to the destination. The controlled broadcast or conventional multi-path routing has duplicate packets that cannot be differentiated as the participating nodes do not have any knowledge as to the number of duplicates being introduced. This is different from the proposed method which is able to adjust the number of data packet clones according to the quality of the link and the conditions of the channel. This enables it to decrease, to the minimum, the contention and energy consumption.

During the process of cloning the packets, if a relay node has already received one copy of an incoming packet, it will not retransmit the packet. Excessive network traffic is avoided in this way. On the other hand, the advantage of having two different copies of one data packet being transmitted along two disjoint routes is attractive to the authors who want to make use of it. To take advantage of the situation, different copies of the original data packet are generated. How many distinct copies are to be made is an adjustable parameter which is altered in relation to the particular conditions of the situation. First, the number of distinct copies wanted will be determined by a source node. After the copies are generated, the node will begin to transmit each copy in order with a particular amount of time between each transmission. The packet header contains data regarding the number of copies that has been generated and which copy the received packet is. When an intermediate relaying node has received a clone packet, it can get some data from that incoming data packet. The data gleaned from the header is helpful in detecting the copies and the number of packets lost. When copies of the same packets are received, they are simply discarded; when new packet clones are received they are relayed further along the route; and when packet clones are missing or lost, they are generated and transmitted further along the route. When the packet cloning is performed by a source node, each clone is transmitted after the node has chosen a proper value for the interval. This depends on the physical parameters of the channel. In this way, there is a reduction in the possibility that there will be any contention among the clones or that they will interfere with each other.

The network robustness is increased by using multipath routing approaches. It is increased in one way because of the increase in the delivery ratios and in another way by the decrease of end-to-end delays. However, the acoustic channel uses up power more greedily than compared to the RF based. More and more routes are suggested so that the delivery ratio can be increased; however, these multiple routes continue to generate duplicates if the quality of the channel is low. To be precise, these approaches can be supported by RF-based communications; however, for an acoustic environment that uses up a high amount of power, methods such as packet cloning are not very affordable.

4.4 Protocols Based On Reliability

With any type of communication, reliability is a challenging issue. However, in environments located underwater, delivery of the sensed data to the sink on the surface, reliably, is even more of a challenging task than it is to send the data that has been collected to the control center. In sensor networks used terrestrially, multiple routes and packet redundancy are taken advantage of so that reliability can be increased. For UWSNs, approaches based on packet redundancy are being proposed by many authors; however, for underwater environments that have limited resources, methods such as these are not very affordable. Usually, reliability is provided by rebroadcasting and acknowledging messages as this recovers lost data packets; however, these actions cause an increase in traffic and large end-to-end delays. The proposed algorithms, promising the reliable sensed data in UWSNs, are described in this section.

4.4.1 Directional Flooding-Based Routing (DFR)

A lot of overhead is required to establish routes in UWSNs. This overhead is in the form of control messages. Additionally, reliability is degraded by conditions that are dynamic and have a high rate of packet loss; these conditions cause increased retransmissions. Routing protocols that presently exist were created to enhance reliability, but do not take into consideration the quality of the link. Because of this, the data packet delivery cannot be guaranteed. This is especially true if a link is prone to error. [31] proposed the Directional Flooding-Based Routing (DFR) protocol, so that reliability could be improved. Basically, DFR is a method used to flood packets; this increases the reliability. A restricted number of sensor nodes participate in this procedure for a particular packet. This prevents the entire network from being flooded. Furthermore, the nodes that forward the packets are chosen based on the quality of the link. Moreover, the void problem is handled by DFR, which allows at least one node to take part in the process of data transmission.

Figure 6 shows the flooding zone, which is determined by the angle between FS and FD; F is the node receiving the packet, and the source and destination nodes are represented by S and D, respectively. Upon receiving a data packet, F makes a decision, in a dynamic manner, regarding the further transmission of the packet. It accomplishes this by making a comparison of the ∟SFD with a criterion angle for flooding. This angle is called BASE_ANGLE and is included in the packet that F received. The BASE_ANGLE is altered in a hop-by-hop fashion related to the quality of the link so that it can deal with the high and dynamic packet error rate. This helps, dynamically, to locate a flooding zone, i.e., the better the quality of the link, the smaller the flooding zone.

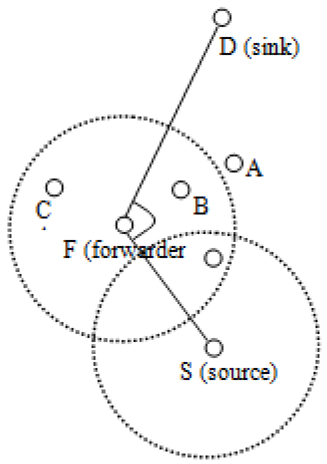

Figure 6. An example of a packet transmission in DFR

The number of nodes selected as the next hop upon the completion of the flooding of the data packets is the depending factor for the performance of DFR. The issue of a void area is dealt with by ensuring that at least one node takes part in this process; however, in locations that do not have a good link quality, more than one node can send the same data packet. This means that more and more nodes will join the flooding of the same data packet. As a result, it will ultimately lead to an increased consumption of the network's critical resources. Secondly, on one hand, the issue of the void has been controlled by choosing at least one node to transmit the data packet to the sink. On the other hand, if a transmitting node is unable to locate a next hop nearer to the sink, DFR will still face the issue of the void. This is because there is no mechanism available to transmit the data packet in a backward direction.

4.4.2 Vector-Based Forwarding (VBF)

In [32], because the high probability of errors is a major issue for dense networks, the authors proposed a position-based routing method called VBF to deal with this problem. In VBF, data regarding the state of the sensor nodes are unnecessary, and during the transmission of the packet only a small number of nodes participate. Redundant and interleaved routes are used for the transmission of the data packets from the source to the sink. This aids in dealing with the issue of node failures and packet losses. The assumption is that each node is already aware of its own position, and that each packet brings with it the position of each of the participating nodes; this includes the source, transmitting nodes and final destination. In this case, the concept of a vector, like a virtual routing pipe, is proposed and each of the packets is transmitted by way of this pipe from the source to the destination. Messages are able to be transmitted from the source to the destination by only the nodes nearer to this pipe or "vector". Utilising this concept can not only significantly reduce the network traffic but it can also make it easier to control the dynamic topology.

However, there are some significant issues found with VBF. One issue is that they have made use of a virtual routing pipe from the source to the destination. The designing of a pipe such as this can have an effect on the efficiency of the routing in the network possessing various node densities. If nodes are deployed too sparsely in some areas or become sparser as a result of the movements of some nodes, while it is possible that routes may exist outside the pipe, there are not many nodes if any that lie within that virtual pipe. As this pipe has the responsibility of transmitting the data, in the end, this can result in only a small amount of data packets being delivered in sparse areas. Another issue is that VBF is very sensitive in regards to the routing pipe radius threshold and this threshold can have a significant effect on the routing performance. Furthermore, in real protocol developments, characteristics such as these might not be desirable. Moreover, the battery power of some nodes along the routing pipe may be used up because the nodes must transmit the data packets from concrete sources to the destination over and over again. Besides these issues, VBF also has a lot of overhead in terms of communication. This is because of its 3-way handshake nature during the communication process. Moreover, it does not take into consideration the quality of the link.

4.4.3 Hop-by-Hop Vector-Based Forwarding (HH-VBF)

An improved version of VBF was introduced in what is known as the Hop-by-Hop Vector-Based Forwarding [33]. This improved version was developed to increase robustness and solve these issues. The authors utilise the same idea of the virtual routing pipe as is used by VBF. However, rather than making use of one pipe from the source to the destination, HH-VBF determines a per hop virtual pipe for each transmitting node. In this way, each intermediate node comes to a decision regarding the pipe direction on the basis of its own current position. This action means that their neighbours have access to at least a small number of nodes. HH-VBF can locate a route for the data delivery as long as a single node is available in the transmitting route within its range of communication. HH-VBF has been shown to produce significantly better results for the packet delivery ratio, especially in sparse areas as compared with VBF. This is evidenced by the simulation results. However; the routing pipe radius threshold remains an inherent issue that can cause performance problems. Furthermore, because of its hop-by-hop nature, HH-VBF generated quite a bit more signalling overhead when compared to VBF.

4.5 Protocols Based On Delay Tolerant Applications

The protocols proposed for applications that are delayed tolerant are described in this section.

4.5.1 A Mobile Delay-tolerant Approach (DDD)

Acoustic channels require higher energy usage than radio signals. Because of the high consumption of power with the acoustic modems, conserving energy in UWSNs becomes even more crucial as compared to traditional sensor networks. A Delay-tolerant Data Dolphin (DDD) approach for delay tolerant applications was proposed in [34]. It was proposed to enhance the energy efficiency in underwater environments that are resource constrained. DDD takes advantage of the movement of collector nodes known as dolphins to gather the data sensed by the stationary sensor nodes. The proposed approach prevents the multi-hop communication energy expense. Moreover, the sensor nodes are only required to transmit their collected data directly to the nearest dolphin as it gets into their communication range.

In the proposed architecture, sensor nodes that are stationary are deployed on the bottom of the sea in the entire area of interest. Data is gathered by these static nodes from the environment. After being processed, this sensed data is stored locally. These sensors wake up from time to time to perform their task of sensing and for event generation. The acoustic modem is based on two elements. The first element is for acoustic communication with the closest dolphin. The other element is a low power transceiver that is for determining if there are any dolphin nodes present (a special signal is transmitted from the dolphin for this purpose); it also triggers the first one. Other than the sensor nodes, several dolphin nodes are utilised to gather the data packets when they come to within the one-hop range of any of the scattered sensor nodes. Their movement can be either random or controlled in relation to conditions of the network. A dolphin node transmits beacons to introduce their presence in the area. The same acoustic frequencies that are compatible with the low-power sensor modem are used to broadcast the beacons. Advertising period t is altered in relation to the deployment, communication range 'r' of the sensor nodes and the speed of the dolphin 'v'. Finally, the collected data packets are delivered by the dolphins as soon as they come to a base station on the surface.

In order to evaluate the performance of DDD, the most important parameter is the quantity of dolphin nodes. If there are not enough dolphin nodes, they will be unable to collect all of the data packets from the sensor nodes. Dolphins move in a random manner so it is quite possible that some sensors will not be visited directly. This would result in existing data packets being lost as they are removed when there is no space left in the limited memory of the sensor node. If the number of dolphin nodes is increased, like as used in the simulation results with 7 dolphins for 25 sensor nodes, then a major issue is the cost.

4.5.2 Temporary Cluster-Based Routing (TCBR)

There have been a lot of multi-hop routing protocols proposed for USWNs; however, the majority of these protocols come across the issue of nodes around the sink consuming more energy. This extra usage of energy means that the nodes will fail earlier than expected. [35] Proposed a Temporary Cluster-Based Routing (TCBR) algorithm to deal with this problem and make the consumption of energy equal throughout the entire network.

There is deployment of multiple sinks on the surface of the water in the TCBR architecture. As a result, if any sink receives a data packet, the packet is considered to have been successfully delivered. This is because, with the help of radio communication, they are able to communicate at a higher bandwidth and with only a small propagation delay. Two kinds of nodes are utilised; they are ordinary nodes and special nodes called Courier nodes. An ordinary sensor node is utilised to sense the event that is occurring, collect data and try to send these data packets to a Courier node in close proximity to itself. Only a small number of Courier nodes (2% to 4% of the total sensor nodes) are utilised. They are able to sense as well as receive data packets being transmitted from the other regular sensor nodes. They can also send these packets to a sink on the surface. These Courier nodes have a built in mechanical module that aids in pushing the node down through the water at a variety of predetermined depths. It then pulls the node back up to the surface of the ocean. This is accomplished using a piston that has been installed in the module to create both positive and negative buoyancy. These Courier nodes will reach various depth levels and then stop for a certain amount of time. After coming to a preset location, they will transmit hello packets so that the regular nodes in their close proximity become aware of their presence. Only 4 hops can be used to transmit these hello packets. If an ordinary node gets them from more than one Courier node, it will then send the data packet to the Courier node nearest to itself within a defined amount of time that has been included in the hello packet.

Rather than supplying the mechanical module with every sensor node, TCBR completes its job of making energy consumption equal throughout the entire network by requiring only a minimal number of Courier nodes. Nevertheless, data can be picked up when a courier node gets to the communication range of each sensor node. Because of this, on one hand, the generated data packets of each of the sensor nodes will be kept in the node's limited buffer until a Courier node visits it. On the other hand, applications that are time critical cannot utilise TCBR.

4.5.3 A Resilient Routing Algorithm for Long-term Applications

For communication underwater, various issues are dealt with on different layers. For example, most of the problems regarding an acoustic channel are found on the physical layer; however, issues involving temporary losses of connectivity, limited bandwidth and failure of nodes must be dealt with on higher layers. By taking this phenomenon into account, a resilient routing algorithm for applications involving long-term underwater monitoring was proposed [36]; it uses two stages to complete its task. In the first stage, the most favourable node-disjoint primary and backup multi-hop data routes are determined so that the consumption of energy can be reduced. This is necessary because unlike the sensor networks for land use where nodes are deployed in a redundant manner, a minimum number of nodes are needed for the underwater networks. In the second stage, an online distributed approach monitors the network and only switches to the backup routes if necessary. Underwater monitoring missions can without a doubt be extremely expensive; therefore, it is vital that the deployed network is very reliable so that mission failure related to a single or multiple devices failing can be avoided.

The resilient routing algorithms have a communication architecture that needs sensor devices which are winch-based, i.e., devices affixed to the bottom of the ocean. The sensor devices have floating buoys that are adjustable using a pump. The buoys enable the sensor devices to rise up towards the surface of the ocean. Regulation of the depth of the device is performed adjusting the length of the particular node's anchoring wire. An engine, which is electronically controlled and located on the same device, is used for this purpose.

In the proposed architecture, the sensor nodes are unaffected by both weather and tampering, and the nodes are less affected by the water currents; these are two of its strengths. On the other hand, this approach can only be used with the proposed architecture and in long-term applications; moreover, if large areas are chosen for node deployment, then a major issue will be the cost.

4.6 Protocols Based On Localisation Approaches

Without data pertaining to time and location, sensed data, in some applications, has no meaning. Localisation is vital for the labelling of the data, and some applications which are time critical require that data is received in a timely manner. For applications employed in water, it is vital that each sensor node is aware of its own current location data and synchronised timeliness in regards to other coordinating nodes. Because of the impracticality of GPS, UWSNs are able to depend on time synchronisation or distributed GPS-free localisation methods that are known as cooperative localisation. Described below are the proposed methods related to localisation.

4.6.1 Localisation scheme for UWSNs

Network architecture and routing protocols can be designed using information related to location. The concept of Dive and Rise (DNR) was proposed to be used as a positioning system [37]. The authors replaced the static anchor nodes with mobile DNR beacons. However, a large number of expensive DNR beacons are needed and that is a major disadvantage of this DNR approach. As a means to solve this issue, a hierarchical localisation approach was proposed in [38]. The authors attempted to reduce the need for mobile beacons. They did this by exchanging the beacons with four different kinds of nodes. These nodes are, Detachable Elevator Transceivers (DETs), anchor nodes, regular sensor nodes and surface buoys. It is assumed that a GPS facility is installed on the surface buoys. The DETs connected to the surface buoys mostly consist of an acoustic transceiver and an elevator. The DET can dive vertically in the water with the help of the elevator which also helps it to rise back up to the surface of the water. Communication with the anchored nodes is provided by the acoustic transceiver. The specific purpose is to transmit messages containing coordinates. In addition, many special nodes are affixed at various locations and depth levels all over the area of interest. These nodes have a higher amount of energy. They can aid in the locating of regular nodes through communication with DETs via the acoustic transceiver. The final kind of node, the regular sensor node, has the task of sensing. Their job is to monitor the messages containing the coordinates which the anchored nodes transmit. Upon receiving more than 3 messages from different affixed nodes, the regular node begins calculating its own location in the network.

After the deployments of such specialised hardware, this localisation approach possessed a few assumptions. Firstly, it was assumed that each of the sensor nodes was equipped with a pressure sensor so that it could provide its depth location or z-coordinate data. Then, after the complete infrastructure was acquired, it was assumed that the network was static. While, it could have been improved for a mobile network, the authors, during their simulation results, still did not take mobility into consideration. On the other hand, for long term applications, all of these arrangements are not very easy to accomplish. Moreover, if large areas are intended to be used, then the cost would be a major issue.

4.6.2 Localisation and Routing Framework

In [39], the framework that was proposed utilises a restricted number of distinctive nodes known as Mobile Beacon and Sink (MBS). These MBS nodes are able to dive down into the water and then return to the surface vertically by altering their density. The remainder of the ordinary nodes remains under the water at various locations and are able to move along with the water current movements. MBS's visit various depths from time to time so that they can localise UWSNs and collect the packets of data from the nodes. Coordinates from the GPS are received by these MBS's as the nodes are floating on the surface of the water. The collected data is then uploaded to a ground station.

Localisation, in the first phase, is performed iteratively. In the beginning, the GPS is used by the MBS's to receive the data of their location. They then transmit their coordinates, from time to time, while moving down to the deepest site in the network. After an ordinary node has received data from a certain number of beacons (in this scenario, no less than four), it gets the data of its location. A localised node is considered to be an active node. It is able to aid in the process of localisation. It takes on the role of a beacon and continues to distribute its own coordinates. Each stage of the localisation process has a set time period that is declared in the localisation message. The interval duration can be altered according to how deep the network is and how fast the MBS nodes move. As another possibility, the length of this time period can be updated by satellite to the MBS nodes after each dive. The MBS message is helpful in determining the position and speed of the MBS nodes and their neighbours during the localisation stage. A time stamp field is also included in this MBS message. It aids in the determination of the distance by way of the Time of Arrival (ToA). The routing phase begins once the localisation phase is complete. Sensor nodes possessing data packets to transmit can choose an MBS node and send these data packets on towards the sink. The best data forwarding is carried out by the routing algorithm according to the location and the relative motion of the MBS nodes and the regular sensor nodes.

In this framework for localisation and routing, the authors assume that each of the nodes throughout the network is clock synchronised. For short term applications, these kinds of assumptions can be made. However, for long term missions, some additional mechanism is required so that synchronisation can be achieved. Furthermore, the two methods are used when calculating how far two nodes are away from each other. While ToA is thought to be more promising than the other methods of the same kind, like AoA (Angle-of-Arrival) and TDoA (Time-Difference-of-Arrival), accuracy is still not provided at long ranges and it is, therefore, only suitable for short ranges.

5. Additional Classification And Comparisons Of Routing Protocols For Uwsn

In the last two decades, major routing methods proposed for UWSNs for overcoming various kinds of challenges, such as energy consumption, end-to-end-delays, node mobility, delivery ratios etc. under the constraints of volatile environments were compared in this section. The complexity of the data packets was used as parameters in the comparison of the performance of these protocols for routing. The complexity levels of the various data packet sizes were defined as “High” (1000Kbs to 1500Kbs), “Medium” (512Kbs to 1000Kbs) and “Low” (256Kbs to 512Kbs) in relation to the data packet size used in the simulations for evaluating the proposed protocols. Table 3 presents the comparatives.

Figure 7 presents the general classification of routing protocols for UWSN. Although, this type of classification and comparisons are already provided in the existing survey [40]; but the author made the classification and comparisons of routing protocols that published until the year of 2010.

In our survey, we add some new routing protocols that have been recently proposed in the year of 2011-2014. We are considering the protocols for this classification that can handle with multiple characteristics under the main umbrella, like localization, routing and reliability.

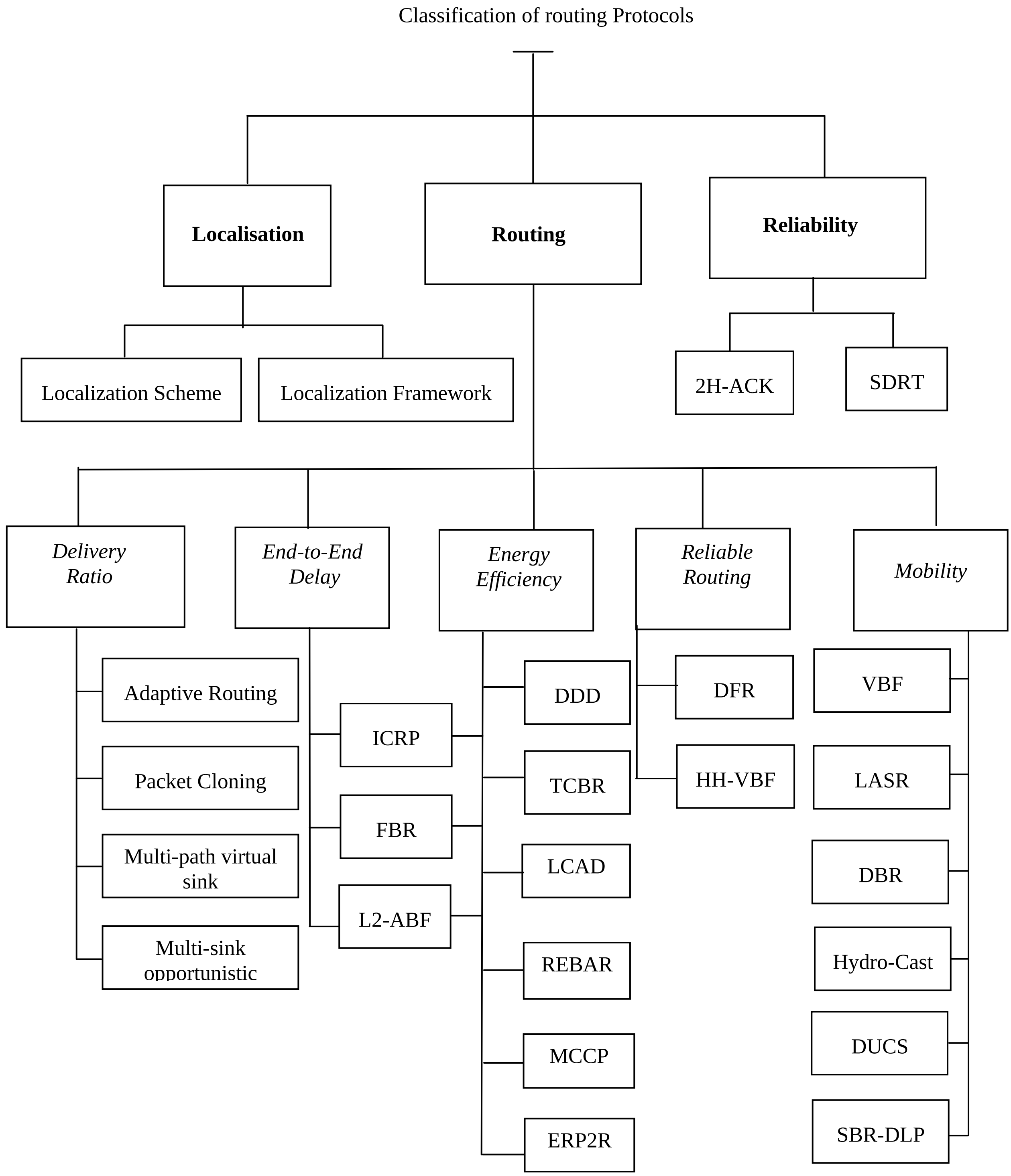

Figure 7. Knowledge Based Classification of routing Protocols

Table 3. Comparisons of routing techniques for underwater wireless sensor networks

Protocols	Routing Mechanism	Data Delivery ratio	Routing Delays	Bandwidth Needed	Data Packet Complexity	Knowledge Needed	Processing	Energy Efficiency	Local Information Needed
VBF	Flooding (vector based)	Medium	Medium	Low	Low	High	Medium	Medium	yes
HH-VBF	Flooding (vector based)	High	Medium	Low	Medium	High	High	Medium	Yes
FBR	Flooding (vector based)	Medium	Medium	Low	Low	Medium	High	Medium	Yes
DFR	Flooding (vector based)	Medium	Medium	Low	Low	Medium	High	Medium	Yes
REBAR	Single Entity	Medium	High	Low	Low	Medium	Medium	High	Yes
ICRP	Path based	Medium	High	Medium	Medium	Medium	High	Low	No
DUCS	Clustering (distributed)	Medium	High	Low	Low	Low	High	High	No
Packet Cloning	n/a	High	Medium	Medium	Low	High	High	Low	Yes
SBR-DLP	Flooding (vector based)	Medium	High	Low	Low	Medium	Medium	High	Yes
Multipath Virtual Sink	Path Base	Low	Low	Medium	Low	Medium	High	Medium	No
DDD	Trail based	Low	Low	Medium	Medium	Medium	High	High	Yes
DBR	Flooding (depth based)	High	Medium	High	Low	Low	High	High	Partially
HydroCast	Clustering (source based)	High	High	Medium	Low	Medium	High	High	No
EUROP	Single-copy	Medium	High	Low	Medium	High	High	Medium	Yes
UW-HSN	Clustering	Medium	High	Low	Low	Low	High	High	No
TCBR	Clustering	Medium	Medium	High	Medium	Low	Medium	Medium	No
Resilient Routing	Wired based	High	Low	High	Medium	Low	High	High	yes
Multi-Sink Opportunistic	Clustered Base	Medium	Low	High	Medium	Medium	High	Medium	No
H2-DAB	Flooding (addressing base)	Medium	High	Medium	Low	High	Medium	High	No
LCAD	Priority based	Low	Low	Medium	Medium	High	Medium	Low	Yes
LASR	Store & forward based	Low	Low	Medium	Low	Medium	Medium	Low	Yes
Adaptive Routing	Priority based	Medium	Low	Medium	Medium	High	High	Flexible	Yes
L2-ABF	Flooding (Angle based)	High	Low	Medium	High	Medium	Medium	Low	No
ERP2R	Flooding (Distance based)	Medium	Low	Medium	Low	High	High	Medium	Yes

6. Current Issues and Future Directions

Based on the work discussed in previous sections, it is clear that many issues are left to be solved. We are listing some of the open research issues; those must be considered during the future work for underwater environments.

- The Research required for variable packet length to increase the channel utilisation.
- The routing must be self-configuring in case of any failure because equipment is deployed far from the experts.
- Taking the routing decision on the latest available information.
- According to the underwater environments, the algorithms should provide strict or loose latency bounds for time critical applications.
- As the available data rates are extremely low, the routing overheads for the protocols of such networks should be kept as minimum as possible.
- Idea of *Per-contact routing* is better, instead of *source routing* or per-*hope routing*, although it can require more processing for large networks, but it provides more reliability for dynamic conditions of the underwater environment [41].
- For delay-tolerant applications, trying to develop mechanisms to handle loss of connectivity without immediate retransmissions. Integration of transport layer with the data link layer can be helpful for this.
- Many of the ground based algorithms use the node movement models and their directions, so water current movement models similarly can give the idea of node movements for the better routing.
- The cone optimization is needed in some designed flooding based protocols to manage the proper size of the flooding area.
- For energy efficiency, local route optimization algorithms are needed in order to manage the consistent variations of the network.
- For energy concern, it is better to develop a routing protocol that sends messages over multiple short steps, instead of sending over long links.
- Distributed protocols can give better results as they divide the processing load into different nodes, and it can help to increase the life of the network.
- In the case of multi-copy algorithms, when one copy has successfully reached on the destination, the way of the intermediate nodes can be informed to discard the remaining copies of the same packet for the best utilization of the resources.
- In WSN end-to-end communication is preferred and the large amount of global identification overhead (tolerated in ad-hoc networks) has to be avoided. Instead of pre-wired identifiers, the nodes' identity is given by their location after deployment. The large amount of global identification overhead, which can be tolerated in ad-hoc networks has to be avoided [42].

7. Conclusion

Routing protocols for UWSNs (underwater wireless sensor networks) is presented in this paper. Their performances, achieved goals and weaknesses are critically described. The reviews revealed that majority of these proposed protocols are energy efficient. They are mostly scalable and able to deal with the adverse underwater environment. However, some of the protocols must needed full dimensional location information of the source, intermediate and destination nodes. The comparison of the protocols with each other has also been presented in regards to some of their important properties. It was important to carry out the comparison so that the best protocol for the desired condition could be pointed out. The complexity of the data packets was the key factor utilised while the protocols were being compared. The work that was presented in the earlier sections clearly showed that not all of the open challenges for UWSNs have been solved and, therefore, need to be investigated further. In addition, an extensive evaluation of the performance and reliability of the proposed routing protocols is required. When comparing the routing protocols with each other, multiple measures should be taken into consideration.

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