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Review

Advancement of Routing Protocols and Applications of Underwater Wireless Sensor Network (UWSN): A Survey

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Abstract: Water covers a greater part of the earth's surface. Even though we know very little about the underwater world as most parts of it remain unexplored. Oceans including other water bodies hold huge natural resources and also the aquatic lives. These are mostly unexplored and very few of those are known due to unsuited and hazardous environments for the human to explore. This vast underwater world can be monitored remotely from a distant location with much ease and less risk. To monitor water-bodies remotely in real-time, sensor networking has been playing a great role. It is needed to deploy a wireless sensor network over the volume which we want to surveil. For vast water bodies like oceans, rivers and large lakes, data is collected from the different heights of the water level which is sent to the surface sink. Unlike terrestrial communication, radio waves and other conventional mediums can't serve the purpose of underwater communication as they pose high attenuation and very reduced transmission range. Rather an acoustic medium can transmit data more efficiently and reliably in comparison to other mediums. To transmit data reliably from the bottom of the sea to the sinks at the surface, multi-hop communication is needed which must involve a certain scheme. For seabed to surface sink communication, leading researchers have proposed different routing protocols. The goal of these routing protocols is to make underwater communication more reliable, energy-efficient and delay efficient thus to improve the performance of the overall communication. This paper surveys the advancement and applications of the routing protocols which eventually helps in finding the most efficient routing protocol for the Underwater Wireless Sensor Network (UWSN).

Keywords: Underwater Wireless Sensor Network (UWSN), Routing Protocols, Acoustic Communication, Multi-hop communication, Energy-Efficient, Reliable

1. Introduction

Water-bodies cover two third of the earth's surface. Moreover, from the very beginning of the human civilization, people have been choosing water-bodies to live nearby. Ocean has always played the most important role as transportation medium, sources of natural resources and host of all marine lives. But we only explored hardly 5% of the whole ocean volume[1]. To inspect the unknown, underwater communication recently attracted the researchers' attention. As traditional systems for underwater monitoring have some limitations and this inimical environment is not suitable for human presence due to high underwater pressure, capricious activity of deep ocean and its expansive areas. This inspires the unmanned exploration of these dicey environment. Neither unmanned exploration nor the distant real-time monitoring can be done without deploying UWSN. So consequently, UWSN has drawn the interests of the researchers recently. This underwater-wireless sensor network is different from traditional wired and terrestrial sensor networks[2][3].

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UWSN is composed of different number of sensor nodes which are deployed at different heights of the sea volume. The number of the sensor nodes depend on the volume of the sea we want to cover and few other factors like the range of the nodes & desired performance of the network. These sensor nodes at different levels of the sea collect the necessary data and eventually send it to the data sinks at the sea surface. This data sinks send the collected data to the nearest terrestrial network by satellite or Radio Frequency (RF) communication. The data transmission from the surface sink to the terrestrial network follows the usual protocols for terrestrial communication. But these communication protocols like Transmission Control Protocol (TCP) is not suitable for underwater communication[4].

Terrestrial system uses radio frequency as their medium of communications which is not viable in underwater due to multiple reasons including high attenuation and low transmission range. Wireless sensor networking using acoustic channels turns out to be the most realistic solution for underwater communications. But the deployment of network, the network architecture, localization and reliability of underwater wireless sensor network (UWSN) are not same as the terrestrial system when it comes to acoustic channel[5].

In compare to the terrestrial sensor network, UWSN is very sensitive due to its 3D nature. Aim of the UWSN is to collect real time data and locate from where data is being collected. This helps to warn about natural hazards precisely and save thousands of lives. Deployed UWSN can also collect data about marine environment, detect underwater mineral mines and many more. Real life applications of UWSN also includes seismic monitoring, ocean sampling, vision based underwater mine searches, ecological monitoring, monitoring of underwater marine cables and gas & oil pipelines. But for these applications, the source of the data needs to be known and that's why localization is very important. As we are using acoustic medium in underwater condition, GPS technology is not feasible there. So localization techniques are different in underwater communication system[6][7]. One of the challenging factors of the UWSN is the reliability of the network. As the underwater condition is very hazardous and prone to sudden changes, it is very difficult to maintain high reliability of the network. Keeping in mind all these challenging factors, researchers have proposed different routing protocols for UWSN. Most of these routing protocols are defined using acoustic medium either using single hop or multi-hop, clustering or clustering-multi-hop communication. Here, different routing protocols emphasized in different factors of the network. Few protocols have given highest priority to the reliability of the network whereas other few has given top priority to the network life time.

The next sections of the paper surveys few prominent routing protocols of UWSN and analyze those based on the mentioned factors and metrics. Section 2 describes the communication mediums, network architecture, localization and reliability of the UWSN. Architectures, working procedures, advantages and drawbacks of the few important routing protocols of UWSN are presented in section 3. section 4 summarizes the evaluation process and depicts the evaluation of the considered schemes in tabular formats. The research applications of UWSN and conclusion are presented in section 5 and 6 respectively.

2. Background

2.1. Underwater Acoustic Communication

Path loss designates the underwater acoustic communication. Mostly the transmitting distance and frequency of the transmitted signal define the path loss[8]. Absorption loss occurs when acoustic energy is transferred into thermal energy. This fact implies that the channel bandwidth has to be set on the basis of the desired transmitting distance. Absorption loss increases as we increase the operating frequency & the interval between the receiver and the transmitter[8]. So the power constraint automatically sets a limit on the availability of the bandwidth. Consequently longer the communication link lesser the bandwidth, shorter the communication link more the bandwidth. Besides lower the bandwidth lesser the data rate[9][10]. As for example, transmission over a distance of 30 km is feasible to perform by a single hop of 30 kHz bandwidth or the same transmission distance can be covered with

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much higher bandwidth of 300 kHz by 10 hop instead. So higher bandwidth (increased throughput) can be obtained by trading-off complicated relays in transmission.

Opportunity for Free Space Optical (FSO) waves in underwater environment is limited as optical frequency band faces acute water absorption and heavy back scatter. Its attenuation is very high and it's almost 1000 times of air even in the clearest water. Furthermore, the attenuation of the turbid water is hundred times than that of densest fog[11]. So in underwater environment, main drawback of FSO is very limited transmitting distance due to high attenuation.

Acoustic communication can be considered as the most versatile underwater communication technique due to its low attenuation. Acoustic medium works out more perfectly with higher depth and steady temperature of the water. But in case of using acoustic waves in shallow water, temperature gradients and surface ambient noise can affect the performance adversely. Multi-path propagation due to reflection & refraction prospects might be another reason. Sound speed in water is 4 times than that of in air. But as the depth, temperature and Practical Salinity Unit (PSU) of water increase, the sound speed also increases[10]. Even though its speed in water is much slower than that of EM waves. But it's the most reliable underwater communication medium which is feasible for practical deployment presently.

2.2. Deployment of Network Architecture

Underwater network is established to perform designated tasks. The network is formed by placing the multiple number of nodes at different depths of the sea volume to perform the task collaboratively. Every sensor nodes will transmit data by multi-hop or clustering technique to reach surface sink. In compared to terrestrial sensor network UWSN is more sensitive and complicated due to its 3D nature. Two communication architectures were proposed by Akyildiz et al.[2].

- Two dimensional network architecture and
- Three dimensional network architecture

When the network is two dimensional, sensors are remain scattered only at the sea bed. These sensors can transmit data with each other. They can also communicate with the Underwater Sinks (UW-sinks) via acoustic medium. UW-sinks send the extracted data from the sensors and send it to the sinks located at top of water surface. To perform this relaying, each UW-sink is provided with two acoustic transceivers- horizontal transceiver and vertical transceiver. Horizontal transceivers communicate with the deployed sensor nodes whereas vertical transceivers relay the data to the surface station. Vertical transceiver must be long ranged in case of deep ocean communication. These floating stations have the transceivers which can handle more than one links with the sinks at a time. These stations also have the facility to communicate with the onshore-sinks. Figure 1 shows a generalized two dimensional underwater network. sensors are randomly spread in sea bed which collects the data and transfer it to the closest UW-sink. UW-sinks send the collected data to their respective horizontal transceiver. From horizontal transceiver data reaches to the surface sinks via long range vertical transceiver.

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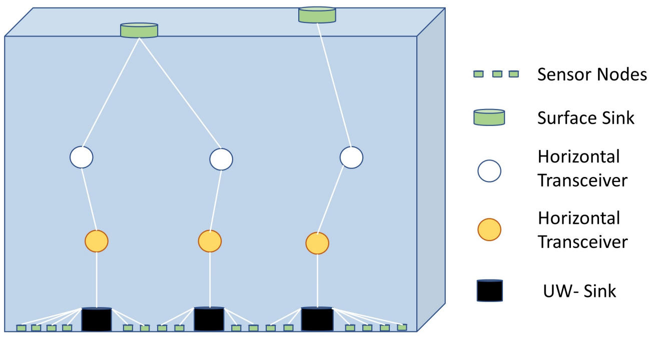

Figure 1. Two dimensional UWSN architecture

A three dimensional network is deployed to perceive the phenomena more precisely and throughly. In 3-dimensional network, sensor-nodes can float at various heights of the sea level to perceive a particular phenomenon. But Akyildiz et al. proposed a slightly different idea in[12]. Authors suggested to tie each sensor-node to a surface buoy by a wire so that we can change the depth of the sensor nodes by changing the wire length. By this, we can place the sensor-nodes at different depth of the water levels with much ease. But these buoys can block the sea vehicles. Besides they are susceptible to weather tampering and pilfering.

2.3. Localization

Most of the applications of UWSN require time and location of the sensed data. So localization is very important to perceive the network architecture and also to collect the data accurately[8]. Localization in underwater is challenging because radio frequency is highly attenuated in underwater condition, thus GPS technology is not feasible there. In most cases we do not need the exact positioning of all the nodes. Rather exact location of few nodes are enough and these are called the reference nodes. Such localization schemes broadly are of two types :

- Range based scheme and
- Range free scheme.

The range measurement is much more preferred when acoustic channel is used instead of radio frequency or optical waves[13][14]. To locate a node in the network, range based scheme utilize distance, angular values, time stamps and difference of time for packet received or sent. Whereas range free scheme rather use anchor node as reference for locating any node within the network[15]. Researchers like Luo et al., Ahmed and Salleh and Su et al. have surveyed these localization schemes elaborately in [16][17][18]. But only small-scale networks are compatible to these solutions. Erol et al. proposed Dive and Rise (DNR) method for positioning[19]. It uses DNR beacons for localization of the sensor nodes. In this method, static anchor nodes are replaced by mobile DNR beacons. But the main downside of this method is that these DNR beacons are very costly and we need a lot of those. Chen et al. reduced the expenses to a great extend by decreasing the requirements of DNR beacons [20]. They replace the DNR beacons with nodes of 4 separate kinds:

- water floating-buoys
- detachable transceivers
- nodes that are attached to the bottom
- regular sensor-nodes

It is presumed that, the network is completely static and also the nodes of the network can measure the water level. A pressure sensor always remain attached to this sensor nodes to perform this task.

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2.4. Reliability

The main challenging factor for underwater networking system is relaying the collected data to the surface station. Congestion control mechanisms of terrestrial networks show many difficulties in underwater wireless multi-hop networks [21]. TCP is such kind of a mechanism that works based on end-to-end connection technique. A TCP-handshake of the sending and receiving nodes is needed even before the transmission begins. In case of UWSN, we have to transmit only a few bytes in each packet. Transmitting this small data is a problem for TCP as it follows the 3 way handshake mechanism. In case of acoustic communication, propagation takes longer time than that of transmission which leads us to bandwidth×delay product problem[10]. For reliability TCP needs end to end ACK and retransmission strategy but it will cause poor throughput along with longer transmission time. It is considered in TCP that packet data losses are caused by congestion only. So TCP only focuses on the decrease of the transmission rate but the error prone acoustic channel and the failures of the nodes can also be a reason for data packet losses in UWSN. So to maintain throughput efficiency, data transmission rate needs not be decreased[10]. Other terrestrial protocols like UDP usually does not maintain this flow control. Rather it just drops the packet without creating any scope for recovery or re-transmission which results in total loss of the data packet[21].

Loss of the data increases with the bigger data packets. On the contrary, the data overhead increases when the packet volume decreases. So data volume affects the reliability directly. One thing is worth mentioning that, as the data volume gets larger, collision rates of the network also gets higher. Therefore, larger data packets are preferable only when the link quality is good enough. However, it is already experimentally proven that, data error rates also depends on the lengths of the packets[21]. Error control mechanism is a major issue in reliability. A successful transmission highly depends on the technique that we use for error control mechanism. Depending on the properties of the wireless channel, packet sizes are determined. For example bad channel conditions require smaller packet size, error detection and retransmission mechanism whereas larger packets are preferable for good channel condition. Moreover, channel access rates are affected by increase in packet sizes, thus the traffic on the channel is also affected which ultimately affects the data error rates. Underwater condition is very transient for wireless networking. So reliable and adaptive protocols are needed for successful transmission of the data packets which is also very challenging. Even though some networking protocols play a decent role in UWSN which we analyze in section 3.

3. Routing protocols for UWSN

3.1. Vector Based Forwarding (VBF) and Hop-by-Hop VBF (HH-VBF)

UWSN is more challenging than the terrestrial network due to low bandwidth capacity, higher delay, 3-D nature, node mobility and transient nature of the medium. To cope with this issues xie et al. come up with a new protocol which is capable of making the routing more sturdy, energy efficient, extensible[14]. This protocol is called Vector Based Forwarding (VBF). Here few nodes take part in the data transmission at a time where other nodes remain idle for that instant. So state information is not needed here. This is a location based scheme. The location information of Sender, target & transmitting nodes are sent with each of the transmitting packet. Transmitting packet from source follows the 'routing pipe' which is formed by all the forwarder nodes.

All the sensor node are well equipped for measuring relative distance of the nodes. They also calculate the angle of arrival of the receiving transmission. And this angle is generally called AoA. After receiving a signal, a node first calculate the AoA and the relative distance of the forwarder. The measurement of distance and AoA is done every time a sensor node receives the packet. Now, the forwarder node calculates its distance from routing vector. If distance is less than the presumed threshold value, only then forwarder node stores its calculated location to the data packet which is

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then forwarded for the next hop. Else it just drops the data. If any node falls outside of the routing pipe, then those will not participate in the forwarding procedure.

In Figure 2, S1 is the source and surface sink is the target. Routing pipe is along the vector from S1 to the surface sink. W is the predefined threshold distance value. All the sensor nodes along this routing pipe act as forwarders during any data transmission. But all other nodes sit idle for that instant which makes it an energy efficient one. As VBF does not require any state information, it is scalable to the network demand. It is energy efficient due to forwarding through the routing pipe only. Its data delivery rate does not depend on the stability on the neighborhood rather on the network density. In dense network it gives descent performance in delivery rate, average delay and energy consumption.

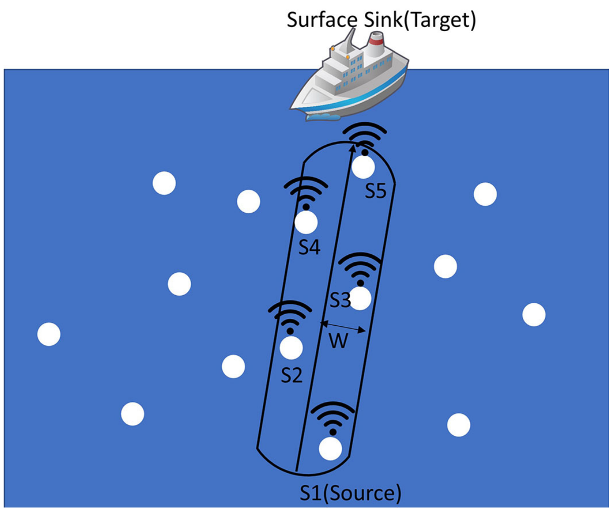

Figure 2. Two dimensional UWSN

Even though VBF has some drawbacks. In VBF, routing path as well as the routing nodes are restricted by the virtual routing pipe. This pipe is extended up to the surface destination, originating from the source. In sparse network, it may happen that no node lies within the predefined routing path, then it will not transmit the data to the sink even if it happens to have other paths outside of the routing pipe. It will decrease the packet delivery ratio drastically. As the node distribution is uneven in underwater environment, it is very troublesome finding the right radius threshold.

To overcome its short comings Nicolaou et al. proposed a improved protocol in which authors preferred per hop routing pipe for individual forwarder over the single pipe connecting sink and the source. It is called hop-by-hop VBF [22]. In this, every intermediate forwarder determines the pipe direction depending on its own position, position of the neighbor nodes and the sink. So HH-VBF can always find a route in sparse region where there is a less number of neighbor nodes. Eventually HH-VBF gives better packet delivery ratio than VBF, specially in sparse region. Yet, its routing pipe radius threshold can degrade its performance. Besides, it gives more signal overhead than VBF due its hop by hop forwarding.

3.2. Distributed Underwater Clustering Scheme (DUCS)

Batteries are the power source for the sensor-nodes which are difficult to recharge or replace. So limited energy is a major constrain for UWSN. Domingo and prior presented DUCS which is : (1) energy-aware (2) non-time-critical (3) self-organized and (4) provides random node-mobility[23]. A distributed algorithm is used to form the clusters. It is assumed, sensor-nodes constantly generates data which needs to be transmitted. Moreover, these nodes have the capability to change the transmission power level whenever necessary. It uses self-organizing technique to form local clusters each having one cluster head. All the cluster members transmit their data to their respective heads by single hop transmission. After accumulation of all the data, cluster heads sent them to the sink. But this

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transmission from cluster-head to the sink is completed by multi-hop communication. Cluster heads control the communication within its own cluster and also the inter-cluster communication. These cluster-heads are chosen randomly from the cluster members on the basis of regular rotation. So it makes this protocol an energy efficient one. Besides, to avoid fast battery-drainage of the cluster-heads, DUCS allows randomize change of the cluster heads withing the cluster members. The function of operation is divided into two rounds. First is called setup in which clusters are formed and the second round called network operation which completes the data transmission. A series of data are sent from the member-nodes to the heads which maintain a particular routine. This series of data are called frames. Member-nodes sent several such frames to their own heads of the clusters during second round. Simulation of DUCS has shown that-(1) it's packet delivery ratio is high (2) network overhead is reduced (3) its throughput increases consequently. Though it has some performance issues, DUCS is energy efficient. The cluster structure can be affected by the movement of the nodes due to water current which may lead to decrease cluster life. It is worth mentioning that, only a cluster head can communicate with another head and this is possible only in the second round. So if by any means these heads are distant-apart such far that they can't communicate directly, even then they can't communicate through the non cluster heads present in between. This can interrupt the network drastically and hamper the life-time as well as performances.

3.3. Depth Based Routing (DBR), Depth Based Multi-Hop Routing (DMBR) and Energy-Efficient DBR (EEDBR)

Knowing the exact location of the sensor nodes is very difficult and also a critical factor of the underwater networking. Yan et al. presented a protocol where we need to know the height of the sensors only instead of the full-dimensional location information. We can get this information just by attaching a depth sensor with the nodes. These depth sensors are not that costly also [24]. Several data sinks should be floating at the top of water body. This ultimately collects the data from the nodes deployed at different level of water. Node from the bottom of the water-body collect the data which act as the source. At first a node compares its height with the height of the prior sender from the bottom surface. Then it distributively takes a decision on packet forwarding. When the height of the node is higher than that of the sender, it consider itself to be qualified forwarder and will forward the data. Otherwise it just discards the packet. Because a node closer to the surface was its prior sender. This procedure continues till the packet reaches the surface. Reception of the packets by any of the surface sinks is considered as successful transmission. As the nodes closer to the surface is always chosen as a forwarding node, it consumes less energy and travels less distance. Figure 3 depicts the routing technique of DBR where S is the source. The range of the source S covers the neighboring nodes n1, n2 & n3. Here, larger circle around source and forwarders depicts the transmission range of the source. Source broadcasts a data packet with its location information. Every nodes falling in the range of S receives the data to compare the depth of node S to its own depth. Node n3 is discarded as its depth is higher than that of S. Though both the nodes n1 and n2 are qualified forwarder, n2 is selected as the next sender as it is closer to the surface. Now, n1 just drops the packet and n2 broadcast the data in the previous way to find the next sender. This is done recursively until the packet finds any of the surface sinks.

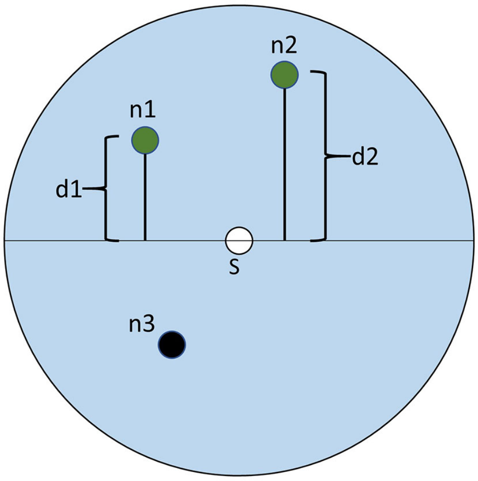

Figure 3. Routing Technique of DBR

Authors introduced a global parameter called depth threshold to control the number of nodes needed to send the data packet. A node forwards data only when it finds that difference of its own depth and earlier hop's depth is greater than that of threshold value. If the threshold value is high, energy consumption will be less as the nodes involving in data packet delivery will be less. But it will cause low packet delivery ratio. On the other hand, setting a higher threshold value will involve larger number of nodes delivering the same packet data and eventually increase the energy consumption. This will result in high packet delivery ratio. So depth threshold value is the key to the trade off between the energy consumption and delivery ratio. Though it gives very good performances in dense network, in sparse areas packet delivery ratio degrades as it works only in greedy mode. Simulations show that, it can performs up to 95% of packet delivery ratio in dense network with reasonable amount of energy consumption[24]. Furthermore, DBR is improved in Depth Based Multi Hop Routing (DMBR) which includes multiple sink network structure[25]. DMBR divides the whole process into two steps : route discovery and send packets, which makes the routing scheme more energy-efficient and also reduce the channel conflicts, thus improves DBR. It was improved further in Energy Efficient Depth Based Routing (EEDBR) [26]. Wahid et al. suggested to improve the life time of the network by utilizing the sensor residual energy. In DBR, a node having smaller depth than neighboring nodes will always forward the data in each and every transmission whereas nodes having slightly larger depth may sit idle. As a result, same nodes will be used repeatedly and eventually die out earlier than the other nodes. This creates routing holes all over the network which partitioned the network into parts. As a result, sensors can't communicate which results in shorten the network life time. This was improved in EEDBR. In EEDBR every sensor nodes share its residual energy and depth with its neighboring nodes. Besides, each sender also broadcasts the depth of its neighboring nodes during transmission. When forwarding nodes receive the data packets, depending on the residual energy it stores the data for a specific period and to maintain the required delivery ratio, nodes take decision whether to transmit or suppress the packet transmission. DBR reduces the delay and improves the network lifetime. Moreover it gives satisfactory delivery ratio of the data packets along with good power-efficiency.

3.4. An Energy Balanced Efficient and Reliable Routing Protocol (EBER^2) and Weighting Depth and Forwarding Area Division DBR (WDFAD-DBR)

An Energy Balanced Efficient and Reliable Routing Protocol (EBER^2) has been proposed by Wadud et al. to achieve improved energy balancing, reliability, energy efficiency, network latency and packet delivery ratio[27]. Unlike DBR, Weighting Depth and Forwarding Area Division DBR (WDFAD-DBR)

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considers depth of the both current hop and expected forwarding hop thus avoid the void holes[28]. But WDFAD-DBR still faces void hole issues as it doesn't consider Potential Forwarding Nodes (PFNs) for the second hop. WDFAD-DBR also increases duplicate packets and packet collisions which affects the energy efficiency and lifetime of the network[27]. Wadud et al. in EBER^2 solved the problems posed by WDFAD-DBR. EBER^2 is formed of three types of nodes:

- sink nodes
- anchored nodes and
- relay nodes

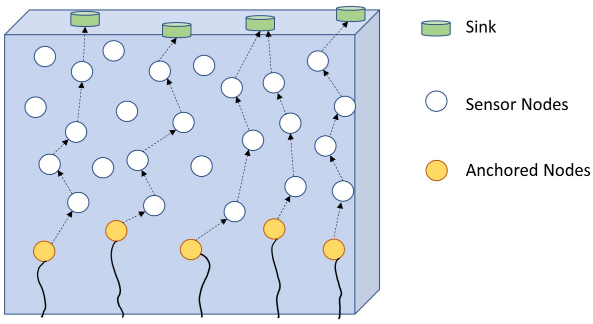

Figure 4. Network architecture of EBER^2

Figure 4. shows the network architecture of EBER^2. Anchored nodes remain attached at the bottom of the water level and remain fixed in their positions. The sensor nodes or the relay nodes are deployed at different layer of water levels which are movable. The relay nodes senses the surrounding data and also act as a forwarder node to transfer the data. The sinks remain floated at the water surface and considered as the destination. The depth of first two hops are considered for selecting the forwarder node which decrease the chance of void hole issue in the network. The residual energy of the nodes is also considered. It is used to avoid duplicate packets by taking higher values of the holding time of the forwarding nodes. This allows energy optimization by avoiding duplicate packets thus increase packet delivery ratio. Moreover, use of residual energy as metric for selecting the forwarder node enables energy distribution in the network. This eventually prolongs the network lifetime. To address the issue of reliability, PFNs of the next forwarder is also taken into account which also decreases the probability void holes in the network.

The energy consumption of the nodes nearer to the sink is always higher due to higher network traffic. If these nodes die earlier it would cause the network to be separated from the sinks. To address this problem, these nodes tune their transmission power level according to the distance to reach the nearest sink. Simulations show that, the EBER^2 performs better in energy efficiency, PDR, and packet loss when compared to WDFAD-DBR. But this protocol increase the end to end delay between the nodes by considering the residual energy.

3.5. Directional Flooding-Based Routing (DFR)

For improving the reliability Shin et al. proposed Directional Flooding Based Routing (DFR)[29]. Authors suggested to consider larger number of nodes to achieve better reliability. These few more forwarding nodes make the data packets reach to the sink reliably. The forwarding activity is performed per hop. Few researchers have already worked on flooding based routing but Shin et al. have the most prominent research work on DFR[30] [29]. Authors suggested to broadcast a data packet by source node having its own location information and one other parameter. This parameter contains an angle known as BASE_ANGLE which is set to its predefined minimum value according to network

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density. Upon receiving a packet, the node measures an angle between two vectors-from source node to itself and from itself to sink & this angle is called CURRENT_ANGLE. When node receives a packet it compares BASE_ANGLE with CURRENT_ANGLE and decide whether to forward a packet. If the node's BASE_ANGLE is bigger than that of CURRENT_ANGLE, it is considered as out of flooding scope and it is discarded. In reverse case, BASE_ANGLE is adjusted so that it can maintain link quality with the nearby nodes. Two conditions must be satisfied by all the nodes to maintain the link quality –

- the CURRENT_ANGLE of the neighbors must be larger than that of CURRENT_ANGLE of the forwarder.
- the distance of the neighboring nodes to a sink must be less than that of the distance of the forwarder to the sink.

Nodes will not transmit packet until the above conditions are fulfilled. The forwarder node then broadcasts the packet with a source location and a new base angle. Packet transmission in DFR is shown in Figure 5.

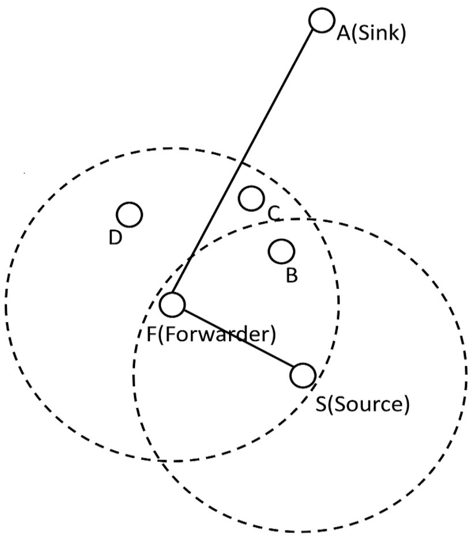

Figure 5. Packet transmission in DFR

The source S broadcast a packet with its location and BASE_ANGLE whose value is set to A_MIN. When F receives the packet, it compares its CURRENT_ANGLE (angle between $\overrightarrow{FS}$ and $\overrightarrow{FA}$) with the BASE_ANGLE. F adjusts its BASE_ANGLE with B and C according to the average link quality in case the CURRENT_ANGLE is larger than BASE_ANGLE. It then floods the packet with the adjusted BASE_ANGLE and its location in it. Otherwise, it just drops the packet. Simulations have shown that, DFR gives better delivery ratio in compared to VBF. Moreover, it offers 73% shorter end-to-end delay and 43% less communication overhead than VBF. Even though it has some drawbacks. When sink finds no node in its range, then a hole is created in the network which may disrupt the network.

3.6. Focused beam routing (FBR)

To avoid unnecessary flooding of the data, Jornet et al. proposed a noble routing scheme called FBR[31]. FBR is suitable with both the static nodes and the moving nodes of the network. Moreover, the network with FBR needs not to be synchronized with global clock. Just by knowing the location of the source and destination a successful transmission is possible irrespective of the location information of the other nodes. FBR performs flooding for routing data packets and this flooding is restricted by the transmission power. To minimize the energy consumption of the network, this protocol engage different power levels for transmission. Figure 6 explains how a data packet is being forwarded in

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FBR. Node A is the source and node B is the destination where node A sends a multi-cast request to its neighbor nodes. This is called a RTS packet which holds the positioning data of node A and B. The lowest power level has the minimum range and range area increases when we switch it to a higher power level. But switching of the power level only occurs when it can not find any node within the designated rage for the next hop. But receiving nodes do not decide which power level to be used instead open loop power control and power level is decided by the transmitting node. It is also considered that there are definite power levels ranging from P1 to PN which can be increased from one level to the upper level when needed[32]. The nodes have to be within the the perimeter of the defined power level to receive any detectable signal. Now the locations of the nodes which receive the multi-cast RTS earlier from node A is determined.

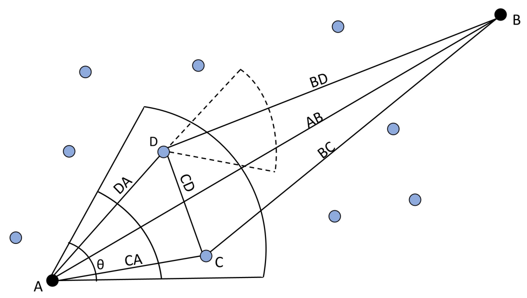

Figure 6. candidate relays within cone θ

This location is relative to the line AB. Nodes which lies within the angle $\pm\theta/2$ at the source node A are selected as the eligible nodes for forwarding. If a node is eligible one, this will response to the received RTS. But in real life FBR may face some difficulties. First, due to transient state of the underwater condition and due to heavy current it may happen that, no node is within the cone of $\pm\theta/2$. Sometimes it may happen that, some of the eligible nodes remain outside of the forwarding cone angle. In this case it can't find the eligible node for the next hope within the forwarding zone, source node needs to rebroadcast the RTS. Thus overhead will increase which eventually disturbs the transmission. Sink is considered to be fixed here which makes the network more restricted.

3.7. Location-Aware Routing Protocol (LARP)

Even though existing routing protocols have improved UWSN drastically, still those pose many problems. Shen et al. proposed a novel routing protocol which gives better performance in delivery ratio and reduce overhead overhead in compare to all other existing routing protocols. This is called Location-Aware Routing Protocol (LARP) [33]. It adopts Received Signal Strength Indicator (RSSI) method to know the location of the nodes[34]. And it utilizes this location information of the nodes for the packet data transmission. It is considered that there are two kinds of nodes in the network-(1) anchor nodes (2) general nodes. Anchor nodes are the reference nodes and are used to determine the location of the other nodes. Anchor nodes are equipped with GPS module which broadcast the location information to the beacon. It is considered that anchored nodes have-

- the property to know the precise location of the anchor nodes by GPS technology or other methods[35].
- enough energy & storage capability.
- enough RF transmission range to cover the whole network scale.
- the property of random mobility.

With the help from 3 or more anchor nodes, a general node usually finds its own positioning. They saves their positioning information. If these general nodes reaches near to any anchor node, it transmit its location information to the anchor node to store. Figure 7 depicts data transmission

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of LARP where N1, N2 & N3 are anchor nodes. S is designated as source and D is designated as destination for the transmission. At first, source node looks for an anchor node within its range or wait for any anchor node to come within its range. Source node requests for the destination node location to the anchor node. When anchor node broadcast the destination ID, all other anchor nodes will check that if there is destination node D within their range. If any of the anchor nodes find the destination node, source node will get the information about the destination node. Now the node S will broadcast the 'destination location' request within its range. If the destination node D is within the range and receives the destination location request, it will reply to the node S. After that node S will directly transmit to the node D. It is mentionable that, no other node will reply the request upon receiving. When source node gets no reply, source node broadcasts 'moving direction' requests. Moreover, Source node S collects all the information of the nodes within its range. Now the node which is moving in the direction of D, reply to the node S. In the next step, the data packet is delivered to that particular node. Thus next best hop is selected. If it happens that, there are more than one node which is directed towards the destination D, then their speed is taken into consideration. The node with the greater speed is chosen as the best hop.

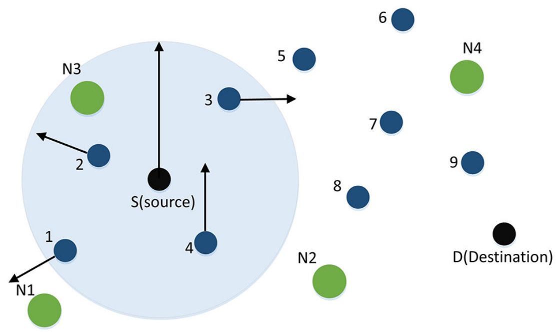

Figure 7. Data transmission in LARP

If it happens that, there is no node directed towards the destination node then no node reply back to the node S & it waits until it get any suitable node to make it the next best hop. In Figure 7, node 3 is selected as the next hop. In this way best hop is selected recursively until the data packet is delivered to the destination node. Simulations shows that, LARP gives decent packet delivery ratio, lower normalized overhead. Moreover it gives more reliable transmission than the other routing protocols. Even though it poses some drawbacks. It needs very dense network to work perfectly, besides a source node had to wait for a indefinite time if it does not get any anchor node within the range. It may also happen that source node may have to wait for a long period of time to get a node which is directed towards the destination node to select it as the next best hop.

3.8. Sparsity-aware energy efficient clustering (SEEC)

In the schemes like DBR & EDBR, two things are considered while choosing the next forwarding node during routing. These are- how close the nodes are to the surface and their remaining power. This creates several coverage gaps which affects the life span of the network badly. Thus for improving network lifetime along with stability and energy efficiency Azam et. al proposes an unique scheme called SEEC [36].

Here, Depth finding modules are attached to the every randomly scattered sensor nodes of the network. The whole network region is divided into few sub regions of equal areas. The denser regions of the network are sort out on the basis of a novel algorithm for finding the denser regions. Similarly, with another dedicated algorithm the sparse areas are also found out. Sinks are used to collect the data from the sparse areas. On the other hand, clustering scheme is employed to extract the data from the denser areas. On the basis of lower depth & high residual energy one of the nodes from each cluster is

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selected as the cluster head. This head has to be the closest node to the water surface in compared to the cluster members. Moreover, its residual power has to be more than the average residual power of the clustering nodes. Data transmission in dense region is completed in three layers. At first the data is collected and aggregated from the member nodes. After that, it is sent to their respective heads. At last, all the heads of the clusters send this data to the nearby static or mobile sink. In case of the sparse region, two moving sinks are used to extract the data from the nodes. For better understanding, these two sinks are supposedly being designated as MS1 & MS2. One of these two sinks (MS2) remain fixed at the most sparse areas. Other sink-MS1 travels from the topmost sparse areas to the least sparse areas in every round. It is mentionable that region of MS2 is not under the consideration of MS1 mobility and MS2 remain fixed in its position until the death of each node of the region. After that MS2 moves to the topmost sparse region for the rest of the sparse nodes. These sinks always choose the center position of the whole region to travel. By this they can cover the maximum number of nodes within their transmission range. Mobile sinks move from one sparse region to another sparse region periodically and eventually collect the data from all the sparse regions. SEEC employs the moving sinks for the sparse areas where it uses clustering schemes for the dense network. This makes this scheme to be more energy efficient than other two schemes like DBR & EEDBR. Moreover, SEEC also shows longer life-span and give better packet delivery ratio than these two mentioned schemes. More over, clustering technique gives SEEC a better stability period But it has lower throughput than DBR & EEDBR.

3.9. Regional Sink Mobility (RSM) and Vertical sink Mobility (VSM)

In SEEC, the throughput was low due to multi-hopping of the clustering head in dense region. To increase the throughput Ali et al. proposed two routing protocols. One is called the Regional Sink Mobility (RSM) where the sinks move regionally to extract the data. Another schemes is called Vertical Sink Mobility (VSM) in which the sink travels vertically to collect data from the nodes[37]. In both the schemes, it is not needed to know the information of each and every node rather one node needs to know the information of its neighboring nodes.

3.9.1. RSM

In RSM the whole region is divided into three equal parts which is depicted by Figure. 8. All the nodes in the network are placed arbitrarily in these three regions. Three Mobile sink are deployed in three different regions. They move randomly in each round within their own region. When sink one moves and takes a new position, the position of the sink two must be such that it maintains maximum distance from the sink 1. Similarly sink 3 must maintain the maximum distance based on the new position of the sink 2. This condition is applied to get a larger coverage area.

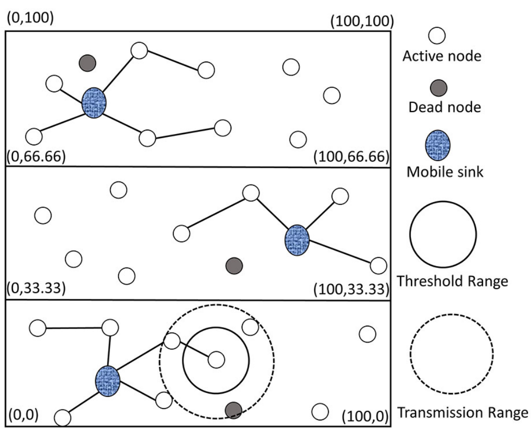

Figure 8. Data transmission in RSM

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The sensor nodes lying in region one and two transmit the data to sink one or two. Similarly sink two or three collect the data from the area two and three. if the sensor nodes fall within the range of the designated sink then it directly delivers the data to the sink. But if any node falls out of the range of the sink then it chooses another suitable node through which it can send its data to the sink. When a node falls out of the threshold range but remains within the transmission range then it is considered as a neighbor of the sender. Now if a neighbor node of the sender is in the range of the sink one or sink two, can be declared as eligible neighbor for receiving. Then the sender node transmit the data packet to the neighbor node & from that node mobile sink gets the data. If a node neither find any sink within its threshold nor it can find an eligible neighbor node then data of this node is discarded.

3.9.2. VSM

Data transmission of VSM is depicted by Figure. 9 which shows the whole network area is divided into 10 equal parts. Sensor nodes are placed arbitrarily over the whole volume. 3 mobile sinks are employed for the whole volume of the area with a predefined distance from each other to maximize the coverage area. These sinks take a new position in every round in such a way that they maintain this predefined distance from each other. When one round ends sink one take a new position by traveling a preset distance in X or Y axis. Sink two traverse the same distance in same direction of the same coordinate to maintain that predefined distance. Similarly Sink three take position depending on the position of the sink two. To transmit data packet, every node calculate its distance with the sink and neighboring nodes. If it finds one or more sinks within its transmission range, the node directly transmit to the sink. If all of the sinks are out of the range, the sending node tries to find a neighboring node who has a sink within its range. In this case, the neighboring node transmit the received data from sending node to the sink. But unfortunately if there is no eligible neighbor nodes even, then the data packet has to be discarded.

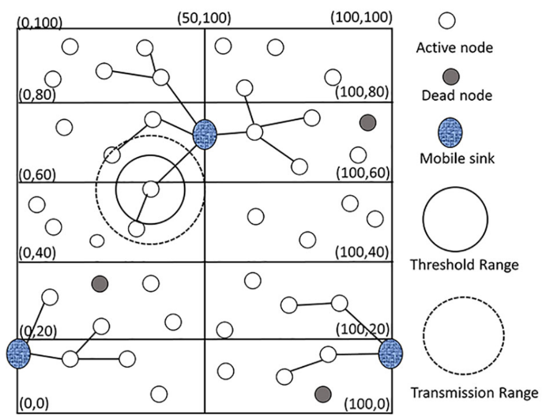

Figure 9. Data transmission in VSM

Both RSM & VSM either transmit directly or by two hop transmission method to the sink. This improves the throughput, the data received rate and initial network stability of both the schemes and have better performance than SEEC. Throughput of VSM is twice and that of RSM is thrice of the throughput of SEEC. But these two schemes poses some limitations also. In both the schemes every node take part in transmission, which eventually decrease the residual energy. So the energy of the nodes decrease fast causing their death. Death of the nodes result in network hole disrupting the network stability. Stability of SEEC is not that prominent at the beginning compared to RSM & VSM but after 800 rounds, SEEC shows more stability than RSM & VSM. The low residual energy causes the death of the nodes earlier which affects the network lifetime of both RSM & VSM. SEEC has longer network lifetime than these two schemes. Even though RSM and VSM gives high performance in throughput & data received rate, their network stability and network lifetime is less than that of SEEC.

3.10. Cooperative Depth Based Routing (CoDBR)

Incorporating co-operation with an existing routing protocol called DBR an unique scheme called cooperative DBR (CoDBR) has been proposed by Nasir et al. The main aim of this protocol is to improve reliability and throughput[38]. In DBR, a source node broadcasts the data to its neighboring node. These neighboring nodes compare their depth with their respective previous hop distance and a forwarder is selected on the basis of minimum depth. By recursion of this depth based single link procedure, eventually data from source reaches to the surface sinks by multi-hop. But this technique is prone to high bit error rate & low reliability due to multi-path fading, noisy underwater environment and hindrance posed by marine life. So authors suggested Cooperative Path diversity via multiple paths to subdue this problem in CoDBR.

CoDBR is also a localization free protocol like DBR which only needs to know the depth of the sensor nodes. Every node has the depth information of their neighbor nodes. A source node compares the depth of its neighbor nodes and the node with the minimum depth is selected as the destination for the next hop. The nodes with the second and third lowest depth are selected as relay node. CoDBR has two phases: (1) path setup (2) data transmission. A cooperative multi hop path is established from source to the sink in the first phase. Data transmission in Co-DBR is explained by Figure 10.

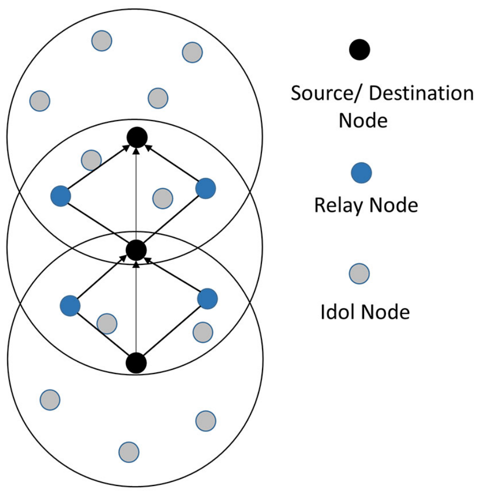

Figure 10. Data transmission in Co-DBR

If the sink is within the range of the source node, then sink becomes the next hop destination. If the sink is not within the range of the source then, source node selects next hop destination from its neighbor on the basis of the lowest depth recursively until the source node finds the sink as its next hop destination. Moreover, In both the cases two relay nodes are selected for simultaneous transmission of the same data to the destination. In data transmission phase, data is transmitted to the sink through multi hop paths which was established in path setup phase. Source node broadcasts its data to the next hop destination node and relay nodes. Relay nodes employ Amplify and Forward (AF) technique to deliver the received data to next immediate destination. Relay nodes do not forward their own sensed data rather they only amplify the data received from the source and send it to the next destination. Upon receiving these three independently faded copies of data at the next hop destination node are merged together by maximal ratio combining technique. If the Bit Error Rate (BER) of the received data crosses the threshold value T, the data packet is simply dropped. T is the maximum allowable Bit Error rate. This is done recursively until the data from the source reaches the sink. As two relay node

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also transmit along with the source node, CoDBR has the higher reliability than DBR but the energy consumption of CoDBR is higher than than that of DBR. It leads to shorten the network life of CoDBR significantly. In comparison with DBR, it offers 83% more throughput & 90% less packet drop. But due to relay nodes it incurs higher power consumption and higher delays. We have to consider this trade off to get higher reliability. Its data delivery ratio can be improved further, if the destination node ask for retransmission, in case the BER of the received data crosses the threshold value instead of just dropping the data. This will improve packet delivery ratio and throughput as well. It is also noticeable that relay nodes do not send their own data to the destination at a time in one round. Throughput can be increased further if they can send their own data and the relaying data together to the destination node in a single round.

3.11. Reliable Energy Efficient Pressure Based Routing (RE-PBR)

Khasawneh et al. propose Reliable Energy Efficient Pressure Based Routing (RE-PBR) to improve energy efficiency of the routing. Moreover, it does not need location information of the nodes for routing. It takes the link quality & depth into account along with the residual energy for reliable transmission [39]. The scheme architecture is depicted in Figure 11. The network comprised of base station, sinks and underwater wireless sensors. Underwater sensor-nodes are provided with acoustic modem and pressure sensors which are placed in different depths of sea. The vertical movement of these nodes are negligible whereas the parallel motions are considered upto 0-3 m/s[24][40]. Sinks are placed at the top of the water. All the nodes aggregate the data and deliver it to the sinks. As the nodes are placed at different depths of the sea, they employ multi-hop technique to deliver the data to the sink. The main feature of RE-PBR protocol is that, it measures link quality precisely with triangle metric in its forwarding process. No other depth based routing protocols have used triangle metric to find the link quality during data forwarding.

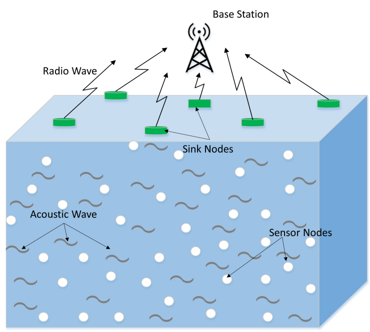

Figure 11. Network architecture in RE-PBR

Every node aggregates information like id, remaining power and depth in a data packet. This data packet is sent to each of its one hop neighbor. So each node can compare its own distance from the surface with that of sender. If the depth of the sender is more than its own depth, the node saves the data of the hello packet. Else, the data packet is discarded by the node. In this way, each node collect the data of one hop neighbor and stores them to select the best forwarding node. Then by computing the distance, the link quality based triangle metric is estimated for each stored data. Two things are considered while selecting the next forwarding node – route cost basing on the residual energy & the distance which depends on the triangle metric. Nodes eventually repeat this process till the data finds any sink for transmission.

Network lifetime of RE-PBR is longer when compared with DBR and EEDBR. This is because, in RE-PBR the forwarding node is chosen depending on their higher residual power and better link quality. The packet delivery ratio of RE-PBR is also better than that of DBR and EEDBR. Moreover the energy efficiency of this scheme is better than that of DBR and EEDBR. As there is no provision for holding or storing the data, the delay is also minimum in this routing protocol.

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3.12. Virtual Tunneling Protocol

With an aspect to improve the energy consumption, Packet Delivery Rate (PDR), transmitting path and latency, Bharathy and Chandrasekar proposed Virtual Tunneling Protocol (VTP) for UWSN[41]. There are three main steps in VTP:

- Choice of nodes for relay
- Tunneling to the destination from source
- Packet transmission through tunnel

It is a cluster based protocol where all the nodes arrange themselves in several groups. Sinks are floated on the surface of the water which acts as the destination. All the clusters in the way of source to the destination is taken into consideration. Each cluster sends data from one to another towards the destination until the packet reaches any of the sinks. Two border nodes from each cluster are selected as relay nodes- one for receiving the data and one for sending it. Border nodes and the nodes which have transmitted the latest data packet are given the highest priority for being the relay nodes. In this way, the selected groups with their relay nodes form a virtual tunnel from source to the destination with good link quality. The collected data from the source is sent continuously to the destination through this tunnel. The transmission follows three-way handshake like TCP. Figure 12 explains the data transmission process of VTP in details.

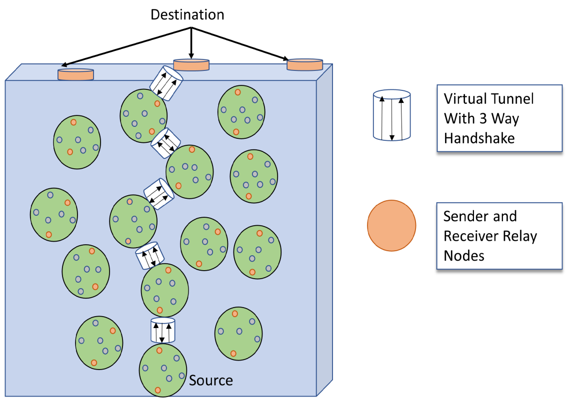

Figure 12. Data transmission in VTP

The figure shows that, a virtual tunnel is formed from source to the destination. This tunnel transfer the data from one cluster to another depending on its distance to the sink. This follows three-way handshake between the relay nodes. Due to the thee-way handshake and tunnel formation, a strong link is formed from the source to the sink (destination). Authors showed that, VTP gives better result in Packet Delivery Rate, latency and number of hops in compared to the Channel Aware Routing Protocol (CARP) and multi-level Q-learning based routing protocol- MURAO[42][43]. But this protocol do not show any results on energy-efficiency, reliability and overall performance. Moreover, VTP might not be energy conservative as it perform three-way handshake for single packet transmission.

4. Evaluation of the Routing Protocols

Different types of designing philosophies and application requirements have to be considered in most of the routing schemes proposed for UWSN. None of these protocols work efficiently for every parameters such as localization, reliability, node mobility, network life-time, latency and energy-efficiency. Every protocol has its own edge and also few drawbacks. An overview of the key features and drawbacks of the considered routing protocols are depicted in Table 1.

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Table 1. Key features and main drawbacks of different eouting protocols

Name of the Protocols	Key Features	Main Drawbacks
Vector Based Forwarding (VBF).	1. End-to-End forwarding. 2. Location based scheme. 3. Only few nodes take part in routing where others sit idle. 4. Doesn't require any state information. 5. Scalable to the network demand. 6. Energy efficient. 7. In dense network gives descent performance.	1. In sparse network packet delivery rate degraded drastically. 2. Difficult to find proper routing radius threshold.
VBF-hop-by-hop (HH-VBF).	1. The data transmission is done by ho-by-hop technique. 2. In Sparse region, it gives better packet delivery ratio than VBF.	1. Gives more signal overhead than VBF.
Distributed Underwater Clustering Scheme (DUCS).	1. It is a self changeable routing protocol which can assemble itself. 2. Distributed algorithm is used to form the clusters. 3. Intra-cluster Communications and inter-cluster communications are controlled by cluster head. 4. Random rotation of cluster head. 5. Energy efficient. 6. Increased throughput.	1. Water current may reduce cluster life by affecting its structure. 2. Inter-cluster communications depend solely on cluster head.
Depth Based Routing (DBR).	1. Packet forwarding decision by a node is taken depending on its depth and the prior sender. 2. Only the depth information of the node is necessary. 3. Gives good performance in dense network.	1. It works only in greedy mode. 2. Packet delivery ratio degrades in sparse network.
Energy Balanced Efficient and Reliable Routing Protocol ($EBER^2$)	1. Packet forwarding decision by a node is taken depending on its depth of first two hops. 2. It also considers Probable Forwarder Nodes of the next forwarder . 3.As it considers residual energy of the nodes for forwarding it also does energy optimization and energy distribution throughout the network. 4. It can avoid network void holes and gives better reliability. 5. It gives much better delivery ratio and overall performance than DBR, WDFAD-DBR and EEDBR.	1. The delay efficiency of the network is average. 2. For the consideration of the PFNs the number of duplicate packet increased.
Directional Flooding-Based Routing (DFR).	1. Per hop forwarding is followed. 2. Comparing BASE ANGLE with CURRENT ANGLE a node decides whether to forward the data. 3. It gives better delivery ratio than VBF. 4. Shorter end-to-end delay and less communication overhead than VBF.	1. Network is disrupted when a hole is created due to absence of any node near to the sink.

Continued on next page

Table 1 – continued from previous page

Name of the Protocols	Key Features	Main Drawbacks
Focused Beam Routing (FBR).	1. Avoids Unnecessary flooding. 2. It works well with both the steady and moving nodes. 3. A source node has to know only its position and position of the destination. 4. It reduces energy consumption by maintaining different power levels.	1. This scheme increases the overhead. 2. Network is more restricted as the sink is fixed.
Location-Aware Routing Protocol (LARP).	1. Good packet delivery ratio. 2. To know the nodes' location it uses a technique called RSSI. 3. Provides more reliable transmission than other routing protocols.	1. To work perfectly it needs very dense network. 2. It has low delay efficiency.
Sparsity-aware energy efficient clustering protocol (SEEC).	1. One node must be aware of the location of its neighbor nodes. 2. In both RSM & VSM sensor nodes are randomly deployed. 3. The whole region is divides into 3 equal parts in RSM and 10 equal parts in VSM. 4. They both have improved throughput, data receive rate and initial network stability than SEEC.	1. Both the schemes have low residual energy. 2. Their network lifetime is less than SEEC.
Regional Sink Mobility (RSM) and Vertical Sink Mobility (VSM).	1. One node must be aware of the location of its neighbor nodes. 2. In both RSM & VSM sensor nodes are randomly deployed. 3. The whole region is divides into 3 equal parts in RSM and 10 equal parts in VSM. 4. They both have improved throughput, data receive rate and initial network stability than SEEC.	1. Both the schemes have low residual energy. 2. Their network lifetime is less than SEEC.
Cooperative DBR (CoDBR).	1. DBR is incorporated with path diversity via multiple path to increase reliability. 2. Localization free protocol. 3. Next hop is selected based on the nodes having minimum depth. 4. Unlike DBR simultaneously same data is transmitted twice. 5. Data packet is dropped if it crosses the maximum allowable bit error rate. 5. It has higher reliability than DBR but it's energy consumption is also higher than DBR. 6. It offers 83% more throughput and and 90% less packet drop.	1. Energy consumption is higher than DBR. 2. Network life is shorter than DBR.

Continued on next page

Table 1 – continued from previous page

Name of the Protocols	Key Features	Main Drawbacks
Reliable & Energy efficient PBR (RE-PBR).	1. Depth based and localization free protocol. 2. It measures link quality precisely with triangle metric. 3. Next forwarding node is selected basing on residual energy and triangle metric based link quality. 4. Its network lifetime is longer than DBR and EEDBR. 5. Comparing it to the DBR and EEDBR it gives better delivery ratio. 6. It consumes less energy than DBR and EEDBR but provides higher reliability than these two protocol.	1. As the node increases, energy consumption increases in compared to DBR and EEDBR.
Virtual Tunneling Protocol (VTP)	1. It is a cluster based scheme. 2. It forms a virtual tunnel for a strong connection from source to the destination. 3. Three-way handshake is followed for packet data transfer. 4. It gives better packet delivery rate, latency in compared to CARP and MURAO.	1.It might not be an energy efficient scheme as it follows three-way handshake to transfer single data packet.

For evaluating the performance of both the terrestrial and underwater sensor networks most frequently used techniques are:

- analytical modeling
- real deployment and
- numerical simulation

For UWSN protocols most of the researchers evaluate their scheme with analytical modeling and numerical simulation. The most commonly used simulation tool is NS-2. Table 2. present the detailed comparison of the routing protocols considering delivery ratio, energy-efficiency,delay-efficiency, localization requirement, reliability and overall performance.

Different routing protocols are suitable for different conditions considering different parameters like network size, localization, reliability and node mobility. There is no routing protocol which gives most efficient performance in every scenario. $EBER^2$, CoDBR, RE-PBR, VTP give best performance in terms of delivery ratio whereas $EBER^2$ and SEEC are most energy efficient. The delay efficiency of RE-PBR and VTP is better than any other considered routing protocols. On the other hand, $EBER^2$, CoDBR and RE-PBR offer highest reliability in data transmission in compared to others. Considering all the metrics and factors, the overall performance of $EBER^2$ and RE-PBR are better than any other considered routing protocols for UWSN.

5. Research Applications for Underwater Wireless Sensor Network (UWSN)

Now a days underwater communication has become very important and is being employed in many practical applications like pollution monitoring, seismic monitoring, remote control in offshore oil industry, monitoring marine life, collect scientific data from different sea level, detecting natural disasters and warn beforehand, discovering natural resources and national security monitoring. Mohsin and prasant work on the topic of early warning of different natural events including hazards[44][45]. Prasant and preetam proposed a low power underwater sensor network enabling

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Table 2. Evaluation of the Routing protocols

Protocol	End-to-End / multi-hop/ Clustering	Delivery Ratio	Energy Efficiency	Delay Efficiency	Localization requirement	Reliability	Performance
VBF	End-to-end	Low	Medium	Low	Not Needed	Low	Low
HH-VBF	multi-hop	High	Low	Medium	Not Needed	High	Medium
DUCS	multi-hop	Medium	High	Low	Not Needed	Low	Low
DBR	multi-hop	High	Medium	High	not Needed	High	High
EEDBR	multi-hop	High	High	High	not Needed	High	High
$EBER^2$	multi-hop	Very High	Very High	Medium	not Needed	Very High	Very High
DFR	multi-hop	Medium	Medium	Medium	Needed	High	Medium
FBR	multi-hop	Medium	Medium	High	Partially Needed	Medium	High
LARP	multi-hop	High	Medium	Low	Needed	High	High
SEEC	Clustering	Medium	Very High	High	Not Needed	High	High
RSM And VSM	multi-hop clustering	high	Medium	High	Not Needed	High	High
CoDBR	multi-hop	Very High	Low	Medium	Not Needed	Very High	high
RE-PBR	multi-hop	Very High	High	Very High	Not Needed	Very High	Very high
VTP	clustering and multi-hop	Very High	Low	Very High	Not Needed	High	High

system for early warning generation of natural hazards like earthquake, tsunamis, hurricanes, floods with necessary information[45]. Underwater communication is also being engaged in applications like ocean sampling network. Monterey bay experiment is one of them which has already shown the improved ability to observe and predict ocean environment using more delicate vehicle and reliable network[2]. UWSN can also be deployed for finding mineral mines. Researchers have developed a UWSN which can be deployed along with Remotely Operative Underwater Vehicle (ROV) incorporated with wireless sensor communication module facilitating vision based monitoring system and monitors. This can be used in detecting and measurement of underwater manganese crust[46][47]. Moreover, researchers have developed a UWSN combining underwater mobile network along with underwater acoustic network for large scale deep sea scan thus to find mineral mines and dig out[46][48].

A real time research is done on Underwater Acoustic Network (UAN) testbed for ecological monitoring in Qinghai Lake from which we can get information about water course, nature and living life of the lake[49]. As it's a salt water lake and also undergoes many natural hazards, it is closest to the real time deployment of UWSN in the marine environment. It is another major step in the real time surveillance of sea area which covers the most part of the water bodies. Researchers have proposed a underwater group based sensor network for marine farms which can accurately measure the amount of food wasted and dirt deposited on the sea bed[50]. Moreover, Mohamed et al. proposed a sensor network model for monitoring underwater pipelines which can be used for monitoring underwater marine cables, gas and oil pipelines[51].

6. Conclusion

A detailed evaluation and survey of the latest advanced routing schemes for UWSN is done in this paper. The nature of underwater acoustic communication and network architecture in regards to reliability, latency, energy-efficiency and localization is described. Moreover, using these basic factors as metrics, overviews of few significant routing protocols of UWSN is done. Due to energy limitations, harsh environment, path loss and low data rate, designing of routing protocols have become a challenging issue and a vital research area due to its vast application. Each of the considered routing protocols poses some robustness and weakness depending on the underwater networking environment and scenario in which the network is to be deployed. Different protocol is suitable

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for different situations and functions depending on the priority of the demands and deploying environment. Considering all the factors, the overall performances of $EBER^2$ and RE-PBR is better in compared to all other considered routing protocols.

This paper summarizes the routing protocols and encourages research efforts to improve the routing protocols of UWSN for enhanced underwater monitoring and exploration. The future work is to explore more about routing protocols and localization to improve its challenges and to propose a more reliable, efficient but a flexible Routing protocol.

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