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Research Article

USPF: Underwater Shrewd Packet Flooding Mechanism through Surrogate Holding Time

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The selection of optimal relay node ever remains a stern challenge for underwater routing. Due to a rigid and uncouth underwater environment, the acoustic channel faces inevitable masses that tarnish the transmission cycle. None of the protocols can cover all routing issues; therefore, designing underwater routing protocol demands a cognitive coverage that cannot be accomplished without meticulous research. An angle-based shrewd technique is being adopted to improve the data packet delivery, as well as revitalize the network lifespan. From source to destination, one complete cycle comprises three phases indeed; in the first phase, the eligibility of data packet belonging to the same transmission zone is litigated by Forwarder Hop Angle (FHA) and Counterpart Hop Angle (CHA). If FHA value is equal or greater than CHA, it presages that the generated packet belongs to the same transmission zone; otherwise, it portends that packet is maverick from other sectors. The second phase picks out the best relay node by computing a three-state link quality with prefix values using the Additive-Rise and Additive-Fall method. Finally, the third phase renders a decisive solution regarding exorbitant overhead fistula; a packet holding time is contemplated to prevent the packet loss probability. Simulation results using *NS2* have been analyzed, regarding packet delivery ratio, packet error rate, communication overhead, and end-to-end delay. Comparing to HHVBF and GEDAR, USPF indeed has outperformed, leading into the evidence of applicability's favor.

1. Introduction

Underwater communication is a quite different and challenging phenomenon. The classical routing algorithms are not suitable for such environment, although these algorithms are suitable for terrestrial sensor networks indeed. Underwater environment possesses unique characteristics like transmission medium and the signal constrained to transmit the data [1]. Radio waves are not suitable for underwater communication as it possesses severe attenuation fistula and requires large antenna with high transmission power that tends to get observed for long range communication [2]. An optical signal leaves negative impact on underwater data communication; it suffers from heavy scattering issue and a careful handling is needed while pointing the narrow laser beam that's applicable only for short range line of sight applications [3]. Acoustic medium has been considered the only available solution to transmit the sensed data in underwater environment. The speed of acoustic signals is much higher in water than in air mainly, depending on salinity, density, temperature, and so forth. Underwater acoustic wave operates at 1500 m/s which is five order magnitudes less than the speed of electromagnetic waves [4]. An acoustic channel has temporal frequency spectrum but spatial underutilization. UWSNs stand to face numerous challenges like confined bandwidth with exorbitant channel error rate, temporal path losses, and multipath fading in shallow water; unlike terrestrial network, the nodes are not static and moves 2-3 m/s with water current [5]. Though speed of acoustic wave is stable in underwater but due to volatile nature of underwater creatures and water current, the acoustic wave reflects in multipath direction when impending to bottom surface. Consequently, variations in speed of sound resulted but a directional transmission can dwindle such probability [6]. A multihop routing causes packet loss with unavoidable delay factor that leads to unreliable communication; therefore, ample retransmissions are required to deliver packet successfully. The localized sensor nodes are fully battery dependent and hard to recharge in such unpredictable harsh environment while replacement could increase a high bit cost [7]. An UWSN enhances the research constituent at large, from underwater warfare to unseen and unpredictable conditions like oceanic accidents, climate and seismic alert, pollution content, tactical surveillance, offshore sampling, and navigation assist. With UWSNs, oil companies got unbelievable achievement in oil and gas exploration sector. In addition, getting oceanographic data, mine recognitions, submarine detection, and nourishment products is made possible. An underwater protocol defines the size of a data packet containing load and bit error rate. An inappropriate packet size selection not only decreases the network throughput but also wastes the resources [8]. The performance of underwater network greatly depends on topology design led by an epitome relay node selection process that eventually increases the packet delivery probability to the destination node. The energy consumption ratio of an intelligently designed topology is highly confined compared to an uncouth and less efficient topology.

Underwater network topologies fall into two categories namely motion-based and coverage-based topologies. A motion-based routing is accompanied by the stationary or localized nodes, while coverage-based routing renders two-dimension and three-dimension UWSN [9].

(a) Motion-based UWSN: to monitor the certain underwater constituent, sensor nodes are anchored at fixed locations, such as surface buoys or bottom surface. These localized sensor nodes possessed various fidget characteristics, floating dynamically and constantly changing location and mainly controlled by a navigation system.

(b) Coverage-based UWSN: it mainly consists of two-dimensional and three-dimensional architecture. For a two-dimension topology, the sensor nodes are anchored at the same depth and utilize underwater link for communication responsible for raw data collection and transport to offshore station. The sink nodes are fixed with horizontal and vertical transceiver which gather sensed data from surrounding nodes. An ocean can be as deep as 10 km; therefor, vertical transceiver should have long range enough, sending data to offshore station while horizontal transceiver is in charge of handling the command towards sensor nodes to get sense data. In order to manage multiple parallel communications, the surface sinks are equipped with acoustic transceiver as well the radio transmitter [10]. The underwater sensor nodes may have direct link with sink node or indirect link via multihop path (relay node). A direct link is a simple communication path but not an energy efficient solution indeed; when sink node located far away from sensor node the power necessary to transmit the packet may decrease with power greater than twice the distance [11]. Therefore, it engulfs high transmission power which likely reduces the network throughput and high acoustic interference might be the result. A multihops link approach increases the delay factor because data is relayed between intermediate nodes which tangle the routing labyrinth. In addition, two-dimensional underwater routing faces key challenges in respect of communication range: selection of water surface and bottom depth.

A three-dimensional underwater sensor network is an enhanced form of a 2D UWSN; the sensor nodes freely float at arbitrary water level to capture the sensed data. It is a more jingoistic approach to attach the sensor nodes with floating buoy at bottom depth and buoy holds the sensor nodes and pull toward the water surface [12]. Anchor nodes' depth can be controlled by adjusting wire length. There are numerous hindrances facing 3D underwater communication; for example, sensor depth should be adjusted ingenuously to get sensed data smartly and network topology should remain connected.

1.1. Underwater Acoustic Signal Propagation Factors. An underwater environment is highly dynamic and acoustic communication ever suffered by variable factors due to bandwidth of an acoustic channel is remnant and merely hangs on frequency and distance between the sensor nodes. The underwater communication differs by ocean division as shallow and deep one. A shallow water possessed high temperature, multipath effect, surface noise, and large propagation delay that ultimately adverse the performance of acoustic signals; whereas,deep ocean water inherits some bequeaths but with different dimensions. Shallow and deep water salient features are listed in Table 1.

Some maleficent propagation elements are pragmatically analyzed in series as follows.

(a) Path loss: a propagation effect implicitly increases the underwater temperature which results in shaky path among the sensor nodes and signal strength becomes atrophy. Path loss is further divided into three segments as follows.

(i) Geometric spreading loss: sound wave hangs on distance but independent of frequency [13], when propagating in deep-water, it generates the spherical spreading loss while causing a cylindrical spreading loss in shallow water.

(ii) Signal attenuation: attenuation lies on frequency and distance between the sensor nodes

Table 1: Salient features of shallow versus deep water.

Feature	Shallow water	Deep water
Temperature	High	Low
Depth	0 to 100 meters	
Multipath loss	Surface reflection	Surface and bottom reflection
Spreading factor	Cylindrical	Spherical

[14]. It is due to the conversion of acoustic energy into another form of energies like heat energy.

(iii) Scattering: it occurs due to a change of angle position to acoustic waves. Varying wind speed causes the roughness of surface area that raise the decay of scattering surface, eventually causing the transmission delay and power loss in underwater communication [15].

(b) High propagation delay: as acoustic signal operates at 1500 m/s, it incorporates unending delay factor about 0.67 s/km which causes a high propagation layoff in the transmission [16].

(c) Noise ratio: any unavoidable condition may atrophy the signal strength in communication causes adding the noise ratio in the system. For an UWSN, ambient noise occurs due to various unknown sources that cannot be identified. The ambient noises are grouped into four categories, namely, (i) wind noise, (ii) shipping noise, (iii) thermal noise, and (iv) turbulence noise. A wind noise occurs due to varying wind velocity which causes the breakage of acoustic waves. Shipping voyage creates the hurdles in acoustic signal due to the fact that acoustic waves divert from destination. Ocean tide generates low frequency turbulence which causes a nonlinear noise during communication phase. Sometimes system creates a matchless noise referred to as a self-noise, which does not have any resemblances with the rest of noises but has direct proportion with frequency know as thermal noise.

(d) Multipath enigma: in underwater communication, multipaths are generated when sound waves impinge to water surface and bottom of the shallow and deep ocean, causing uncouth acoustic communication hindrance which leads to erroneous signal and creates multipath effect. The impulse response of an acoustic channel leaves a dissident impact on variable propagation paths and strength. Due to an uneven sound speed the numerous paths are created and paths only possess delimited reflection and lite energy losses are considered.

2. Related Work

In underwater communication, natural and artificial acoustic system use the middle range frequencies. During the second world war, for the first time USA military adopted underwater communication for submarine system; and till today, UWSNs achieved scrumptious development in link establishment, media accessibility, localization, coding, and modulation techniques. The energy consumption during relay node formation is well explored as a first-order energy model in [17] with adequate energy path occupying equally spaced relay nodes with optimal distance being determined but possessing lack of implications on routing scheme.

Xie et al. [18] proposed an idea of a virtual pipeline in vector based forwarding (VBF). Between source and destination there exists a virtual pipeline and packet travels through this route toward destination nodes. The destination node checks whether packet belongs to virtual pipeline or not; if yes, then it validates by holding time desirable factors. Every time the same sender forwards the packet which is prone to die soon; thereby, exorbitant energy is consumed and probability of packet failure becomes higher. This idea is not feasible for sparse network as paths become vulnerable in virtual pipeline.

A belligerent idea of energy aware and void avoidable routing is blurt out by Wang et al. [19] (EAVARP), where the authors built the concentric shells around the sink node and sensor nodes are dynamically placed within these shells. Additionally, they adopt an opportunistic directional forwarding scheme (ODFS), where data packets are within the same shell, with the remaining amount of energy forwarded which lets bypassing any void region if occurring. Though, the authors proposed a smart shortcut but could not follow the energy wastage scheme which ultimately shortened the network life span.

Underwater acoustic sensor networks (UASNs) are deployed on Named Data Networking (NDN) by Xing et al. [20], using relay node topology. The energy consumption factor is explored for deep and shallow water. The proposed parameters are not applicable when void conceals the active nodes; thereby, no further solution is available yet.

A fuzzy based routing protocol has been broached by Huang et al. [21] aiming to utilize the energy efficiently. This fuzzy system utilizes battery power efficiently and keeps the energy usage at trivial most. Apparently, overhead and end-to-end delay are degraded. However, this scheme accelerates the complexity in dense situation and no solution is given for collision avoidance.

The author in [22] proposed a lower power listening (LPL) mechanism to monitor the faulty nodes and energy wastage through ContikiMAC Cooja in UWSN. The energy consumption is reduced in centralized and distribute approaches. The author figures out the energy consumption with end-to-end delay by proposing a stochastic model for UWSN. However, the proposed model considers cylindrical propagation but lack of common spherical.

Energy efficient routing protocol is encapsulated by Ali et al. [23] to unveil the idea of angle-based routing in the form of diagonal and vertical routing protocol (DVRP). It keeps battery usage trivial and eliminates the end-to-end delay as well. Routes have been created using local information and packet forwarding is accomplished by flooding zone. The authors could not contemplate regarding eradication of duplicate packets.

On the other hand, Yildiz [24] proposed a data fragmentation technique to avoid the packet collision in UWSN. Though the proposed idea is valuable to confine a number of retransmissions and energy consumption which eventually lowers the end-to-end delay probability, no measures have been taken to get rid of channel congestion caused by data fragmentation.

A *QELAR (machine learning)* based eminent approach is suggested by Hu and Fei [25] that led to implementing the adaptive routing protocol. It debuts a reward function which tends to calculating and distributing the sensor nodes' residual energy evenly whereas nodes are subject to remaining alive throughout the operation. The reward function is responsible for allocating relay node to debut the routing. Though scrumptious performance is achieved, frequent updates for residual energy make the entire network bottleneck.

To make UWSN long lasting, an energy balanced and lifetime extended protocol (EBLE) with a cost function is claimed by Wang et al. [26]. It operates in two cycle, that is, the candidate forwarding and data transmission. The position and residual energy information of neighboring nodes with cost value are gathered and analyzed by the cost function. In the next cycle node possesses greater residual energy and trivial cost values have higher priority.

An abstract hop by hop vector based (HH-VBF) independent virtual pipeline from forwarder to sink node is presented by Nicolaou et al. [27]. This scheme has more chances to discover the suitable number of forwarders while packet holding time remains the same as that of VBF but it possess better packet delivery ratio than VBF. Similarly, Yu et al. [28] proposed a modified version of HH-VBF as "Adaptive HH-VBF" (AHH-VBF), where distance and transmission power are controlled by an arbitrary mechanism and duplicate packets from forwarder are controlled by making an adjustment in the radius of pipeline. Neighborhood table is maintained by incoming request along with received messages at varying transmission level. Therefore, a confined and best energy utilization model resulted. Regarding drawback, source node always selects the same forward each time which is not a legitimate method in UWSN; therefore, selection of best and potential forwarder cannot be achieved.

Zidi et al. [29] presented an optimal routing setting to avoid the energy sink holes in underwater communication when an evenly distributed power level is utilized by the sensor nodes with appropriate transmission power adjustments. In addition, the deployment is achieved in two steps, with either fixed or variable nodes possessing separation distance. It claims a uniform energy consumption by all sensor nodes that is hard to be confirmed by simulation results.

To utilize underwater acoustic channel with maximum gain, Luo et al. [30] proposed a cognitive acoustic method which shrewdly analyzes the spectrum performance and control over both power and frequency. It can set the temporal operational parameter to utilize the idle frequencies without knocking other parallel networks. Eventually, the communication is led to be erroneous-free and creates aquatic friendly environment more suitable for marine creatures.

Continuing to energy efficient network, Pooranian et al. [31] arranged the number of nodes in a clustering formation through queen-bee (QB) algorithm. In nature, queen-bee algorithm is based on foraging technique where honey bees rover to get food from flowers and stock back at bee nest. The same strategy has been applied for clustering nodes where every node retains energy after a definite interval. The outcomes of the strategies are best for terrestrial network but not for underwater routing.

Varying temperature effects are shown in Table 2 that affect throughput of the acoustic channel.

Considering various performance factors, the most commonly used localized and nonlocalized underwater routing protocols regarding forward node selection procedure are critically summarized in Table 3.

3. Methodology

Energy efficient and shrewd data packet forwarding architecture is based on conducive and mitigated flooding zone that instigates the link quality prior to sending the packets. The flowchart in Figure 1 comprehensively depicts the flow of information among all stages. When a node broadcasts the packets within transmission zone, only confined numbers of packet shall participate in forwarding process that prevents the packet being flooding into the entire network. The decision-making process is carried out pertaining to angles between source and destination nodes and makes comparison to neighboring couplet nodes which stipulates packets eligibility by computing FHA ≥ CHA values. Active links are determined by the angle α amid node P. When source node S sends a packet, node P determines to receive or rebuff it. If the active forwarding link is prone to be poor to its neighbor, the source node floods more packets to make more nodes in advance to potent the link more scrumptious and, therefore, avoid the chances of void occurrence.

3.1. Proposed Architecture. In the proposed architecture (Figures 2(a) and 2(b)), two angles are proposed: *Forwarder Hop Angle* (FHA) and *Counterpart Hop Angle* (CHA); FHA contains hop distance from nodes S to $P(SP_d)$ and P to $D(PD_d)$ while CHA is occupying hops between nodes S to $Q(SQ_d)$ and Q to $D(QD_d)$.

In order to forward the packet to node P, the packet is scrutinized by computing FHA and CHA value. This ensures that no packet shall be flooded out other than the source node's zone. Further proceedings with Law of Cosine [32] to determine the value of FHA are as shown in the following:

$$\text{FHA} = \alpha \frac{(SP_d + PD_d)}{(\text{RE}_p)}, \quad (1)$$

where RE_p is a residual energy of node P. Similarly CHA is obtained as follows:

Table 2: Varying temperature effects on acoustic channel.

S. No	Area focused	Findings	Sound speed effects due to temperature
01	Underwater routing challenges	The higher the ocean temperature, the greater the speed of sound, but lower in cold ocean. The speed of sound advances 4 m/s when water increases by 1°C.	Increase with temperature
02	Underwater wireless communication problems	Reflection and refraction affect the acoustic communication in shallow water regarding ambient noise and temperature gradients.	Affects communication
03	Underwater transmission faces hindrance by temperature variation	Factors like salinity, depth, and temperature affect the speed of sound, which ultimately affect underwater transmission.	Variation in speed
04	Variable depth and temperature have unequal channel capacity	At a short distance, with the increase of temperature, having higher channel capacity	Improves throughput
05	Underwater channel simulation	Sea surface temperature gets higher and gets down at depth. When temperature, depth, and salinity vary they also affect the velocity of sound.	Increases with temperature
06	Mathematical equation for sound speed in the oceans	Temperature remains a dominating factor that has effect on the sound speed.	Increases with temperature

Table 3: Comparative analysis of underwater next forwarding nodes selection protocols.

Type		Protocol	Objectives	Principle area	Neighbors selection strategy	Forwarder selection strategy
Localization routing protocols	Virtual shape	VBF	Robust, scalable, energy efficient	Distance information	Neighbors placed inside pipeline from source to sink	Minimum distance to the sink inside the pipeline
		HH-VBF	Energy efficient, robust	Distance information	Neighbors placed inside each single pipeline from each source to destination	Minimum distance to the sink inside pipelines
	Energy efficiency	PER	Energy efficient, improving the network lifetime	Residual energy, distance information, angle information	Neighbors based on their angle and distance to sink	Minimum distance to the sink with angle value and the highest residual energy
		SEANAR	Energy efficient, topology aware	Residual energy, distance information, node degree	Neighbors placed in layer (inner and aside)	Minimum distance to the sink with layer (inner and aside) and highest residual energy
	Void aware	VBVA	Void handling and energy efficient	Distance information	Neighbors placed inside each single pipeline from each source to destination	Minimum distance to the sink inside pipelines
		FBR	Energy efficient, scalable	Distance information	Neighbors placed in cone from each source to destination	Minimum distance to the sink inside the cone
		DFR	Reliable packet delivery	Distance information and link quality (ETX)	Neighbors placed in zone based on angle and reference	Minimum distance to the sink inside the zone with best link quality (ETX)
Nonlocalization routing protocols	Addressing based	H2-DAB	Robust, scalable, energy efficient	Address information	Neighbors with lower dynamic address	The lowest address
		2H-ACK	Ensure reliable data deliveries, energy consumption	Address information	Neighbors with lower dynamic address	The lowest address
	Energy efficiency	APCR	Ensure data delivery	Layer information residual energy	Neighbors with lower ID	Lower ID with highest residual energy
		DBR	Energy efficient, scalable	Depth information	Shallower neighbors	Shallower neighbor with lowest holding time
		DBMR	Energy efficiency	Depth information, residual energy	Shallower neighbors with calculated weight value	Shallower neighbor with the highest weight and lowest holding time

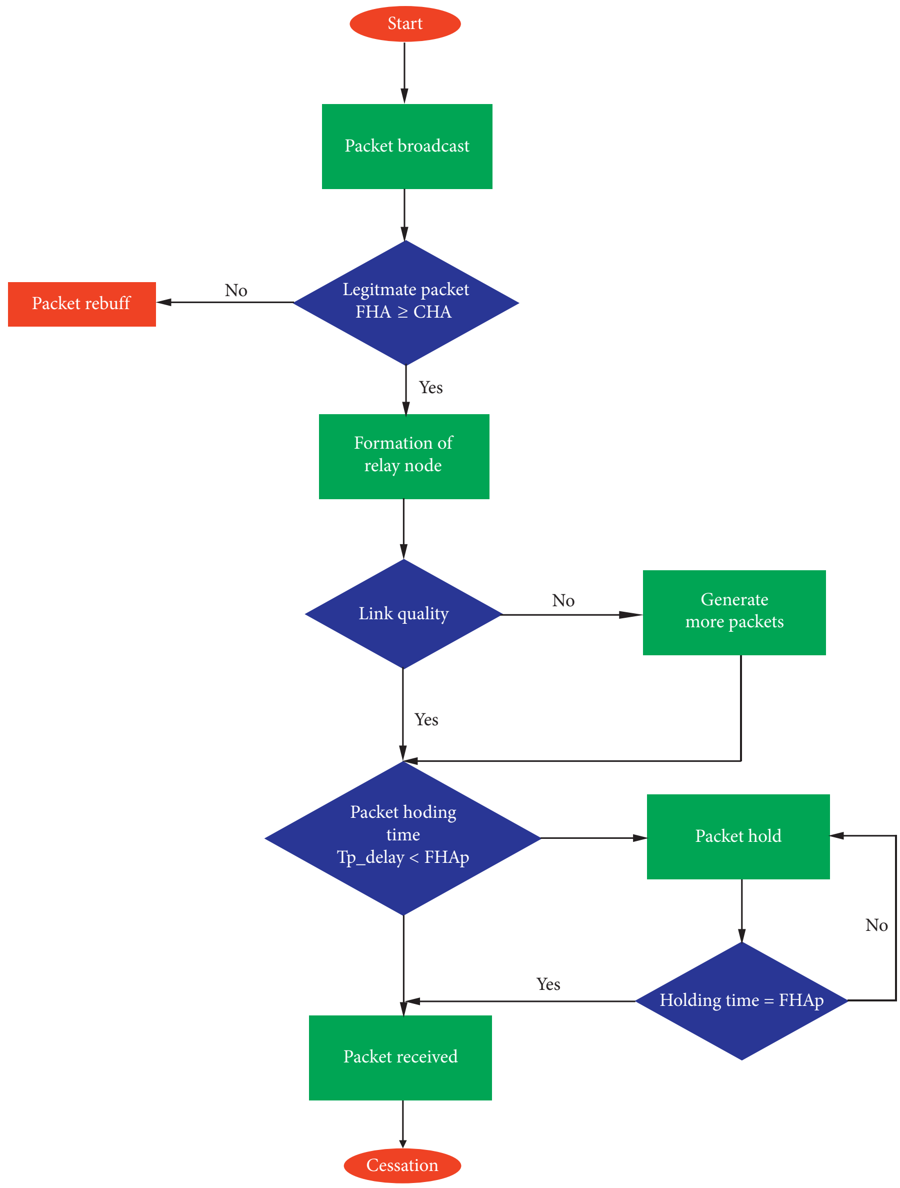

Figure 1: USPF operational flowchart.

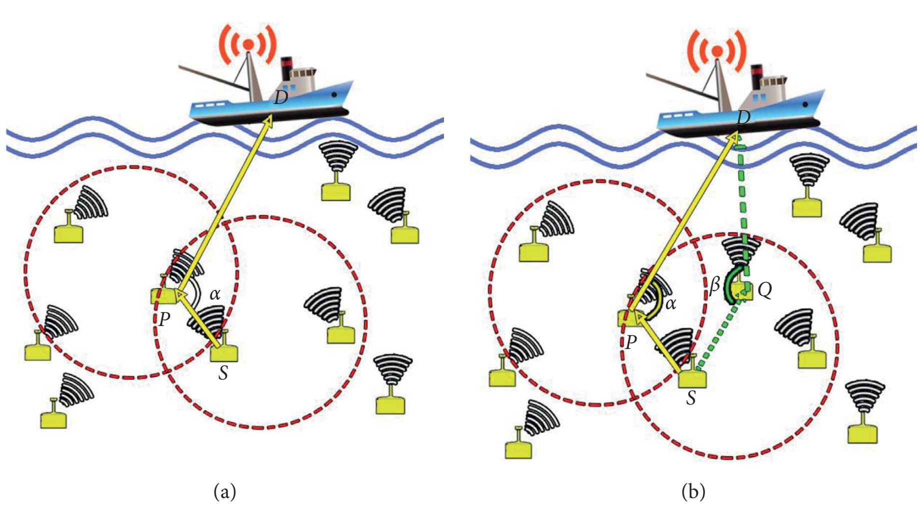

Figure 2: Forwarder Hop Angle (FHA) and Counterpart Hop Angle (CHA) operational architecture.

$$\text{CHA} = \beta \frac{\left(SQ_d + QD_d\right)}{\left(\text{RE}_q\right)}. \quad (2)$$

Node p forwards the packets toward next neighboring node including its Forward Hop Angle value. If FHA is equal or greater than CHA, this assures that node belongs to the same transmission zone, further updating the CHA parameter and packet duly rovers toward destination. However, if FHA is found to be lower than CHA, it concludes that received packet does not belong to the same flooding zone and thereby is rejected. The weighting factors are α and β which increase the advances toward destination node as well as link quality.

Any neighboring node lies out of transmission zone cannot overhear the packet; eventually, traffic congestion and energy consumption will get lower. In a dense environment when multiple forwarders are available, the holding time for hop angle sets criteria whether to allow the forwarder to proceed or not because the proposed scheme relies on flooding mechanism rather than depending on link passage. In addition, the size of flooding zone is managed by the forwarder node and a full relay node formation has been sought in Algorithm 1.

3.2. Contributions. The proposed USPF method adopts the idea of Forwarder Hop Angle and Counterpart Hop Angle provides threefold benefits. (i). Packet forwarding hangs on the angle of the link; therefor, no use of control message to repair the passage and thereby less routing load occur. (ii). The number of transmission cycles is fewer. (iii). Nodes within flooding zone are legitimate for packet forwarding; therefor, state of reliability is achieved.

3.3. Link Reparation Adjustment. In order to maintain a link quality between forwarder node P and neighbor nodes illustrated in Figure 3, the Additive-Rise and Additive-Fall methods [33] are utilized which eventually adjusts the states of Forwarding Hop Angle values.

Step 1: When link state (Sh_L) is shaky or ramshackle compared to the prefix value (Prefix_v) with neighboring nodes, the forwarder node p adjusts the path by generating more packets αi to explore the next forwarding node more scrumptiously.

Step 2: If the link state (St_L) is stable and satisfies the prefix value (Prefix_v), thereby packet forwarding is carried out without any hindrance.

Step 3: At a point when link state (Nr_L) is normal but not ready to forward the packet due to some salinity effects, it requires some energy packets with extra shell to proceed and, therefor, only fewer nodes shall participate in forwarding.

Link reparation has been explained in Algorithm 2.

A flooding zone is adjusted with link quality from forwarder to neighboring nodes only. According to equation (3) every node updates the threshold value on temporal basis. A better link always sets small forwarding delay.

$$\text{FHA}_p = \begin{cases} \alpha i + \text{sh\_}L, & \text{if } \alpha i < \text{Prefix\_}v, \\ \alpha j, & \text{if } \alpha i = \text{Prefix\_}v, \\ \alpha k + \left(\text{Nr}_L\right) - \left(\text{sh\_}L\right), & \text{if } \alpha i > \text{Prefix\_}v. \end{cases} \quad (3)$$

There is very rare chance for flooding zone getting effete by void occurrence during the reparation of the Counterpart Hop Angle because Counterpart Hop Angle value is dynamic in hop by hop fashion. Nevertheless, every relay node is well aware about Counterpart Hop Angle of thereabout nodes' and apparently makes possible for nodes to take part in forwarding process thereby avoid the void tangle.

3.4. Holding Time. Traditional underwater routing protocol utilizes the link quality estimator (*Expected Transmission Count-ETX*) to choose the best quality path between nodes and forwards the data packet thereon. ETX is suitable for sparse UW network but fails in dense environment under a high traffic load [34]. An increment in traffic overhead led to decreasing ETX value from 30% to 10000% [35].

In order to smoothen the packet forwarding mechanism during heavy overhead and to decrease the probability of packet forwarding fiasco, each node utilizes a surrogate packet holding technique, thereby, reducing the collision due to the fact that packet loss could be minimized. Holding time hangs on link quality between the nodes; thereby, nodes with pristine link resulting in shorter holding time and lesser number of retransmissions and reduce the overhead. For instance, for a node with strong link when forwarding the packet with shorter holding time towards neighboring node, the chances are high to overhear it. In contrast to node with atrophy link when forwarding the packet, the neighboring node may not overhear it and an additional forwarding may result in the packet suppression and energy wastage as well. A link quality is set to consider the average estimation of successful packet delivery between two nodes and each node is responsible for calculating its holding time by equation (4).

$$\text{Holding Time} = T_{P\_\text{delay}} \frac{\gamma\left(P_{\text{good}} - P_{\text{node}}\right)}{\left(P_{\text{good}} - P_{\text{bad}}\right)}. \quad (4)$$

The propagation delay between two nodes hereby is symbolized as T_{P_delay} while γ represents the network parameter when setting the maximum transmission range. The packet delivery status is depicted as Good P_{good} and Bad P_{bad} delivery between sending and neighboring nodes. A successful packet delivery is represented by P_{node}.

An eminent holding time representation is shown in Figure 4; among all the nodes, O and R possessed pristine links, T_{P_delay} and γ shall be 1 when propagation delays for all nodes are set to uniform. At first instance, nodes O and R transmit the packet and while holding time has been calculated to be zero. Meanwhile, node P and Q hold the packets until $0.6 \times T_{P\_\text{delay}}$ and $1.1 \times T_{P\_\text{delay}}$, respectively. Thereupon, some arbitrary packets are generated by node O or R and nodes P and Q shall receive them immediately which results in suppression. Hence total of 3 packet transmissions occurred from source to destination node; this

(1) Sensor node S broadcasts the packet (Pkt_{br})
(2) Node P receives the packet (Pkt_{rcv})
(3) P determines path (SP_d), locates the destination D (PD_d)
(4) (FHA) Forwarder Hop Angle appears at P, count α
(5) Neighboring node with higher residual energy RE, (CHA) Counterpart Hop Angle Q, count β
(6) If FHA > CHA then Q is within transmission range Else
(7) If FHA < CHA, (Pkt_{rcv}) rebuff
(8) End if

Algorithm 1: Relay node formation.

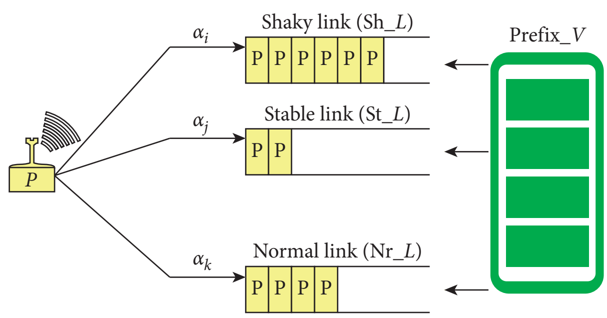

Figure 3: Link reparation phase.

(1) Input: α_i(Sh_L), α_j(St_L), α_k(Nr_L), Prefix_v, FHA_p Output: Next hop relay node Q
(2) Node P broadcasts packet (Pkt_{br}) towards Q While FHA ≥ CHA, count β
(3) Endwhile
(4) If Sh_L is shaky than Prefix_v
(5) $FHA_p = \alpha i$ + sh_L;
(6) if $\alpha i > Prefix_v$ then
(7) $FHA_p = \alpha i$ + (Nr_L) − (sh_L)
(8) if αi is eligible then FHA_p = Prefix_v
(9) End if
(10) else rebroadcast (Pkt_{br}); detour (Algorithm 1, perform line 6)
(11) End if rebuff (Pkt_{br})

Algorithm 2: Link reparation.

might increase to more than 5 if there was not the packet holding time and at destination node packet collision may be the case.

4. Performance Evaluation

The USPF scheme cognitively depends on the size of flooding zone as well as the direction of angles. Simulation is conducted by an object-oriented discrete event simulator NS2 with Aqua-Sim package for underwater attainment, which hangs out all the results in discrete events. Simulation performance was evaluated by 1000 iterations with 800 nodes, deployed randomly across the defined area with dimensions 1000 m × 1000 m × 500 m. The bandwidth and communication range were set to 30 kHz and 500 m, respectively. Each data packet size is fixed to 50 bytes. Every node started dynamic displacement and could move to new position with speed between 1 m/s and 5 m/s. Sensor MAC (S-MAC) protocol is used at MAC layer that is fully supported with energy constraints for UWSN [36]. It possessed a timely wake-up mechanism that controls the fixed length alive and fixed length sleep periods of the nodes. The S-MAC is proficient to deal with idle listening states and the collisions as well. Therefore, by adopting sleep schedule mechanism, the wastage of energy could be reduced with idle listening state.

Packet delivery and network overhead have been meticulously analyzed by surrogate Nr_L and Sh_L values. Changing Sh_L angle from 0 to 30° and Nr_L 0 to 45° found that size of flooding zone is changed in lieu packet delivery and network overhead is affected as well. Therefore, it is concluded that by adjusting values for Nr_L and Sh_L best results are obtained for the proposed scheme.

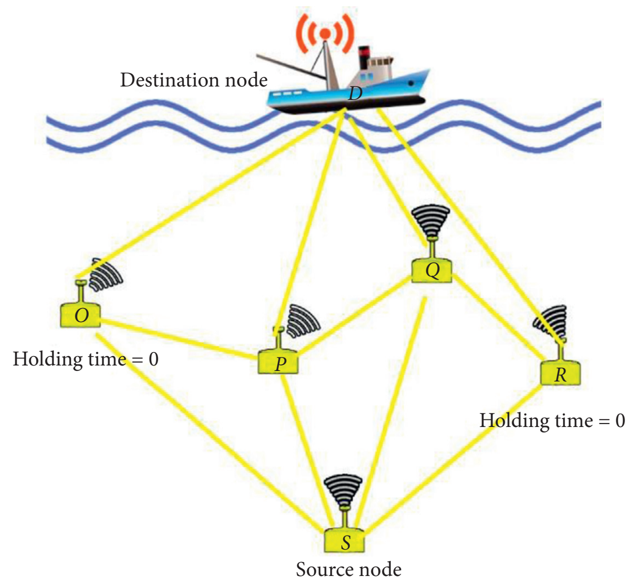

Figure 4: Link reparation phase.

4.1. Angle Displacement: Packet Delivery Ratio. Ratio at which packets are received successful to the destination (sink) node at water surface generated by all sensor node is called a Packet Delivery Ratio. From Figure 5(a), when Sh_*L* increases and Nr_*L* decreases, thus overall packet delivery ratio is also increased.

4.2. Angle Displacement: Communication Overhead. While changing an angle of orientation to a minor displacement, it is prone to affect the flooding zone; thereupon, flooding zone blurts out due to various transmission adjustments depicted in Figure 5(b). Therefore, Sh_*L* and Nr_*L* have lowered the communication overhead in specific ranges of the packet delivery ratio.

4.3. Packet Error Rate. It could be observed (Figure 6), for USPF and HHVBF protocols, the packet error rate is inversely proportional to the packet delivery ratio. In HHVBF, packets are forwarded along with routing vector without considering any link quality, whereas, the proposed USPF dynamically determines the number of nodes participating in forwarding the packet according to the average link quality and even it produced a 35% less packet error rate than HHVBF.

To some extend void instance appears and may affect the USPF packet delivery ratio as depicted in Figure 7, when approaching near node 80 but it is a temporal effect. In addition, as the packet error rate increases, the packet delivery ratio is decreased because relay nodes suffered from packet losses. Thereon, HHVBF possessed the worst packet delivery ratio because it does not address the void problem at all. On the contrary, USPF has the best delivery ratio because it controls the flooding zone in order to achieve the reliable packet delivery ratio at sink node. USPF has 13% and 25% higher packet delivery ratio than HHVBF and GEDAR respectively.

4.4. Communication Overhead. A geographic routing relay on message transmission-based procedures explore and maintains thereof explicit paths to route the packets along with communication void regions but it impinges an extra overhead to acoustic channel which renders the packet collision. In addition, a GEDAR uses greedy opportunistic mechanism to route the data packet for any destination without considering the link status that results in higher communication overhead as illustrated in Figure 8. The HHVBF utilizes three-way handshaking technique to transmit the packet. The packets are flooded out along the routing vector which is redefined per hop and additionally it requires more packets to detours path which increases overhead as appearing in Figure 8 whereas USPF has utilized only pristine link to forward the packet regardless of number of nodes; thereby, only fewer nodes have participated in forwarding which degrades the overall communication overhead as compared to GEDAR and HHVBF.

4.5. End-to-End Delay. An average delay for all data packets received successfully at sink node is known as the end-to-end delay. A pragmatic comparison for end-to-end delay between USPF, GEDAR, and HHVBF has been illustrated in Figure 9.

It is assumed that each node merely utilizes 0.3 seconds to process the data from receiving to transmitting states; thereby, each relay induced at least 0.3 seconds for each sending process. A longer routing path might cause the higher delay ratio which cannot be ignored in the transmission. As HHVBF follows a three-way handshaking process before the data packets are transmitted [37], a large end-to-end delay is found. According to the GEDAR results, it seems that more nodes are in void region that increases the delay instance; thereby, packets are queued in recovery mode to get rid of void fistula but it becomes too long in lieu instance. Due to the shrewd void avoidance mechanism the

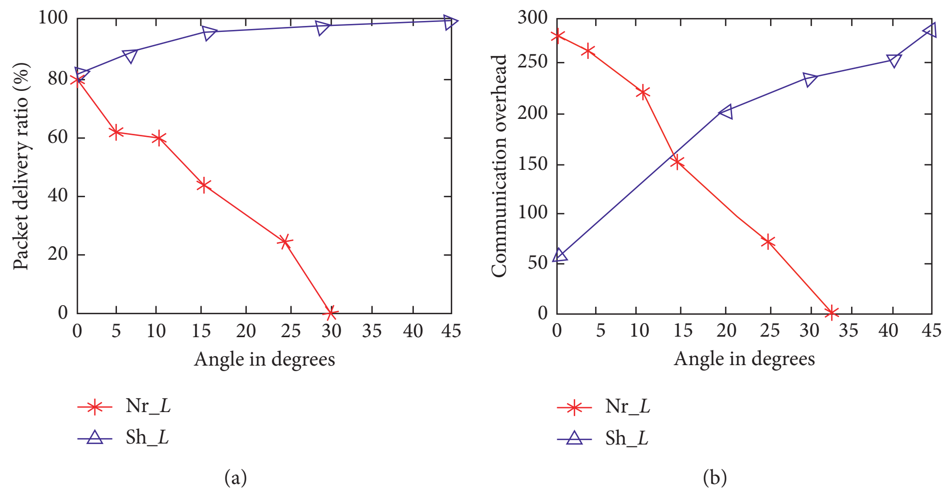

Figure 5: Effect of angle displacement on packet delivery ratio and communication overheard.

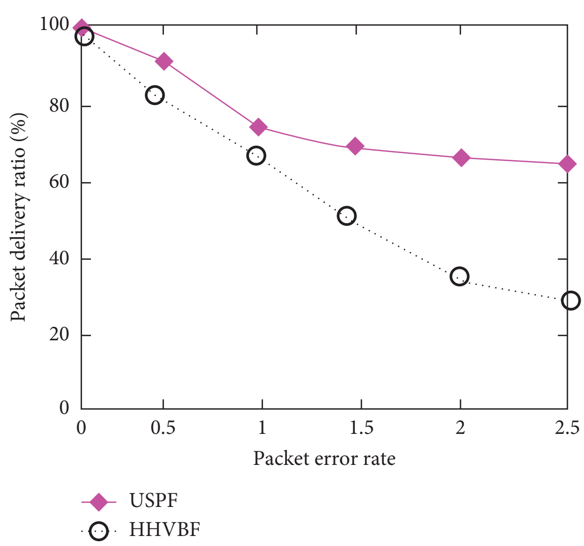

Figure 6: The packet error rate versus packet delivery ratio.

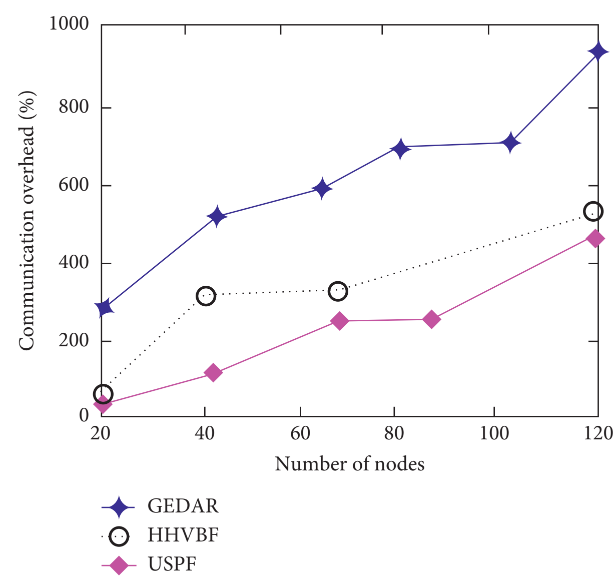

Figure 8: Number of nodes versus communication overhead.

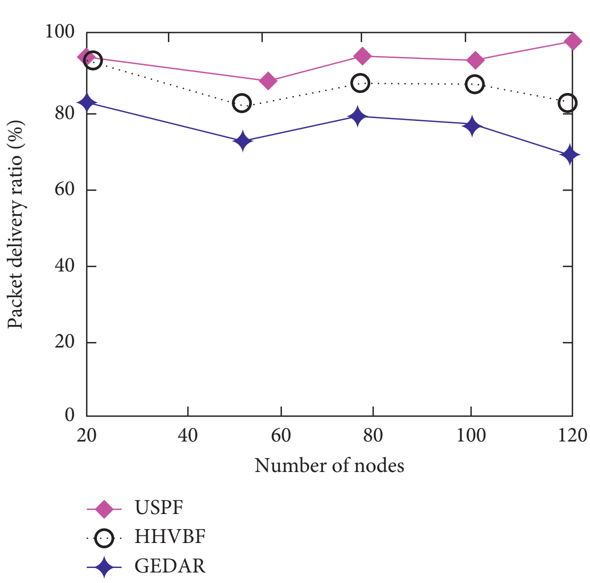

Figure 7: Number of nodes versus packet delivery ratio.

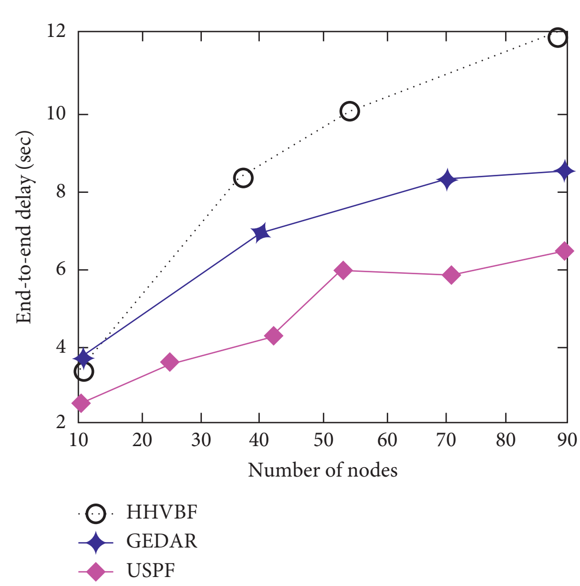

Figure 9: Number of nodes versus end-to-end delay.

USPF has vouched the minimized end-to-end delay during the transmission.

5. Conclusion

The proposed packet forwarding scheme is contemplated to put forth that only qualified nodes could participate in the packet forwarding cycle. The eligibility of qualified forwarder nodes inhabiting legitimate transmission zone has been checked out by introducing two angles; Forwarder Hop Angle (FHA) encompasses the hop distance between source and destination node while Counterpart Hop Angle (CHA) covers hop distance from source to neighboring node. By computing FHA and CHA, if FHA becomes equal or greater than CHA, it vouches the node belongs to the same transmission zone; otherwise packet is rebuffed. The link quality is determined by Additive-Rise and Additive-Fall methods; thereby, three link states are pragmatically compared with prefix values; thereupon most reliable link is unveiled. Holding time is adopted to avoid the packet losses and redundant packet transmission probability when heavy overhead is expected.

The performance is evaluated by *NS2* simulator and unprecedented results are obtained in terms of packet delivery ratio, packet error rate, communication overhead, and end-to-end delay. Adjusting the flooding zone in size could revitalize the better packet delivery ratio and reduce network overhead through surrogating angle values. USPF produced 35% less packet error rate than HHVBF and its packet delivery ratio is more than 13 and 25% as compared to HHVBF and GEDAR, respectively.

6. Future Work

A morphing based flooding control mechanism is a future quest which aims to be achieved by setting control to packet flooding direction according to changing network dynamics preferably for deep and shallow ocean water. The flooding zone would be morphed according to network overhead in spares and dense underwater environment. The intended plan is being achieved by taking shrewd measures in regard to preventing the chances of void area occurrence.

Data Availability

For readers, supporting data has been placed on Google drive for a limited time due to Google policies (https://drive.google.com/open?id=11QArJX3phSNjGqW4yFbGyQgCFXwbL6Fy) ; however, for any discrepancy the explanation is available upon request.

Conflicts of Interest

All the authors hereby declare no conflicts of interest.

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References

[1] R. W. L. Coutinho, A. Boukerche, L. F. M. Vieira, and A. A. F. Loureiro, "Geographic and opportunistic routing for underwater sensor networks," *IEEE Transactions on Computers*, vol. 65, no. 2, pp. 548–561, 2016.

[2] D. Shin, D. Hwang, and D. Kim, "DFR: an efficient directional flooding-based routing protocol in underwater sensor networks," *Wireless Communications and Mobile Computing*, vol. 12, no. 17, pp. 1517–1527, 2011.

[3] L. Emokpae and M. Younis, "Surface based anchor-free localization algorithm for underwater sensor networks," in *Proceedings of the 2011 IEEE International Conference on Communications (ICC)*, Kyoto, Japan, June 2011.

[4] L. Liu, M. Ma, C. Liu, and Y. Shu, "Optimal relay node placement and flow allocation in underwater acoustic sensor networks," *IEEE Transactions on Communications*, vol. 65, no. 5, pp. 2141–2152, 2017.

[5] A. Khasawneh, M. Latiff, O. Kaiwartya, and H. Chizari, "Next forwarding node selection in underwater wireless sensor networks (UWSNs): techniques and challenges," *Information*, vol. 8, no. 1, p. 3, 2016.

[6] Z. Liao, D. Li, and J. Chen, "A network access mechanism for multihop underwater acoustic local area networks," *IEEE Sensors Journal*, vol. 16, no. 10, pp. 3914–3926, 2016.

[7] H. Wu, M. Chen, and X. Guan, "A network coding based routing protocol for underwater sensor networks," *IEEE Sensors Journal*, vol. 12, no. 4, pp. 4559–4577, 2012.

[8] Y. Ding, C. Li, K. Hao, X. Du, L. Zhao, and Q. Liu, "Adaptive routing protocol for underwater wireless sensor network based on AUV," in *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, pp. 541–553, Springer International Publishing, Cham, Switzerland, 2019.

[9] R. W. L. Coutinho, A. Boukerche, L. F. M. Vieira, and A. A. F. Loureiro, "Underwater wireless sensor networks," *ACM Computing Surveys*, vol. 51, no. 1, pp. 1–36, 2018.

[10] M. A. Rahman, Y. Lee, and I. Koo, "EECOR: an energy-efficient cooperative opportunistic routing protocol for underwater acoustic sensor networks," *IEEE Access*, vol. 5, pp. 14119–14132, 2017.

[11] V. G. Menon and P. M. J. Prathap, "Comparative analysis of opportunistic routing protocols for underwater acoustic sensor networks," in *Proceedings of the 2016 International Conference on Emerging Technological Trends (ICETT)*, Mangalore, India, May 2016.

[12] Q. Lu and J. Shengming, "A review of routing protocols of underwater acoustic sensor networks from application perspective," in *Proceedings of the 2016 IEEE International Conference on Communication Systems (ICCS)*, Shenzhen, China, December 2016.

[13] C. Li, Y. Xu, B. Diao, Q. Wang, and Z. An, "DBR-MAC: a depth-based routing aware MAC protocol for data collection in underwater acoustic sensor networks," *IEEE Sensors Journal*, vol. 16, no. 10, pp. 3904–3913, 2016.

[14] R. Su, R. Venkatesan, and C. Li, "An energy-efficient relay node selection scheme for underwater acoustic sensor networks," *Cyber-Physical Systems*, vol. 1, no. 2–4, pp. 160–179, 2015.

[15] A. Khan, I. Ali, A. Ghani et al., "Routing protocols for underwater wireless sensor networks: taxonomy, research challenges, routing strategies and future directions," *Sensors*, vol. 18, no. 5, p. 1619, 2018.

[16] Z. Wadud, S. Hussain, N. Javaid et al., "An energy scaled and expanded vector-based forwarding scheme for industrial underwater acoustic sensor networks with sink mobility," *Sensors*, vol. 17, no. 10, p. 2251, 2017.

[17] B. Li, H. Yang, G. Liu, and X. Peng, "An energy-efficient routing algorithm in three-dimensional underwater sensor networks based on compressed sensing," *Information*, vol. 8, no. 2, p. 66, 2017.

[18] P. Xie, J. H. Cui, and L. Lao, "VBF: vector-based forwarding protocol for underwater sensor networks," in *Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks*, F. Boavida, T. Plagemann, B. Stiller, C. Westphal, and E. Monteiro, Eds., vol. 3976, Springer, Berlin, Germany, 2006.

[19] Z. Wang, G. Han, H. Qin, S. Zhang, and Y. Sui, "An energy-aware and void-avoidable routing protocol for underwater sensor networks," *IEEE Access*, vol. 6, pp. 7792–7801, 2018.

[20] G. Xing, Y. Chen, L. He et al., "Energy consumption in relay underwater acoustic sensor networks for NDN," *IEEE Access*, vol. 7, pp. 42694–42702, 2019.

[21] C.-J. Huang, Y.-W. Wang, H.-H. Liao, C.-F. Lin, K.-W. Hu, and T.-Y. Chang, "A power-efficient routing protocol for underwater wireless sensor networks," *Applied Soft Computing*, vol. 11, no. 2, pp. 2348–2355, 2011.

[22] S. Ashraf, M. Gao, Z. Chen, S. Kamran, and Z. Raza, "Efficient node monitoring mechanism in WSN using contikimac protocol," *International Journal of Advanced Computer Science and Applications(IJACSA)*, vol. 8, no. 11, 2017.

[23] T. Ali, L. T. Jung, and I. Faye, "Diagonal and vertical routing protocol for underwater wireless sensor network," *Procedia—Social and Behavioral Sciences*, vol. 129, pp. 372–379, 2014.

[24] H. U. Yildiz, "The impact of data fragmentation on network lifetime in underwater acoustic sensor networks," in *Proceedings of the 2018 26th Signal Processing and Communications Applications Conference (SIU)*, Sivas, Turkey, 2018.

[25] T. Hu and Y. Fei, "An adaptive routing protocol based on connectivity prediction for underwater disruption tolerant networks," in *Proceedings of the 2013 IEEE Global Communications Conference (GLOBECOM)*, Atlanta, GA, USA, December 2013.

[26] H. Wang, S. Wang, E. Zhang, and L. Lu, "An energy balanced and lifetime extended routing protocol for underwater sensor networks," *Sensors*, vol. 18, no. 5, p. 1596, 2018.

[27] N. C. Nicolaou, A. See, P. R. Xie, J. Cui, and D. Maggiorini, "Improving the robustness of location-based routing for underwater sensor networks," in *Proceedings of the OCEANS 2007—Europe*, pp. 1–6, Aberdeen, Scotland, June 2007.

[28] H. Yu, N. Yao, and J. Liu, "An adaptive routing protocol in underwater sparse acoustic sensor networks," *Ad Hoc Networks*, vol. 34, pp. 121–143, 2015.

[29] C. Zidi, F. Bouabdallah, and R. Boutaba, "Routing design avoiding energy holes in underwater acoustic sensor networks," *Wireless Communications and Mobile Computing*, vol. 16, no. 14, pp. 2035–2051, 2016.

[30] H. Luo, Z. Guo, K. Wu, F. Hong, and Y. Feng, "Energy balanced strategies for maximizing the lifetime of sparsely deployed underwater acoustic sensor networks," *Sensors*, vol. 9, no. 9, pp. 6626–6651, 2009.

[31] Z. Pooranian, A. Barati, and A. Movaghar, "Queen-bee algorithm for energy efficient clusters in wireless sensor networks," *World Academy of Science, Engineering and Technology*, vol. 73, 2011.

[32] N. Goyal, M. Dave, and A. K. Verma, "Data aggregation in underwater wireless sensor network: recent approaches and issues," *Journal of King Saud University—Computer and Information Sciences*, vol. 31, no. 3, pp. 275–286, 2019.

[33] L. K. Ketshabetswe, A. M. Zungeru, M. Mangwala, J. M. Chuma, and B. Sigweni, "Communication protocols for wireless sensor networks: a survey and comparison," *Heliyon*, vol. 5, no. 5, Article ID e01591, 2019.

[34] S. H. Ahmed, S. Lee, J. Park, D. Kim, and D. B. Rawat, "iDFR: intelligent directional flooding-based routing protocols for underwater sensor networks," in *Proceedings of the 2017 14th IEEE Annual Consumer Communications & Networking Conference (CCNC)*, January 2017.

[35] D. D. Mai, A. T. Tran, and M. K. Kim, "Measuring link quality based on ETX metric in multi-hop wireless networks," *Advanced Science and Technology Letters*, vol. 46, 2014.

[36] P. T. Kalaivaani and A. Rajeswari, "An energy efficient analysis of S-MAC and H-MAC protocols for wireless sensor networks," *International Journal of Computer Networks & Communications*, vol. 5, no. 2, pp. 83–94, 2013.

[37] S. Ashraf, T. Ahmed, A. Raza, and H. Naeem, "Design of shrewd underwater routing synergy using porous energy shells," *Smart Cities*, vol. 3, no. 1, pp. 74–92, 2020.