Link Quality Estimation VBF Routing for Underwater Wireless Sensor Networks (UWSNs)

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Abstract—*Underwater Wireless Sensor Networks are necessary for many applications such as marine search and underwater monitoring like measuring water speeds, currents and temperatures. The challenge is, that the special underwater environment, which is, require specified routing and security protocols and the traditional protocols are suffer many problems. Therefore there is continuous motivation to search and develop to enhance its performance in viral applications. Vector Based Forwarding is an Underwater Wireless Sensor Networks protocol. This protocol is recognized by its dependency on default pipelines for routing, the packets are routed through these pipes. The disadvantages of this protocol are, the sensitivity to the radius of the pipe, which effects routing efficiency and in the case of spaces found (voids) the protocol may fail to find a communication path. This paper conducts enhancing on VBF by Link Quality Estimation to enhance packet delivery ratio, End to End delay and Energy Efficiency. The simulation was done and the final results which indicate to regarded enhancements in terms of Packets Delivery Ratio, reduced End to End Delay, and increased Energy Efficiency.*

Keywords—*UWSNs; Efficient Routing; VBF; LQE; PDR; E2E delay.*

I.INTRODUCTION

In recent years, Underwater Wireless Sensor Networks (UWSNs) have witnessed huge developments resulted in increasing the interest in their various applications like environmental monitoring, disasters discovery and oceans researches [1]. These networks recognized by unique challenges related to Aquatic environment, including significant delays in data transfer, Link quality fluctuates and high energy consumption [2], [3]. Vector-Based-Forwarding (VBF) algorithm is one of the most prominent algorithms used in data routing in UWSNs, where it relies on specific path to move packets according nodes geographical position [4]. However, VBF faces challenges in the underwater environment because quickly changes in link quality, Resulting in packet loss and delay increasing [5]. To overcome these challenges, VBF can be improved by using Link Quality Estimation (LQE). LQE is a technique aims to evaluate link quality periodically using metrics like “Received Signal Strength Indicator (RSSI) or Packet Received Ratio (PRR)” [6]. By combining LQE with VBF, the efficiency of packets routing can be improved and increase delivery ratio [7]. In recent research, new methods are suggested relies on machine learning to improve LQE precise in UWSNs. Such as, using learning deep learning methods to classify link quality depending on data extracted from real artificial environments that is results potential improvements in evaluation precise and energy consumption [8], [9]. Furthermore, the studies showed using multi channels and evaluating link quality in this channels can improve data transferring efficiency in environments include high signally interference. However, these methods required updating to able to adapt with changes in interference level [10]. The recent researches also include routing algorithms developments that adapt with changing environment conditions, as routing algorithm that relies on adaptive link quality evaluation, which can select optimal paths according to dynamics changes in link quality [11], [12]. *Fig.* 1, is UWSNs architecture.

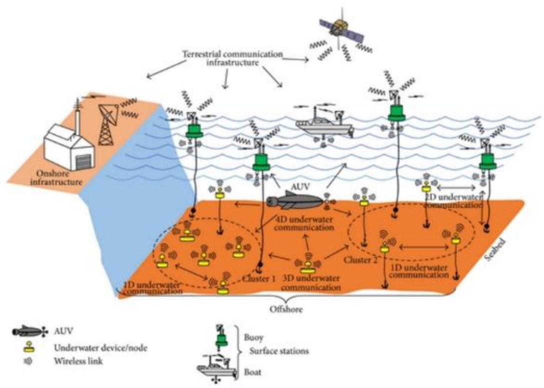

Fig. 1: Underwater Wireless Sensor Networks Architecture [13].

The paper's contribution-is to introduce a new approach to evaluate link quality in Underwater Wireless Sensors Networks (UWSNs), it is support packet routing efficiency, as result, that is will improve energy efficiency, end-to-end delay and increase delivery ratio. The remaining paper sections are ordered from section 2 until section 5 as follows: 2. Related works. , 3. Suggested LQE-VBF Algorithm. , 4. Comparative Study and Performance Evaluation. , 5. Conclusions and the references are at end of paper.

I. RELATED WORKS

In [14], the researchers suggest a routing protocol depending on Particle Swarm Optimization (PSO) to improve energy efficiency in Underwater Wireless Sensor Networks (UWSNs). The protocol aims to reduce energy consuming and increase “network lifetime”. This achieved by improving routing paths depending on node position and remaining energy level. The experiments showed that the proposed protocol achieved big improvements in terms of energy efficiency, packet delivery ratio (PDR) comparing with traditional protocols.

In [15], they are induced new routing protocol based on aggregation to improve network efficacy in Underwater Wireless Sensor Networks UWSNs. The protocol uses the deep information and energy level to form effective node clusters and reduce the interferences. It contributes in improve “Packet Delivery Ratio” and reduce delay. The results showed the suggested protocol prolong network lifetime and improve overall performance comparing with traditional methods.

In [16], the researchers suggest adaptive routing protocol rely on depth to improve routing efficiency in Underwater Wireless Sensor Networks. The protocol depends on routing paths that are modified dynamically based on depth changes and energy consumption. The protocol helps to improve Packets Delivery Ratio and reduce energy consumption. The experiments results showed the protocol is increasing of network stability and confidently comparing with previous methods.

In [17], this paper introduces protocol relies on fuzzy logic to improve energy efficiency and data transfer reliability in UWSNs. This protocol uses multi evaluations like energy level and signal quality to make efficient routing decisions. The protocol contributes to reduce energy consumption and increase “Packet Delivery Ratio”. The trials showed, the suggested protocol achieve regarded improvements in network performance comparing with traditional protocols.

In [18], they suggest that the routing protocol relies on reinforcement learning to improve UWSNs' performance. The protocol uses depth-learning techniques to improve routing decisions depending on historical data and current conditions of the network. The protocol helps to improve energy efficiency and increase “Packet Delivery Ratio”. The results showed, the protocol can adapting itself according changing circumstances and arrive to best performance comparing with traditional methods.TABLE *1*, summarizes previous works. This table elucidates the recommended methodology employed in this research, which aims to address the drawbacks identified in the below studies.

TABLE 1: PREVIOUS WORKS.

Ref. and Year	Approach Algorithms or Techniques	Compared Algorithms	Environment	Pros	Cons
[14] (2023)	LQE-enhanced VBF	VBF, DBR	UWSNs	Improved energy efficiency	Sensitive to node density
[15] (2023)	Machine learning-based LQE	Traditional LQE, DBR	UWSNs	High adaptability	Requires high computation
[16] (2023)	Adaptive LQE with fuzzy logic	VBF, FBR	UWSNs	Better in dynamic environments	Increased delay
[17] (2019)	Multi-channel LQE	Single-channel LQE, DBR	UWSNs	Enhanced data throughput	Complex implementation
[18] (2024)	Reinforcement learning for routing	VBF, Adaptive LQE	UWSNs	Optimal path selection	High learning time

II. SUGGESTED LQE-VBF ALGORITHM

The enhancement includes inputting a mechanism depended on Link Quality Estimation (LQE) with addition to node position. This paper will combine LQE with VBF protocol to enhance the “Packet Delivery Ratio (PDR), end-to-end delay and energy efficiency” especially for low or high-density networks. To estimate link quality this paper can use “Received Signal Strength Indicator (RSSI) or Packet Received Ratio (PRR)” or any another suitable metric. This paper add a new field to data packet to store LQE value for each node that is forward the packet. This paper choose a set of candidate’s nodes that is positioned inside default current pipe according distance and angles. The candidates nodes is evaluated by LQE value that stored in the packet in addition to Distance Factor (DF). The selecting of optimal node that have best value of LQE and min value of DF to forward the packet, with is give high performance communication and energy consuming. This paper do smart forwarding by selected node and updates LQE value that attached in packet. Low LQE nodes are avoided dynamically, this reduces packets loss and increase overall network performance. This enhancement on VBF can enhance the performance of underwater wireless sensor networks (UWSNs). Fig. 2, is a flowchart of suggested enhancement. Fig. 3, is pseudo code for Distance Factor calculation. Fig. 4, is a part of suggested enhancement python pseudocode. Below are the main steps of enhanced algorithm.

Algorithm Steps:

1. **Initialization**
   Each underwater wireless sensor node is estimate link quality (LQE) depending on received signals.
2. **Receiving packet**
   When the packet received by node it will extract the following information:
   Source Position (SP)
   Target Position (TP)
   Current Forwarder Position (FP)
   Link Quality Estimation (LQE)
3. **Compute Distance Factor (DF) for candidate node.**
   It will be mentioned in the later section.
4. **Compute Link Quality Estimation (LQE) for candidate node**
   The LQE is calculated for each candidate node according Received Signal Strength Indicator (RSSI).

5. Selecting best node

Combine DF and LQE to make decision about selecting best candidate node to use it for forwarding the packet, the packet with min DF and max LQE will be selected.

6. Forwarding the packet

The selected node forwards packet, update its own LQE in the packet header, and send it to the neighbor node.

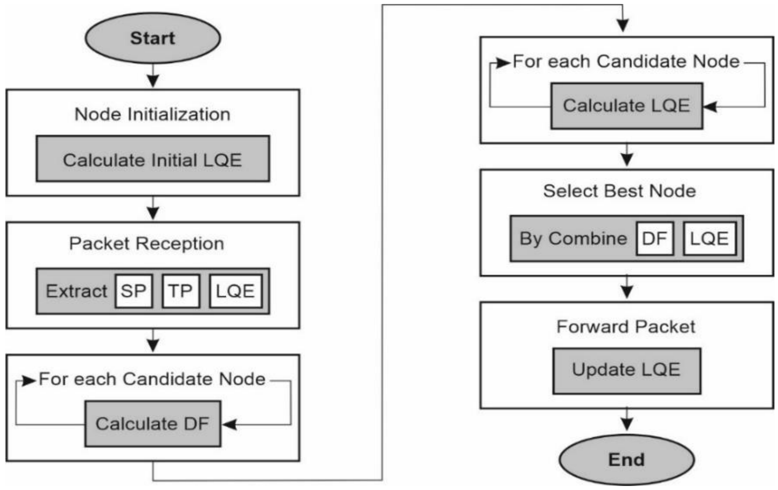

Fig. 2: Flowchart for LQE_VB

```
Start
def calculate_df(packet, node):
    Inputs:
    - packet: The data packet being forwarded.
    - node: The candidate node for forwarding the packet.
    Outputs:
    - df: The distance factor, that represent the distance of the node from the optimal
path.
     x, y = node.position
    x1, y1 = packet.source_pasition
    x2, y2 = packet.target_position

    # Calculate the numerator and denominator for the DF formula
    xx = abs((y2 - y1) * x - (x2 - x1) * y + x2 * y1 - y2 * x1)
    yy = ((y2 - y1) ** 2 + (x2 - x1) ** 2) ** 0.5
       # Return the calculated DF
    return xx / yy
End
```

Fig. 3: Distance Factor pseudocode .

```
Start
def enhanced_vbf_with_lqe(packet, current_node, candidate_nodes):
Inputs:
- packet: The data packet  to be forwarded.
- current_node : The current node handling the packet.
- candidate_nodes: A list of neighboring nodes to which the packet could be
forwarded.
Outputs:
- best_node: The node selected to forward the packet based on the calculated score.
# Initialization
best_node = None
best_score = float('inf')
# Loop through each candidate node
for node in candidate_nodes:
# Calculate the distance factore (DF)
df = calculate_df(packet, node)
# Calculate the link quality estimation (LQE)
lqe = calculate_lqe(current_node, node)
# Calculate the score based on DF and LQE
score = df - lqe  # Lower score is better
# If this node has the best score, select it as the best node
if score < best_score:
best_score = score
best_node = node
# Check if a best node found
if best_node:
# Forward the packet to the best node
forward_packet(packet, best_node)
else:
# Handle the case where no suitable node found
handle_no_route_found(packet)
End
```

Fig. 4 Part of Main Program python pseudocode of suggested enhancement.

Computing Distance Factor (DF)

It is the distance of node to virtual pipe, which connect the sender node to the destination node. DF is calculated by perpendicular distance from the node to the default line that is link the source to the destination. DF play important role for decision-making, where the node have minimum DF will be closer to the optimal path and will have advanced priority to forward packets. Through selecting nodes that have lower DF, the reduce of energy consuming will done as well as number of hops, and this will lead to transmit data with high performance. The DF can be calculated by:

$$DF = \frac{|((y2 - y1) * x - (x2 - x1) * y + x2 * y1 - y2 * x1)|}{\sqrt{(y2 - y1)^2 + (x2 - x1)^2}}$$

Where (x,y) is node position, (x1,y1) is source position and (x2,y2) is destination position, خطأ! لم يتم العثور على مصدر المرجع., is a pseudo code for select best node and distance factor calculation functions.

III. COMPARATIVE STUDY AND PERFORMANCE EVALUATION

Here, the paper study the performance of our enhancement to ensure the validity of the enhancement. The paper conduct comparison between our approach and two famous algorithms, traditional Vector-Based-Forwarding (VBF) algorithm and Depth-Based Routing (DBR). This paper do comparison between these two algorithms and our LQE-VBF in terms of three performance evaluation metrics, energy efficiency, end-to-end delay and Packet Delivery Ratio (PDR). To conduct reliable justice comparison among different algorithms of Under Water Wireless Sensor Networks (UWSNs). This paper must specify consistent simulation scenario include number of nodes, simulation area, and other essential parameters. TABLE 2, represents used scenario simulation parameters.

TABLE 2: SIMULATION PARAMETERS.

Parameter	Value
Number of nodes	100,200,300
Simulation area	1000m X 1000m X 500m
Simulation time	1000 second
Node Mobility	Constant
Packet generation	One packet/10 second
Communications model	Sound waves
Error rate	0.01 (1%)

A) Packet Delivery Radio (PDR)

Is the measure to expose the network protocol activity and efficiency to deliver data [19]. The "Packet Delivery Ratio" (PDR) is determined by the number of packets that are successfully delivered to their final destination to the total sent packets from the source [20]. The following equation can be used to measure PDR.

$$\text{PDR} = \frac{\text{Number of Successfully Received Packets}}{\text{Total Number of Sent Packets}} \times 100 \quad [21]$$

The importance of PDR is considered as essential metric for network protocols performance evaluation. High PDR indicates to the protocol that can deliver most send data, and this mirror its efficiency and reliability [22]. The PDR reflects the network reliability for data delivery without losing. PDR used as metric for network protocol enhancement. Networks developers can use PDR as reference to update and enhance the performance to achieve higher delivery ratio [23]. Fig. 5, is the PDR for three mentioned protocols under three different number of nodes, 100, 200 and 300.

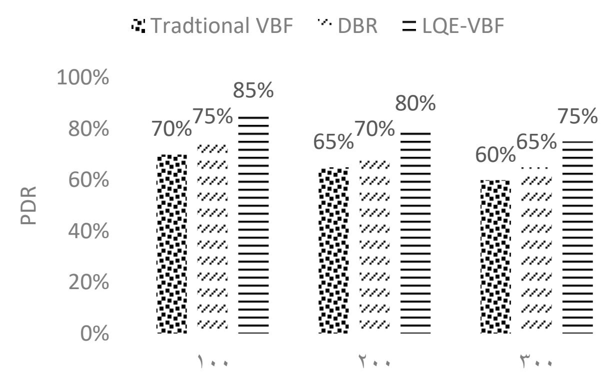

Fig. 5: Packet Delivery Ratio for 100,200 and 300 nodes.

From the Fig. *5*, this paper note that the LQE-VBF algorithm achieves the best Packets Delivery Ratio (PDR) compared to other algorithms in all cases. This result is caused by precisely path selecting, and this will avoiding lost packets. Where the LQE-VBF is the best through deferent number of nodes scenarios. The reason of that is the ability of LQE to enhance the paths and avoid unstable or low efficiency paths, which is leads to reduce packet losing and grow data arriving reliability.

B) Energy Efficiency

Indicates to the efficiency range of using energy by nodes of Wireless Sensors Networks to perform its tasks, such as send and receive packets, data processing and communication among nodes [24]. The following equation can be used to measure Energy Efficiency [25].

$$Energy\ Efficiency = \frac{The\ amount\ of\ data\ transmitted}{Aggregate\ Energy\ usage\ in\ the\ network}$$

High-energy efficiency means the nodes are consuming less energy to achieve same performance or better performance comparing with other alternatives. The importance of energy efficiency come from maximize network life and increasing nodes batteries life spans and that results increase general network lifetime [26]. The energy efficiency also reduces costs through reduce maintenance needing and batteries replacement which is reduces operational costs. Routing protocols that select paths that are more efficient can significantly reduce energy consuming. Getup and sleep operations are help to reduce energy consuming by deactivate the nodes when there is no needing to activate it [27]. *Fig.* 6, is the Energy Efficiency for three mentioned protocols under three different number of nodes, 100, 200 and 300.

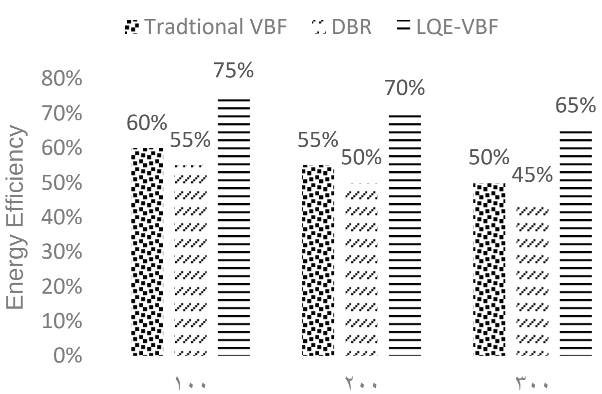

Fig. 6 : Energy Efficiency for 100,200 and 300 nodes.

The results show LQE-VBF algorithm achieves the best energy efficiency. That is by the improvements, which reduce the number of used nodes that used for sending packets and therefor will reduce comprehensive energy consuming. That is considered as very important property for underwater wireless networks environments where the energy resources are limited.

C) End-to-End Delay

It is the time consumed by packet to move from source to the destination through network. This time includes all possible delays which can face the packet through its trip, including delays resulting from processing, waiting's in queues, transferring, routing across deferent nodes on the network. The following equation cab be used to fined End-to-End Delay.

$$E2E = \frac{\sum_{j=1}^{m}(T_{Rreceive_i} - T_{Send_i}}{m}\ [28].$$

Where:

- Trecv$_i$ is the time when the i-th packet is received, and so on for Tsend$_i$.
- m is the total number of packets.

Time consumed to transfer packet is critical for the application that required immediate response or in the real time like artificial control, internet games, and online monitoring. End-to-End delay indicate to high quality of service, which is increase users satisfaction and support application performance [29]. End-to-End delay increase overall network efficiency, reduces crowding, and delays [30]. Fig. 7, is the End-to-End Delay for three mentioned protocols under three different number of nodes, 100, 200 and 300.

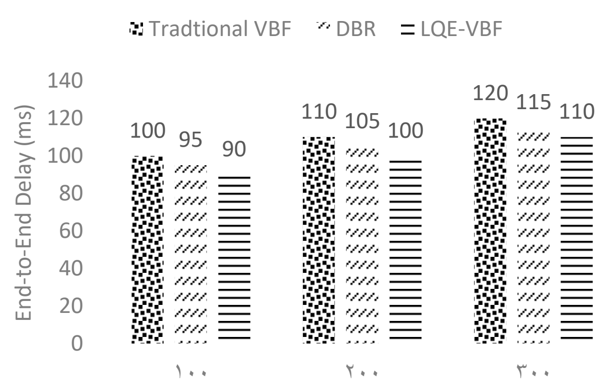

Fig. 7: End-to-End Delay for 100,200 and 300 nodes.

Time consumed to transfer packets is the minimum in the case of LQE-VBF, and this mean less time to transfer packets, and so this algorithm more efficient for speedy packets transferring through a network. This considers as critical issue in the applications that required low responsibility time, such sensitive time application and real time controlling.

V. CONCLUSION

According to the analysis already shown, This paper can conclude the LQE-VBF algorithm excels the traditional algorithms in terms of Packet Delivery Ratio (PDR), Energy Efficiency and time consumed for packets transferring. Where it supports packet routing efficiency by 15% and reduce the delay by 10%. This enhances considered as especially useful in the Underwater Wireless Sensor Networks (UWSNs) where the resources are limited and the environmental conditions are harsh. LQE enhances network reliability through precise estimating for link efficiency and this leads to avoid paths that lead to packets losing, which lead to increase network stability and supports user's confidence in term of network performance. Improving performance of this algorithm makes it suitable option for many application that requires precise and high reliable translate data. The LQE-VBF algorithm can be used in a wide collection of applications, such as marine data monitoring, environment sensing and underwater defense application. This paper recommended adopting this algorithm to enhance the efficiency and performance of UWSNs.

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