A Systematic Review of Energy Aware Routing Protocols For Underwater Acoustic Sensor Networks

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ABSTRACT

Underwater Acoustic Wireless Sensor Networks (UAWSNs) are collective monitoring and data-gathering platforms that integrate sensor nodes and vehicles, which are scattered on the sea floor to perform such missions. Meanwhile, the challenge in an underwater environment stems from the fact that nodes at the sea floor cannot communicate directly with others near the water surface. This results in a critical need that carries multi-hop communication, which can be effectively enabled by suitable routing protocols. The newest technological accomplishment leads to the development of low-power, small-sized acoustic modems with minimal cost and enables long ranges to provide communications. However, acoustic communication is still susceptible to environmental interference, which results in losses in transmission and time-varying signal distortion. The main objective of this paper is to discuss a general review of the actual state of energy-aware routing protocols in the field of UAWSNs. This Research proposes a novel taxonomy for this class of routing protocols and carries out an exhaustive analysis based on performance, scalability, robustness, and suitability for different applications. This review also discusses a key contribution toward comparative assessment through major performance metrics such as energy consumption, network lifetime, packet delivery ratio, and latency, which bring out the strengths and weaknesses of every protocol. The emerging trends and others are being bioinspired by cross-layer design and machine learning techniques, particularly in the challenges of the underwater environment. Furthermore, this paper also identifies relevant research gaps, from real-world testing, aspects of security, and solutions that can be scalable. Finally, This review can act as a valuable resource for researchers and practitioners to understand current energy-aware routing protocols, which will guide future innovations toward more efficient and reliable UAWSNs.

***KEYWORDS*:** Underwater Sensor Network Acoustic communication; Routing protocols; overhead; Monitoring; Energy efficiency; and optimization

I. INTRODUCTION

The Unpredictable nature of the acoustic channel creates significant hurdles in the design of environmentally friendly and reliable algorithms in underground wireless sensor networks (UWSNs) [1]. Standard UWSNs protocols [2] do not consider reliability when sending data packets; in these protocols, packets are advanced using a single-hop technique. As a result, they cannot accomplish maximal packet progress at the water's surface [3]. Most existing cooperative communication strategies proposed for UWSNs are targeting issues at the physical and MAC layers. In particular, there is a significant gap at the network layer and it has not been addressed properly [4]. In cooperative routing, the source node employs a two-way approach to forward data to the destination [5]. On the one hand, it uses direct-hop interaction between the sender and the destination [6]. For underwater applications to be feasible, it is pertinent to find solutions to problems of effective communication among the devices to be used in underwater [7]. Underwater acoustic waves typically have frequencies ranging from 10 Hz to 1 MHz and an undersea sensor node. This Narrow range comes with a delay in propagating, but it is the only viable option forward on a limited energy store [8].

UWSNs are restricted by the following challenges; relatively low bandwidth, high latency delay, high bit error rates, and high energy consumption [9]. Besides, the UWSNs perform specific monitoring tasks in deep or shallow water environment with cooperation communication which contains the incremental relaying nodes and the fixed relaying nodes. The fixed relaying technique is given priority with the view of increasing the reliability of data using better results of the relay data. Meanwhile, non-cooperative methods that transmit data at a single link include less energy and time but have fluctuation and high probability of data packet loss [10]. They are more likely to be subjected to noise, which compromises data in non-cooperative environments hence aggravation of data loss. Re-transmitting data over the same noisy link is inconceivable as this wastes time and increases the likelihood that more errors will be made. Furthermore, the placement of a number of antenna in underwater is not feasible and become very expensive.

Furthermore, the underwater routing involves certain constraints like node mobility, energy a consumption and many others. One of the serious issues is the "hole problem" which is typical for terrestrial routing and is very difficult to solve in underwater networks. Acoustic signalling presents several obstacles in the underwater environment because the signal's propagation delay is five orders of magnitude greater than radio signalling [32-50]. The Networks route the sensing data and correctly deliver it to the sinks; hence, this is considered the key challenge. As a result, few routing techniques for UAWSNs have been devised [11-12]. Furthermore, the submerged link property sometimes makes the network more expected in terms of reliability and supply accessibility. For permitting efficient communication, quick admission techniques must be used in marine wireless environments.

A. Motivation of the study

The study aims to address some of the challenges caused by energy and routing in underwater acoustic sensor networks. As a result, this work provides two unique UWSNs methods [13]. The first is the energy path and channel aware (EPACA) routing protocol, which improves network energy utilization and can be utilized for long-term communication. The routing protocols are addressed in this survey. The merits and demerits of these efficient routing protocols in UAWSNs are also addressed here. Finally, this survey motivated us to present efficient routing protocols in the future to overcome the demerits of existing routing protocols in UAWSN.

II. REVIEW OF LITERATURE OF SUGGESTED UAWSNs

This section evaluated recent literature on UAWSNs with networking protocols, artificial intelligence, and related literature. Furthermore, variables, protocol-based analysis, and the pros and disadvantages of the relevant technique in the research were discussed.

A. Channel and Energy-aware routing Protocols based analysis in UAWSNs

Meanwhile in 2020, Qadir, J.et al. [14] discussed the energy path and channel aware (EPACA) protocol in which the source node determines for every neighbouring node a value of a function to prefer the target destination. However, in terms of packet delivery, single-channel transmission used in EPACA may affect the reliability of the packet being transmitted. In this regard, the Cooperative-Energy Path and Channel Aware (CoEPACA) routing strategy was proposed with an objective of employing relay nodes in the necessity of optimizing packet stability. CoEPACA helps the destination node to get multiple copies of packets originating from the source and relays, making it more reliable. The outlined EPACA protocol showed a 29 percent median improvement in scores among the patients. Similar to this a system implemented CoEPACA had 19% less energy compared to the same system, and thus fulfilling the objectives of the projects. 04% reduction. As an effort to address the energy consumption problem, Rahman, M. A. et.al [15] designed the energy efficient cooperative opportunistic routing (EECOR) to enhance the effective packet transmission to surface sink. In the case of EECOR, a fuzzy logic-based relay selection (FLRS) is employed to select the proper relay optimally with respect to energy and packet delivery probability.

In Yahya, A, et al [16], the authors proposed the Region Based Courier nodes Mobility with Incremental Cooperative (RBCMIC) routing technique, which uses the broadcast property of the wireless nodes for progressive cooperative routing. This method also revealed increased energy efficiency of the network and its lifespan this is closely related with fact that the proposed method use less energy than DEADS protocol in the average 20%, and delay was decreased on the average 89%. In underwater wireless sensor network (UWSN), different sensor nodes have low power batteries and gather information and send it to the sink node. Irfan Ahmad et al. [17] also stressed on the economizing energy in UWSNs since forwarding data from the nearest sensor node directs energy to initial points where it is not useful. To address the problem of hotspot and guarantee the reliability and life time of the network, they presented the cooperative energy-efficient routing (CEER) protocol which makes use of sink mobility strategy. In 2021, Gul H. et al. [18] proposed Energy-Efficient Regional Base Cooperative Routing (EERBCR) while Partitioning the network into 12 regions having four mobile sinks evenly distributed, and there are 100 sensor nodes placed randomly.

Bhattacharjya K. et al. [19], in 2019 proposed for the simulation of the CUWSN using QualNet 7. 1. The simulation to assess the performance was based on energy consumption, throughputs, probability of delivering packets, delay in transmitting, signal error and packet loss rates. CUWSN has shown that AODV routing protocol is on an average 80% more energy efficient than DYMO,75% than IERP,47% than STAR and 81% than the efficient one-ZRP. Ahmad, A. et al. [20], in 2017, elaborated on the works on cooperative diversity at the physical layer and multihop routing at the network layer and suggested the minimum energy routing as a through joint optimization of transmission power and link selection. In their study, they implemented Their Cooperative Energy-Efficient Routing for UWSN (Co-EEUWSN) which had comparable performance when compared to other non-cooperative and cooperative protocols such as; depth based routing (DBR), Energy efficient DBR (EEDBR), and cooperative DBR (Co-DBR), in terms of packet delivery ratio, end to end delay and energy efficiency.

The series of requirements and challenges highlighted by Zenia, N. Z. et al. [21] in 2016 include a large propagation delay, low bandwidth, communications disconnected, unpredictable sound speed, and less supply of energy in UWSNs. Even though routing protocols concerning node mobility exist in plenty, there is still a need to enhance the movement of the nodes, as stated by Ahmed M. et al [22], in 2017. As for the classification of mobility-based routing protocols, their work was mainly on the vector-based, depth-based, clustered-based, AUV-based, and path-based ones; deployment, node mobility, data forwarding, the route discovery phase, and the route maintenance phase constituted a primary consideration. The research performed both analytic and numerical simulation methodologies to handle these challenges.

According to Reeta Bhardwaj *et al.*, in 2017 [23], the design of routing protocols for underwater sensor networks presents several obstacles due to crucial aspects of the underwater setting. Many routing protocols have been proposed to enable efficient, dependable route finding between sources and sinks. It also offers a higher throughput than the current approach. Nam, H., and An, S. (2008) [24] show that the suggested methodology improves performance. Energy savings are achieved by reducing the number of data transmissions, delay is reduced by automatically moving the aggregation point, and the lifetime of underwater sensor networks is extended. This approach uses a dynamic trimming and grafting mechanism to reconfigure the aggregate tree to operate a temporal path from the sources to the sink.

B. Conventional techniques for acoustic UAWSNs

Some restrictions, including as high transmission delay, energy consumption, deployment, lengthy propagation delay, and high attenuation, affect the operation of UAWSN in Gola, K. *et al.*, in 2021 [25]. Aside from that, the presence of vacant regions on the path can impact UAWSN's overall performance. As a result, the void region can be avoided by selecting the best forwarder node. The optimum forwarder node is determined by depth variance, depth difference, residual energy, and link quality. The suggested approach extends the network lifetime by avoiding the vacuum zone and balancing the network energy. When estimating a packet's queueing time, Song, Y. *et al.*, [26] consider the retransmission delay caused by the transmission of packet faults and packet collisions. In this section, we define a basic optimization problem with the goal of minimizing data sink density while ensuring an upper bound on packet error probability. Following comprehensive numerical assessments, network operating solutions for achieving the requisite performance criteria in 3D UAWSNs are described. In Mohammadi, Z. (2018) [27], UAWSNs outline a basic optimization problem that tries to minimize data sink density while guaranteeing an upper bound for packet error probability. Network operating strategies for achieving the requisite performance criteria in 3D UAWSNs are described using comprehensive mathematical evaluations. Relay Node Setting Algorithm (RNSA) works in a 3D UAWSNs. The suggested approach for increasing network lifetime is to select an appropriate spot to place the relay node upon admission. The outcomes of the simulation show that the RNSA method is more efficient in terms of network endurance.

The transmission power needed for sensor nodes, cluster head residual energy, and cluster head loads are all considered in the model by Li P. *et al.*, in 2017 [28]. Using the clustering model, we create a novel clustering technique based on the discrete particle swarm optimization algorithm (PSO). We cluster UAWSNs regularly using the suggested clustering algorithm, with the cluster head rotating dynamically. The simulation findings show reduced network energy usage and a longer network lifetime. Jin Z *et al.*, [29] found that sink nodes are evenly distributed on the water's surface and serve as cluster heads. The sensor nodes in a cluster are arranged vertically to form the topology, with the sink node as the root node, so all network nodes are connected. Network deployment is optimized by determining the best location for each node while keeping the network topology constant as a constraint. We presented a deployment optimization mechanism in UASNs that uses depth-adjustable nodes to accomplish joint optimization of network coverage and connectivity. Yang, H. *et al.*, [30] proposed an optimization problem in 2009 that tries to minimize energy consumption while accounting for other performance indicators such as data dependability and communication delay. Under plausible assumptions, we obtain a simple, explicit, but nevertheless accurate, approximate solution using Karush-Kuhn-Tucker (KKT conditions). This approximation solution provides theoretical instructions for developing long-lasting and dependable UWSNs.

III. STUDY OF REVIEW RESULTS ANALYSIS

The inclusion and exclusion criteria, as shown in Figures 1 and 2, are linked to select the significant relevant research. The key research papers are chosen based on the established criteria following a match of title, abstract, and thorough published investigations to ensure the outcomes are relevant to the current study effort.

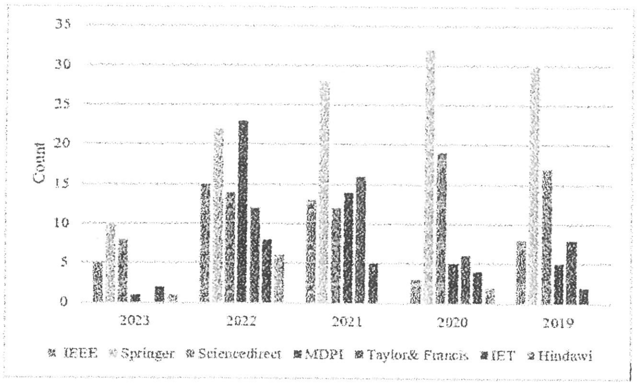

Fig. 1. Number of papers published in UAWSN

As shown in Figure 1, the authors published their research papers from 2019 to 2023 in various publishers, including IEEE, Springer, Science Direct, MDPI, Taylor& Francis, IET, and Hindawi, In UAWSNs [31], the publications are classified based on the methodologies they employed as Conventional Technique 3D Model, Cooperative based, and non-Cooperative based. The goal of this protocol is not just to meet the needs of various applications but also to accomplish a suitable trade-off between delivery ratios, end-to-end latency, and energy consumption for all data packets.

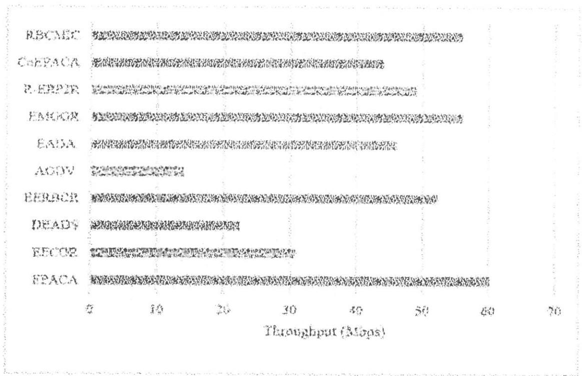

Fig. 2. Protocol Vs. Throughput Analysis

These metrics are said to be improved by advancing route requests to a certain surface node. The technique works effectively, although it limits the network's overall throughput. Figure 2 shows that the ZRP routing protocol delivers 82% more throughput than the EPACA and AODV routing protocols in the CUWSN. The reduction in latency is offset by a drop in throughput, which leads to packet loss in the middle as the relay path is chosen instead of the direct connection. This protocol allowed for the re-transmission of failed communications via cooperating nodes. A CoDBR method is presented to improve throughput and data reliability. An EERBCR protocol's throughput efficiency is defined as the average ratio of usable packet time to total time spent. An EERBCR protocol's transit efficiency is defined as the ratio of useful packet time to total time spent on average for a successful packet transfer. These protocols' throughput (measured in Mbps) can be maximized by determining an ideal packet size as a function of the acoustic link parameters. The aim is to utilize the mobility of underwater sensor nodes to boost the network's total throughput. The precision of conventional optimization techniques analysis is represented in Figure 3. The discovery overheads are high because all nodes must be discovered in such architectures. It improves the precision of the path over which packets are sent. A data aggregation method was investigated as a supplement to acquire better results from these methods. It collects data in an energy-efficient manner by decreasing data redundancy while also improving network accuracy and longevity.

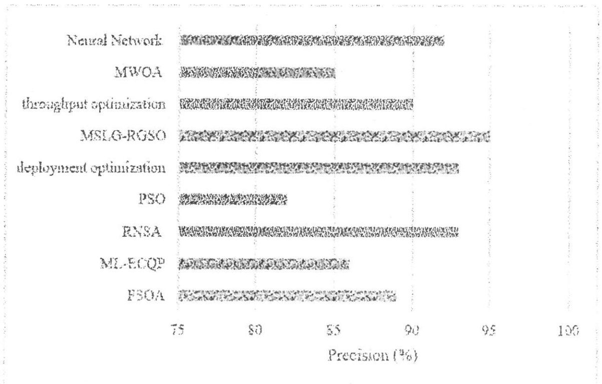

Fig. 3. Precision Vs Conventional (optimization & learning) Technique

The authors enhanced UAWSN accuracy by incorporating a neural network into a novel localization approach. Performance metrics vs yearly published papers are graphically represented in Figure 4.

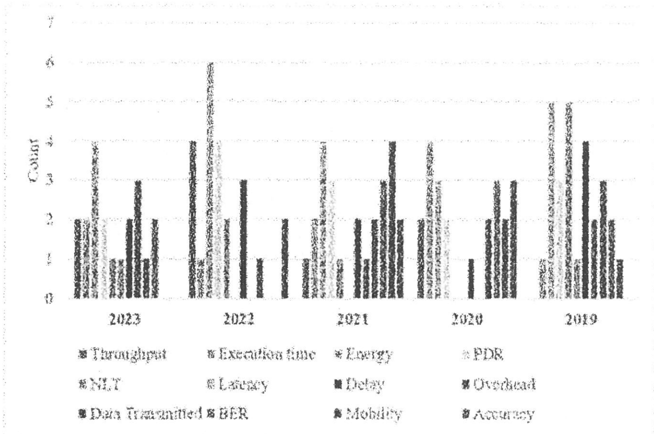

Fig. 4. Year-wise Analysis Vs Metrics

Underwater communication networks must use sound waves that do not interfere with natural auditory communication or the organs of aquatic creatures. Furthermore, acoustic systems' mobility and idle listening may lead the spectrum to be underutilized temporally. Figure 5 depicts the citations of UAWSNs publications with performance measures from 2019 to 2023. The parameters like throughput are 9; Execution time is 6; Energy is 16; PDR is 9; NLT is 8; Latency, BER, and mobility are 3; Delay & Overhead, Data Transmitted is 8, about 5 to 10 papers; Accuracy is five papers. Acoustic channel study is not new; three decades ago, academics began to focus their attention on this field. Given the importance of routing in UAWSNs and the large range of routing protocols available, a full survey is required. The underwater sensors network addresses the issue of the underwater network's physical and network layers. However, routing approaches at the network layer are a relatively recent area of research.

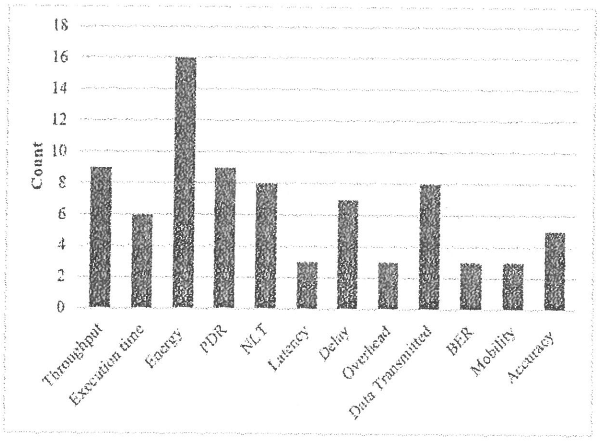

Fig. 5. Metrics Vs. Number of Citation count

IV. INFERENCE

Reviewing the recent articles in the previous section, we observed that UAWSNs are subject to several constraints that affect how well they work, including a long propagation delay, high attenuation, energy consumption, deployment, and a large transmission delay. A routing strategy for underwater sensor networks faces its biggest challenge in the absence of void regions. Data loss during data transfer from one sink node to another could occur because of the void. The network's longevity, propagation delay, and energy consumption are all impacted by the hole made during routing. Additionally, this work focuses on important problems like routing processes that can offer effective solutions for energy conservation. This routing problem optimization issue is regarded as an NP-Hard issue.

A. Key Findings:

This review highlights a few critical observations and findings related to the energy-aware routing protocols for UAWSNs.

.Diversified ways to enhance energy Efficiency: This paper discusses a variety of protocols that use energy-efficient communication strategies, sleep scheduling, energy-aware routing algorithms, and load-balancing mechanisms to improve energy efficiency. These approaches have innovatively varied in countering the challenge of energy consumption within UAWSNs.

- Trade-offs with Energy Efficiency and Performance: Achieving success in reducing energy consumption, many protocols necessarily trade-off with performance metrics, such as latency, packet delivery ratio, and network lifetime. Such a balance between energy efficiency and the network's general performance remains a central challenge in protocol design.

- Environmental Factors Have an Impact: Due to water currents, the underwater environment experiences high propagation delay, limited bandwidth, and dynamic topology change. Therefore, designing protocols for this environmental factor will enhance their energy efficiency and reliability.
- Scalability Issues: In large-scale UAWSNs, several protocols have problems with scalability. On the other hand, such protocols, designed for small- to medium-sized networks, do not perform optimally when scaled up, indicating a need for scalable solutions that can maintain energy efficiency across various network sizes.
- Emerging Trends in Protocol Design: Researchers have recently focused on cross-layer design, bio-inspired algorithms, and machine-learning techniques to enhance energy-aware routing. These emerging solutions are very promising for addressing the complex challenges of UASNs.

B. Key Contribution:

In this paper, we provide a detailed, systematic survey of energy-aware routing protocols designed for underwater acoustic wireless sensor networks (UAWSNs). Here are the key contributions of this survey:

- A Novel Taxonomy: We introduce a novel taxonomy employed to categorize existing energy-aware routing protocols for UASNs. It is based on critical factors such as energy efficiency mechanisms, routing strategies, and network topology considerations, which provide a clear framework for understanding the diversified approaches in this field.
- In-depth Analysis: Every protocol has undergone an in-depth analysis of its energy efficiency, scalability, robustness, and suitability for various underwater applications. We detail each's strengths and weaknesses, as well as the practical and performance consequences for different underwater scenarios.
- Performance Evaluation: We evaluate the reviewed protocols comparatively based on the following key performance metrics: energy consumption, network lifetime, packet delivery ratio, and latency. The process effectively identifies the most promising candidates and pinpoints potential areas that need improvement.
- Emerging Trends: Recently, emerging trends in the development of energy-aware routing protocols in UASNs have been presented, along with future research directions. In this paper, we outline the challenges in the peculiar underwater medium, like bandwidth constraints, high latency, and dynamic topology, and suggest potential resolutions to handle those.
- Research Gaps and Opportunities: The systematic review of extant literature highlights important gaps in research and opportunities for innovation. Indeed, the greatest benefit of this paper for researchers and practitioners is that it provides direction for further studies on the design of more efficient and reliable energy-aware routing protocols for UAWSNs. This systematic review summarizes the current state of the research and shows an avenue toward further progress in the

domain of underwater acoustic sensor networks in terms of energy efficiency and sustainability.

The summary of this proposed research work's contribution to the existing literature on protocols introduces a new taxonomy that can categorize existing protocols based on other important features like energy efficiency, routing strategies, and network topology. This can explain the various related approaches in this field by presenting a clear framework that classifies protocols. We analyze each protocol based on its energy consumption, scalability, reliability, and application to various underwater scenarios, highlighting its advantages and limitations. We perform a comprehensive analysis to compare the different protocols based on energy consumption, network lifetime, packet delivery, and end-to-end delay, identifying the most promising protocols and pinpointing areas for improvement. However, the review also presents future trends and research directions, discusses the challenges due to the nature of the underwater environment in terms of bandwidth, latency, and topology, and suggests possible solutions. This systematic review identifies significant research gaps and opportunities for innovation.

V. CONCLUSION

This survey analyzed research articles introducing the coherent acoustic modem in UAWSN, which can run energy-efficient MAC and routing protocols. Many researchers have presented energy and channel-aware routing protocols, but they failed to consider some challenging criteria, highlighting the need to improve the efficiency of existing procedures. Routing strategy in underwater sensor networks faces more than adequate challenges, being largely contributed to by the void regions since they are a potential ground that imparts data loss in the transfer process between sink nodes. This will affect network lifetime, increase in propagation delay, and lead to greater energy consumption. Addressing the formation of these voids is essential for enhancing overall network performance. This systematic review presents a novel taxonomy for energy-aware routing protocols, identifies strengths and weaknesses, conducts a comparative evaluation of the key performance metrics, and discusses emerging trends and challenges. This review also highlights the need for ongoing field tests implemented jointly with independent telecommunication companies, along with security issues. In the future, research will strive to fill the identified gaps in making routing protocols more adaptive and resilient to change in the dynamic underwater environment. Furthermore, the integration of deep learning techniques is very promising in the development of optimal paths between source sensor nodes and monitors to enhance routing efficiency and network reliability.

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