Computer Systems Science & Engineering
DOI: 10.32604/csse.2022.022662
Article

Provisioning Intelligent Water Wave Optimization Approach for Underwater Acoustic Wireless Sensor Networks

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Received: 14 August 2021; Accepted: 18 October 2021

Abstract: In the Acoustics channel, it is incredibly challenging to offer data transfer for time-sourced applications in an energy-efficient manner due to higher error rate and propagation delay. Subsequently, conventional re-transmission over any failure generally initiates significantly larger end-to-end delay, and therefore it is not probable for time-based services. Moreover, standard techniques without any re-transmission consume enormous energy. This investigation proposes a novel multi-hop energy-aware transmission-based intelligent water wave optimization strategy. It ensures reduced end-to-end while attaining potential amongst overall energy efficiency end-to-end packet delay. It merges a naturally inspired meta-heuristic approach with multi-hop routing for data packets to reach the destination. The appropriate design of this Meta heuristic-based energy-aware scheme consumes lesser energy than the conventional one-hop transmission strategy without re-transmission. However, there is no hop-by-hop re-transmission facilitated. The proposed model shows only lesser delay than conventional methods with re-transmission. This work facilitates extensive work to carry out the proposed model performance with the MATLAB simulation environment. The results illustrate that the model is exceptionally energy-efficient with lesser packet delays. With 500 nodes, the packet delivery ratio of proposed model is 100%, average delay is reduced by 2%, total energy consumption is 8 J, average packet redundancy is 1.856, and idle energy is 6.9Mwh. The proposed model outperforms existing approaches like OSF, AOR, and DMR respectively.

Keywords: Acoustic applications; energy efficiency; network communications; underwater sensor networks; meta-heuristic approach; intelligent water wave optimization

1 Introduction

The Earth is occupied by water (ocean) which plays an essential role in sustaining human life. It is an essential role in global development components [1]. Underwater detection and marine surveillance are not simple approaches. Underwater acoustic sensor networks (UWASN) give a higher ability to resolve these issues. The underwater communication and networking technology is flexibly applied over various environments like diverse water depths, coverage distance, and network structure and so on [2]. It is extensively utilized in practical observations to comprehend information interaction among various device-based observations in diverse spatial locations [3]. Underwater acoustic networking and communication technology have recently been an active and hotspot research topic in the marine field [4].

The UWASN link-based reliability is influenced rigorously owing to the underwater acoustic channel's complexities [5]. The link performance among neighbourhood nodes may reduce over a specific period that summons multi-hop re-transmissions those outcomes in energy dissipation [6]. Moreover, energy provisioning are generally complicated, and constraints to recharge. Therefore, during multi-hop UWASN, energy-efficiency is hugely significant to select an optimal routing to transmit data packets from source to destination [7]. It needs the routing protocol for both energy consumption and the network's energy consumption. Therefore, balanced energy utilization helps to enhance network lifetime [8].

Usually, energy consumption is the primary metric during the modelling of UWSAN. The principal target of this research is to model multi-hop energy-aware transmission-based water wave optimization to deal with multi-objective constraint in UWSAN [9]. The analysis over routing protocol for multi-hop UWSAN possesses various research priorities. The author in [10] proposes an enhanced vector-based forward routing protocol that adopts the number of re-transmission, location information, and residual energy for periodic information during data forwarding compared to conventional vector-based routing protocol in multi-hop UWSAN. Vector-based forward routing enables the utilization of the energy node and examines the appropriate data transmission. The author in [11] discusses energy-efficient and reliable protocol to enhance the network life by distributing the residual nodes' energy eventually and finds the most appropriate data transmission among the routing path. The author in [12] discusses the energy-efficient awareness-based routing protocol is initiated. It executes various greedy hopping and location-free packet forwarding approaches that significantly increase network capacity and diminish communication costs.

Subsequently, to eliminate more extended path loss and unpredictability over acoustic channels, cooperative transmission is applied to get an optimal solution. Zhou et al. [13] depicts the cooperative superiority of communication systems over P2P solutions and fulfils the need for multi-hop UWSAN eminently. The multi-hop networking environment can reliably enhance bandwidth utilization and enhance underwater acoustic communication systems and bit error rates. However, it expands the network coverage via the relay node cooperation. On the contrary, direct lost-distance/multi-hop transmission diminishes the entire system's energy consumption [14]. The basic idea towards the optimization approaches like ACO is determined as an intellectual approach for the heuristic process with appropriate feasibility and distributed computing abilities. It is easier to merge with other models. Moreover, the drawback associated with these converges towards a locally optimal solution rather than the global optimum solution. The intelligent swarm algorithm can converge quickly to a globally optimal solution; however, it provides lower precision in determining a globally optimal solution. Jin et al. [15] ACO-FSA integration-based routing algorithm is anticipated for multi-hop UWSAN which merges both ACO and FSA's benefits. The fusion process possesses virtues; practically, it can diminish prevailing routing protocols, energy consumption, transmission delay and enhance the routing protocols. Moreover, it is still unfeasible to attain reliable data transmission owing to the harsh marine environments (multi-hop UWASN), and more action is considered to enhance the feasibility of the algorithm. The significant contributions of this research are given below:

1) Based on the extensive analysis of the general approaches, this work proposes a novel approach known as the multi-hop energy-aware transmission-based intelligent water wave optimization (MEA-WWO) strategy. It ensures reduced E2E error rate while attaining potential amongst overall energy efficiency and E2E packet delay. MEA-WWO merges a naturally inspired meta-heuristic

approach with multi-hop routing for data packets to reach the destination. The randomness of the model is adopted to predict the optimal global solution with a faster convergence speed. The energy consumption of the model is lower than the conventional approaches during multi-hop UWSAN. Specifically, the anticipated MEA-WWO model applies to both cooperative nodes. Owing to the beneficial MEA-WWO model, the anticipated system is reliable towards multi-cases in bandwidth efficiency and transmission delay.

2) The performance of the anticipated MEA-WWO routing algorithms with ACO, AFSA and enhanced ACO based on a tuneable model in diverse network scaling, specifically with network model (small and medium scale) with practical outcomes in multi-hop UWSAN. It is more resourceful for promoting the AI applications during practical execution as the routing model is considered with diverse networking scale w.r.t. energy conservation. The work is organized as follows: Section 2 is an extensive analysis of background studies. Section 3 is the MEA-WWO methodology with optimization for multi-hop UWSAN. Section 4 is numerical results and discussion with the conclusion in Section 5.

2 Related Works

This section discusses various existing approaches with network models and various performance metrics that help improve network lifetime, energy efficiency, etc. With the extensive analysis of UWASN, Su et al. [16] propose a novel chain-based routing model. This model reduces the data packet transmission over the network and improves network efficiency. The consequences of packet size and number of data packets on energy consumption are evaluated. The UWASN-based grid technology is examined by Jin et al. [17]. The energy consumption of various energy nodes is evaluated, and network performance is examined. Zhuo et al. [18] have investigated a MAC protocol by analyzing the scalable, distribution, and energy-efficient protocol for more extended UWASN medium and propagation delay. The simulation carried out by the proposed model shows no longer propagation delay and general E2E delay. The transmission-based energy waste and the duty cycle, and the number of nodes over collision are examined. Yan et al. [19] discuss the lifetime maximization by packet size optimization in UWASN is examined. Similarly, packet size and transmission size is jointly considered to enhance the network-lifetime. Chen et al. [20] discuss the link-layer realistic model to reduce the network model's energy consumption. The energy analysis for designing the routing protocols is cluster-based capacity based UWASN research. Here, the stochastic geometry-based network model is examined for examining the cluster-based capacity. The simulation outcomes determine whether the model is theoretically analyzed and verified to examine the error rate causes. The energy-based routing protocol and avoidable void model over UWASN are examined by Ahmad et al. [21]. Flooding, void, and cycle transmission has to be avoided in UWASN. The energy consumption, network lifetime, packet delivery ratio, and transmission delay are performance measures utilized to examine the functionality of UWASN. E2E delay, PDR, network density, and energy consumption are discussed efficiently. The energy hole avoidance in UWASN using load balance is examined in Alkindi et al. [22]. Load balancing characteristics, live nodes, residual energy, and dead nodes are determined for computational purposes. The energy harvesting and lifetime analysis over UWASN are carried out by Azam et al. [23].

Sherubha et al. [24] discuss the minimization of hole problem and energy consumption during data collection. The protocol is evaluated in a cooperative, optimal, and energy-efficient manner. This energy-efficient relay model is chosen to make the energy-efficiency model more efficient for UWASN. As well, E2E delay, energy consumption, PDR, dead, and throughput are examined. Uniform nodes distribution over the 2D scenario is deployed where interference and noise are considered as UWASN. The localization interference and energy minimization hole for UWASN routing is examined. The total amount of packets attained from the sink, number of dead nodes, packet drops and the total energy consumption is further discussed by Sasirekha et al. [25]. Sherubha et al. [26] anticipate a novel coverage control model adopted with control scheduling and probabilistic detection approach to enhance the network lifetime. Also, diverse approaches are known as Network Connectivity Restoration through inserting and adjusting the model and Network Connectivity Restoration through adjusting that deals with the issues over coverage problem in an underwater sensor network [27]. The anticipated model provides better performance during coverage ratio and fulfils the connectivity with lesser time complexity.

Yildiz et al. [28] anticipate damage prediction approach for wind turbines actuator and WSNs. With a fuzzy logic model, the functionality over damage prediction state is examined appropriately over the wind turbines. For better performance analysis, the accidents are eliminated, and delays and maintenance cost with power generation is further reduced. Wang et al. [29] provide an efficient way for underwater acoustic-based clustering approaches, and comparative examination is done with various performance metrics. Some non-conventional communication approaches demonstrate the features of specific vital characteristics. Sandeep et al. [30] anticipate a novel optimization approach via the Integer Linear Programming model. The initiation with these Link-Level transmission-based power control methods with the most acceptable power level was selecting all ACK frames and data over each link. The transmission power and packet size are considered for enhancing the network lifetime. Based on diverse underwater models; the outcomes are optimized and examined for analyzing the time complexity. Tab. 1 depicts the comparison of diverse optimization approaches.

Table 1: Comparison of various optimization approaches

Methods	Objectives	Deployment criteria		
		Energy consumption	Coverage	Connectivity
Self-deployment PSO	Optimize events coverage	✓	✓	✓
Constructive GA	Node placement algorithm to reduce transmission cost	No	✓	✓
Uneven cluster model	Enhance network reliability	✓	✓	✓
Fisher score model	Target positioning	✓	No	No
3D coverage pattern	Preserve network coverage	✓	✓	✓
Game theory		No	✓	✓
Multi-objective framework	Optimize nodes mobility	✓	✓	No
Greedy iterative approach	Enhance network connectivity	✓	✓	✓
Stratified connected tree	Optimize leaf nodes position	✓	✓	✓

3 Methodology

Here, a multi-hop energy-aware mechanism is performed with nodes like sensor nodes (SN), relay nodes (RN), and destination nodes (DN). The nodes are specified by 'S', N_{h-1}, *and* D, respectively. The relay among the nodes are provided by $RN_i = (i = 1, 2, 3, \ldots, N_{h-1})$, and the broadcasting nature is provided based on C_i *where* $i = 1, 2, \ldots, N_h$. The hopping-based transmission is expressed in N_h UWSAN. It is explained below:

1) The nodes are half-duplex and cannot transmit/receive data simultaneously;

2) The transmitted data from one node is received by successive neighbourhood relay nodes, i.e., R_i and R_{i-2}; and the transmission from the source is heard only by neighbourhood relay nodes RN_{i-1} and R_i. With these assumptions, data transmission over every hop should not influence the successive hops.
3) When the distance (relative) among the neighbourhood relay nodes RN and the RN and cooperative nodes' distance over certain coverage regions are provided with better data decoding. It is assumed that $r_1 = 3$ m and $r_2 = 4$ m is the boundary regions for decoding the data. The transmission distance from $i \to i+1$ is represented as d_1. These nodes help in constraint transmission power and distance transmission. Thus, the relay node selection within these ranges r_2 and cooperative node selection need to be located to complete the transmission task efficiently. Fig. 1 depicts the transmission mechanism for multi-hop UWASN.

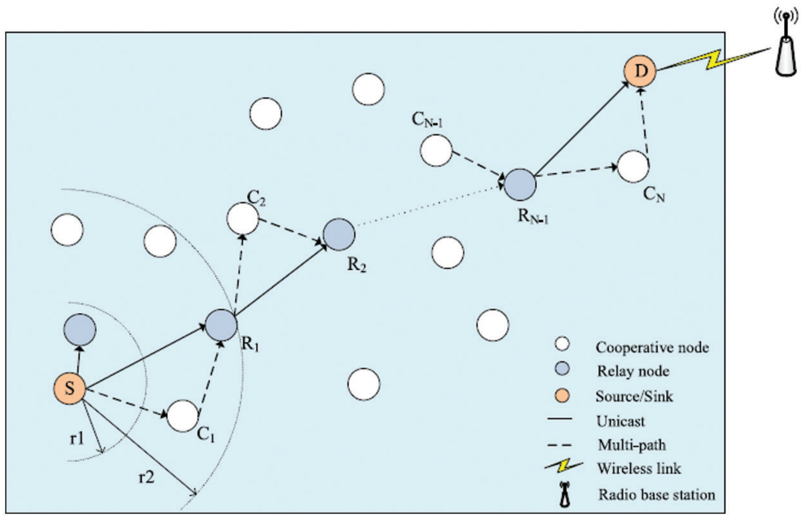

Figure 1: Transmission mechanism for multi-hop UWASN

The next i^{th} hops are performed among the nodes with nodes-level synchronization. The nodes receive a transmission from RN_i, and the relationship between the input and output nodes are expressed as in Eq. (1):

$$RN_{i+1} = CM_{R_i,\, R_{i+1}}(l) + N_{RN_{i+1}}; \qquad l = 1,\ 2,\ \ldots,\ N_{li} + \Delta \tag{1}$$

Here, RN_{i+1} is a vector form of relay nodes with sub-carriers; 'l' is transmitted symbol vector, $CM_{R_i,\, R_{i+1}}$ is channel among the mobility nodes RN_i and RN_{i+1}, and $N_{RN_{i+1}}$ is ambient noise. The destination node receives the signals' super-position from RN_i and C_{i+1}, respectively. The cooperation among the nodes is termed as redundancy cooperation where the CN is expressed as in Eq. (2):

$$RN_{i+1} = \begin{cases} CM_{R_i,R_{i+1}}[l] + CM_{i+1,R_i+1}[l]s[l] + +N_{RN_{i+1}}[l] & \textit{For all redundancy cooperation} \\ CM_{R_i,R_{i+1}}[l]s[l] + CM_{i+1,R_i+1}[l]\hat{s}[l] + +N_{RN_{i+1}}[l] & \textit{For all energy} \end{cases}$$

$$l = 1,\ 2,\ \ldots,\ N_{li} + \Delta \tag{2}$$

Here, $CM_{R_i,R_{i+1}}[l]$ is a combined channel matrix among the nodes, $\hat{s}[l]$ is the information block transmitted from cooperative nodes C_{i+1}. There is a difference between $s[l]$ and $\hat{s}[l]$. Thus, there is a need for two parallel data streams that have to be separated from R_{n+1}. The transmission path is considered as the fusion of the routing process with optimal node selection for all hops. The energy-consumed during the multi-hop process is termed as the sum of energy consumption in every hop.

3.1 Energy Consumption Module

The underwater communication process is based on acoustic waves (transmission), where energy consumption process is hugely different. It is initiated as follows: 1) P_0 is the lowest level of power where the packets are decoded successfully towards the receiver; 2) $U(d)$ is the power attenuation over the distance 'd'. It is mathematically expressed as in Eq. (3):

$$P = P_0.U(d) \tag{3}$$

Specifically, $U(d)$ is a physical quantity that is associated with propagation and transmission frequency. It is given as in Eqs. (4) & (5):

$$U(d) = (1000.d)^m.\xi^d \tag{4}$$

$$\xi^d = 10\frac{\gamma(f)}{10} \tag{5}$$

Here, $\gamma(f)$ is the absorption coefficient (dB/km). Based on the propagation condition, the 'm' value varies. If $m \rightarrow 1$, then it is related to the shallow water channel with appropriate wave propagation. When the value is 2, then it is related to the deepwater channel. Based on this consideration, we take $m = 1.5$, and 'f' is frequency. The empirical formula is given as in Eq. (6):

$$f_{optimal} = \left(\frac{200}{d}\right)^{\frac{2}{3}} \tag{6}$$

Therefore, the optimal frequency is related to the path with the determination of 'd', where the distance measures from $i \rightarrow j$. Then, in case of no further re-transmission in every hop, the energy consumed during transmission is expressed as in Eq. (7):

$$E = P.T \tag{7}$$

$$E = P_o.U(d).T$$

Here, 'T' is transmitting time without any generality loss. It is considered that $P_0 = 1$ watt and the data length is 1024 bits for every time, and the data rate is 106 bps; transmitting time is $T = 6.5$ seconds at the transmitter.

3.2 Multi-Hop Energy-Aware Transmission Based on Intelligent Water Wave Optimization (MEA-WWO)

The proposed MAE is integrated with WWO to provide a global solution with a feedback mechanism, randomness, and supportive nodes. Here, multi-hop energy-aware transmission is adopted to find the sequence of routing and some nodes are considered supportive nodes where routing table (final) is of two forms. The energy consumption during the routing strategy needs to be reduced (see Fig. 2), where the single-hop functionality of the proposed model is given as follows. It is shown in Algorithm 1 to demonstrate the functionality of the supportive nodes and the neighbourhood nodes. Similarly, the multi-hop functionality is measured using intelligent water wave optimization. It is shown in Algorithm 2.

Algorithm 1: Single-hop node functionality

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1) Initialize transmission with single-hop;

2) Broadcast 'HELLO' message;

3) Every SNs hold their information;

4) Nodes possess residual energy, the total number of single-hop neighbourhood nodes;

(Continued)

Algorithm 1 (continued)

5) Analyze the information depth of packets received;

6) if essential packets received → accept;

7) else

8) Discard the packets

a) if $d_1 < r_1$, the node $i + 1$ is appropriately decoded with information;

b) If $r_1 < d_1 < r_2$, the node $i + 1$ is not appropriately decoded information from primary node 'i', and it has to assist supportive nodes.

9) Generate random transmission;

a) if $d_1 > r_2$, the nodes' transmission information is not successfully decoded from $i + 1$.

b) if relay node r_2 and the cooperative node selection needs to be located to complete the transmission efficiently

10) Perform data forwarding with a single hop.

11) Update the position of the nodes

12) Repeat the process

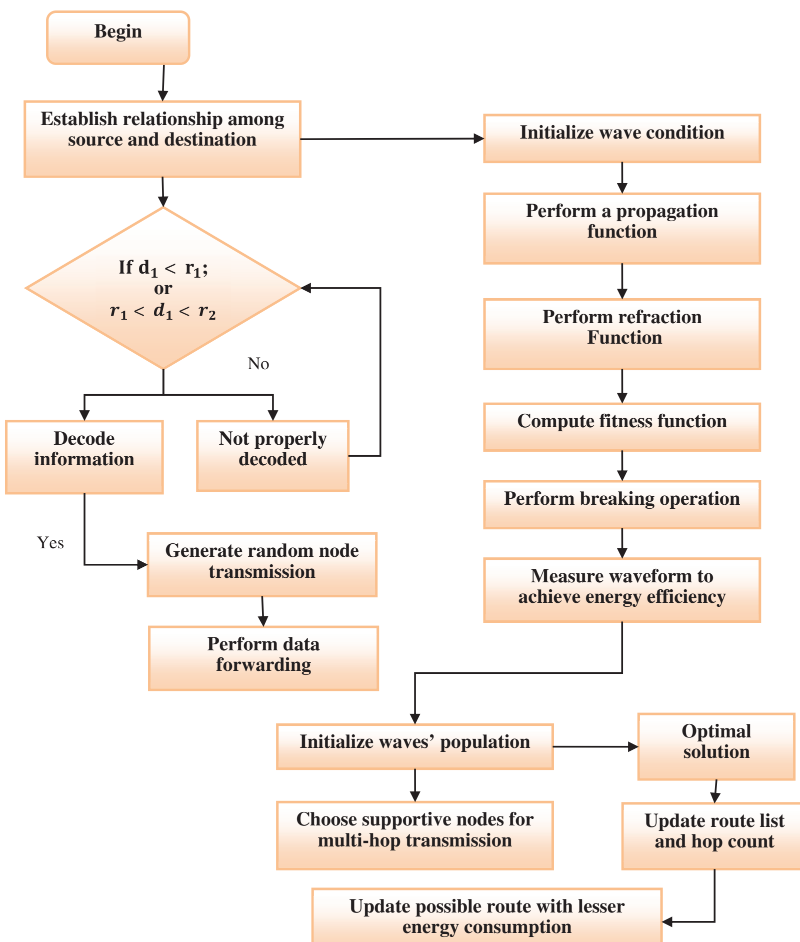

Figure 2: Flow diagram of MAE-WWO

3.3 Intelligent Water-Wave Optimization (IWWO)

Intelligent water-wave optimization is inspired by a shallow wave model for handling constant optimization problems [31–33]. The individual wave possesses a height of 'h' and wavelength 'λ'. The searching space is associated with a certain region. The fitness solution is evaluated for handling the maximal optimization issue and is inversely proportional to seabed depth. The waves are expressed as $x = [x(1),\ x(2),\ \ldots,\ x(l)\}$ with the height of 'h' and wavelength 'λ'. There are three diverse operations known as propagation, refraction, and braking. During propagation, the new wave x' is produced with original η, as shown in Eq. (8):

$$x'(a) = x(a) + rand\ (-1,\ \ 1)\ \lambda\ L(a) \tag{8}$$

Here, $(-1, 1)$ is random numbers of range $[-1, 1]$ with uniform distribution, $L(a)$ is the length of search space. In this scenario, when the x' is superior to 'x', then 'x' is substituted to x'. Similarly, the height is set as $h_{max.}$ Else, the values remain the same. It is mathematically expressed as in Eq. (9):

$$\lambda = \lambda\alpha^{(-(f - f_{min} + \varepsilon)/(f_{max} - f_{min} + \varepsilon)} \tag{9}$$

Here, 'f' is the fitness function, f_{max} and f_{min} is maximal and minimal values of wavelength reduction coefficient, and ε avoids division by zero. The current waveform is expressed mathematically as in Eq. (10):

$$x'(a) = N\left(\frac{x^*(a) + x(a)}{2},\ \frac{|x^*(a) - \ x(a)|}{2}\right) \tag{10}$$

Here, N is a Gaussian random function with appropriate mean and SD. After refraction, $x \rightarrow x'$ and height are reset to h_{max}, where the λ is expressed as $\lambda' = \lambda\, \frac{f(x)}{f(x)}$. The operator is used for improving the local search with promising outcomes. When the wave is superior to the current position, the dimensionality of the waves is chosen randomly. The breaking operations are expressed as in Eq. (11):

$$x'(a) = x(a) + N(0,\ 1)\beta L(a) \tag{11}$$

where β is the breaking coefficient, when there is no change with the wave, it remains the same. Else, x^* is replaced by the new wave, as shown in Eq. (11).

Algorithm 2: Multi-hop node functionality using water wave optimization

1) Initialize transmission with multi-hop;

2) Initialize parameters for underwater SNs;

3) Randomly generate the nodes and position.

4) Information is broadcasted from the sink;

5) For $i, j = 1, 2, 3, \ldots, N$ do

6) Compute distance measure

7) End for

//Intelligent Water Wave Optimization-based routing

8) Initialize the wave condition;

9) For $x = [x(1),\ x(2),\ \ldots,\ x(l)\}$ do

10) Perform propagation function

11) $x'(a) = x(a) + rand\ (-1, 1)\ \lambda\ L(a)$

(Continued)

Algorithm 2 (continued)

12) Perform refraction operation
13) $\lambda = \lambda\alpha^{(-(f - f_{min} + \varepsilon)/(f_{max} - f_{min} + \varepsilon)}$
14) Perform fitness function using Eq. (10)
15) Perform breaking operation
16) $x'(a) = x(a) + N(0, 1)\beta L(a)$
17) *end for*
18) Among the rising waves measure the route wave to provide lesser energy efficient node as a solution

//Routing with MAE-WWO

19) Initialize the waves to get optimal solution over the routing list
20) For $x = 1, 2, 3, \ldots, N$ do
21) Choose the supportive nodes to perform multi-hop transmission.
22) Choose the appropriate supportive nods when needed.
23) Update the routing list
24) Update the hop count
25) End for
26) Update the routing position
27) End process
28) With all the possible routes, select the prompt route with lesser energy consumption.
29) Output: multi-hop energy-aware routing process.

4 Numerical Results and Discussion

Here, the simulation is carried out in a MATLAB environment. The proposed MEA-WWO routing model's performance is evaluated and compared with existing approaches to provide a better trade-off. Due to the lower bandwidth ability, the collision probability is increased at the receiver side. Therefore, collision detection and avoidance are not so efficient. Thus, some investigators like adopt the aloha method for long propagation delay computation. The simulation environment is deployed with 10–500 nodes over 10 * 10 * 10 kilometres with ten sink nodes uniformly distributed over the ocean surface at equal distance. Based on the consideration, the sink remains stationary at SNs and water's surface, which moves towards the X-Y plane direction (2D random walk). The nodes movement is 1 to 3 m/s towards the horizontal direction, where the vertical direction is negligible. The performance of the proposed MAE-WWO is evaluated against the prevailing routing approaches like optimal selective forwarder (OSF), adaptive opportunistic routing (AOR) and distance measure routing (DMR) protocol. The simulation is conducted to analyze the metrics like E2E delay, PDR, energy-efficiency, and redundant transmission. The simulation is performed multiple times, and 20 runs are plotted. Node density varies from 100–500 nodes over the deployed region. The nodes are deployed randomly over the network. Disk model is extensively used over the communication range, and the link over the transmitting packets gives PDR 100%, else PDR is 0%. However, the model gets closer proximity to energy consumption. Fig. 3 depicts the topological view of node placement. Fig. 4 shows the sink and source/destination node generation. Fig. 5 depicts the energy consumption during a simple routing mechanism. Fig. 6 depicts the energy consumption during the multi-hop routing mechanism.

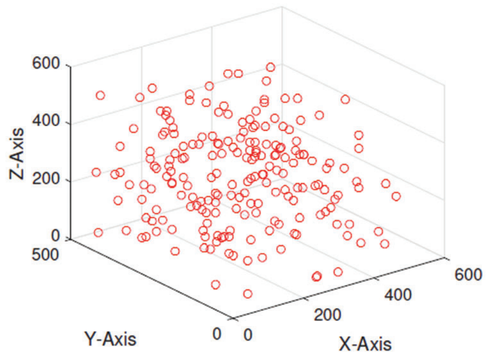

Figure 3: Topological view

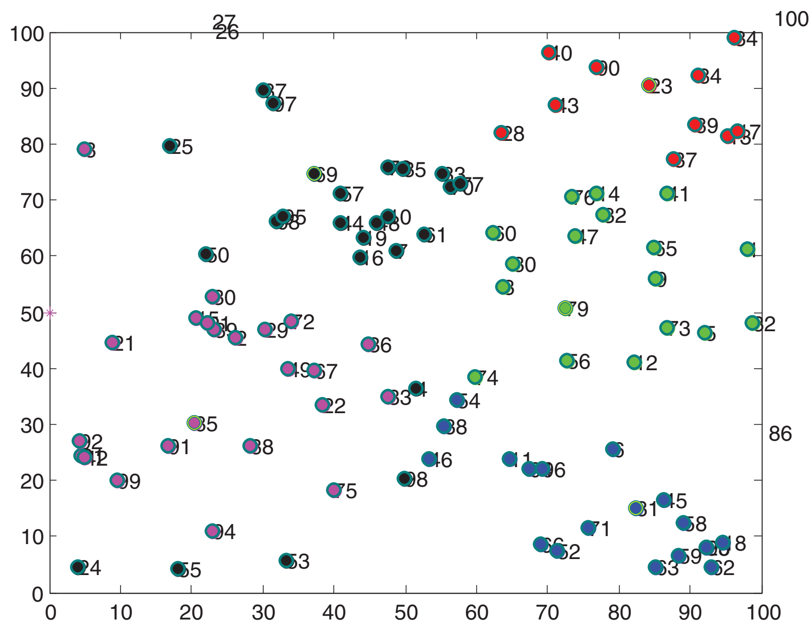

Figure 4: Node creation

4.1 PDR Computation

PDR is depicted as the reception of packets successfully over the final destination. It is evaluated as the total amount of packets received to the total transmitted packets. It is mathematically expressed as in Eq. (12):

$$PDR = \frac{number\ of\ received\ packets}{total\ transmitted\ packets} \tag{12}$$

The average number of PDR at diverse node density is demonstrated. The outcomes depict the constant increase towards the PDR as the increase in nodes' density and the sustainability in MEA-WWO is due to the network partitioning. The division of forwarding area redundant packets are successfully suppressed when the PDR is successful with the reception of data packets distinctively. With proactive approach to attain the neighbourhood information, the optimization model's local maxima should be avoided. As illustrated in Fig. 4, the PDR is doubled when the number of nodes = 150. It is observed that the ratio of PD is gradually increased with number of nodes. In the contrary, MEA-WWO selects the neighbourhood node based on multi-hop energy-aware information from source node. However, it adopts the control parameter to select suitable forwarder node. Based on this parameter, it is observed that neighbourhood nodes' choice over the cyclic manner leads to quicker energy dissipation, which makes the network nodes prone (void region). Also, inefficient data forwarding maximizes duplicate packets with the least packets over the destination region (Tab. 2). Hence, it is proven that PDR is higher when compared to other models like OSF, AOR and DMR. The transmissions of packets are reliable. Due to the existing model's lesser distinctive nature, the PDR of those models is lesser compared to other approaches.

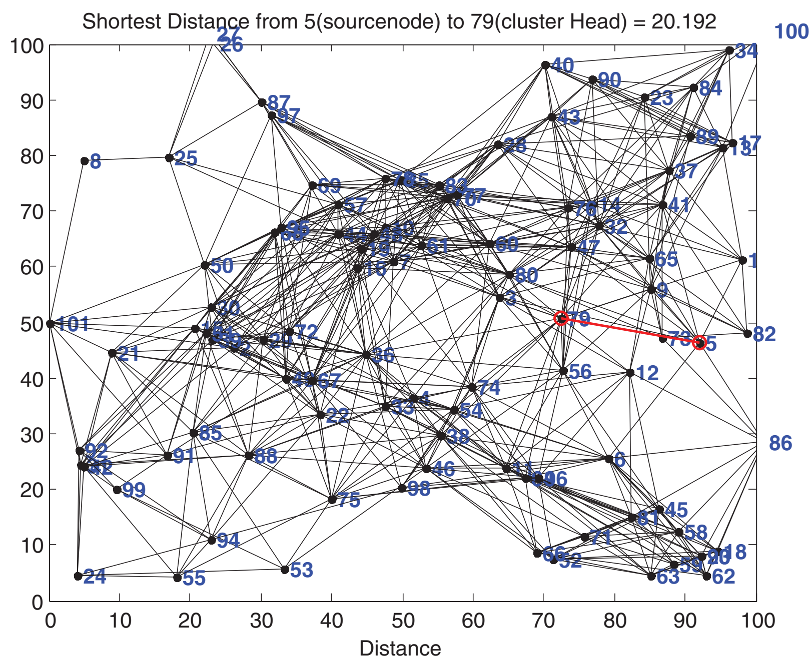

Figure 5: Node connectivity (lesser energy consumption)

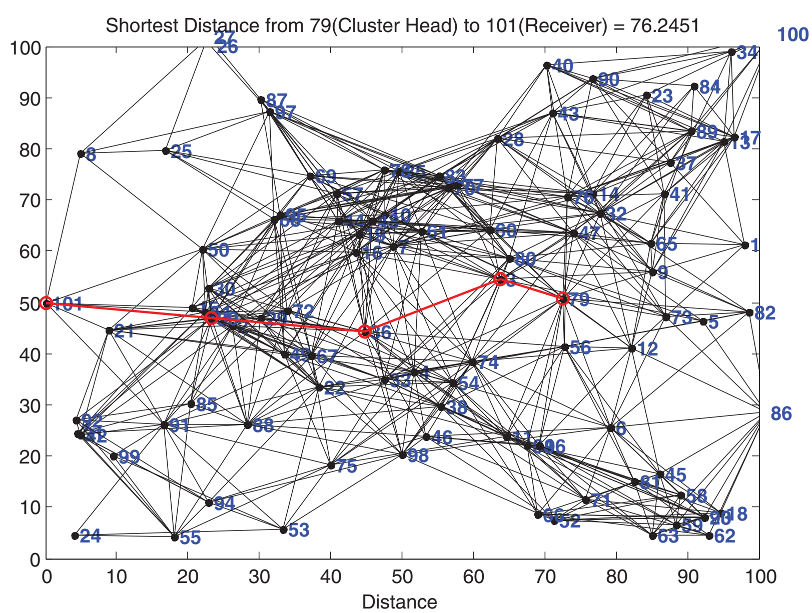

Figure 6: Node connectivity (higher energy consumption)

Table 2: PDR computation

Number of nodes	OSF	AOR	DMR	MAE-WWO
150	0.49	0.38	0.3	0.52
200	0.62	0.52	0.47	0.68
250	0.73	0.63	0.57	0.76
300	0.81	0.74	0.68	0.85
350	0.9	0.81	0.71	0.93
400	0.92	0.89	0.75	0.96
450	0.94	0.90	0.78	0.98
500	0.98	0.92	0.79	1.0

4.2 E2E Delay Comparison

E2E is depicted as the packets' total time to reach destination, where the average time after data generation till it reaches the destination. It is evaluated in seconds. The E2E delay of the proposed MEA-WWO is reduced due to avoiding the void region (See Tab. 3). The proposed MEA-WWO exploits AOR to choose backup nodes responsible during the fall of the back procedure. Hence, the computational time is less when compared to another model. The average E2E delay of existing OSF, AOR and DMR is higher due to the added computational time required during the forwarding region. It partitions the communication range into various regions, and these regions are managed to reduce the duplication of nodes transmission. When the nodes are deployed over the forwarded packets after node priority failure, it incorporates unnecessary delay. It is the cause behind the higher E2E delay.

Table 3: Average E2E delay

Number of nodes	OSF	AOR	DMR	MAE-WWO
150	0.75	0.6	0.5	0.25
200	0.86	0.77	0.63	0.54
250	1	0.82	0.64	0.60
300	1.25	1.3	0.68	0.64
350	1.56	1.5	0.82	0.73
400	1.85	1.76	1.35	1.24
450	2	1.79	1.35	1.30
500	2.2	2.4	2.2	2

On the contrary, MEA-WWO model shows lesser E2E delay when compared to the other models. The forwarding regions are chosen selectively, and the unnecessary nodes are terminated from the deployment region and terminate the same transmission process over the receiver side. With the avoidance of these nodes, surplus energy is being saved when transmitting the packets via the intermediate nodes. It is proven that E2E delay is more sustainable when the node density increases. The concept behind these E2E delay computation increases the transmission range with avoidance of collision with sparse environment. Number of nodes over the communication region requires enormous time to transmit the corresponding destination. The forwarding nodes are chosen based on the primary and the secondary forwarding regions with lesser holding time. Therefore, it is concluded that the results attained shows higher advantages corresponding to the communication range. Thereby, it diminishes the holding time of data packets. Thus, delay among the intermediate nodes is reduced with the proposed MEA-WWO model.

4.3 Energy Consumption Comparison

Energy consumption is depicted as total energy dissipated during the data packets transmitted from source to destination. It is composed of transmitting, receiving, and idle nodes that participate in the energy communication process. It is mathematically expressed as in Eq. (13):

$$Energy\ consumption = E\ (t) + E(r) + E(idle) \tag{13}$$

Based on Eq. (13), $E\ (t)$ is transmitter energy, $E(r)$ is receiver energy, $E(idle)$ is the energy consumed when the node is in the idle region. Fig. 5 depicts the energy consumption of the proposed MEA-WWO with existing OSF, AOR and DMR. The graph shows that the battery utilization is slightly increased with the nodes deployment (See Tab. 4). The reductions of redundant packets are suppressed with the partitioning of the transmission region. Here, nodes may directly discard the packets to fulfil the packet transmission successfully. The avoidance of packet energy consumption reduces the computational time is compared to existing approaches. The prediction of nodes holding time over the intermediate regions is lesser than the prevailing approaches. The claim of the proposed MEA-WWO model is validated with the simulation environment. It efficiently increases the network lifetime.

Table 4: Total energy consumption

Number of nodes	OSF	AOR	DMR	MAE-WWO
150	43	42	39	35
200	34	32	27	24
250	27	25	23	20
300	22	19	17	15
350	18	16	15	13
400	13	12.5	12	10
450	12	11	11	9.7
500	11	10.5	10	8

The energy consumption of the general approaches is notably higher when compared to the proposed model. The cause behind the higher energy consumption over the existing model determined as the fall back in every probable direction to predict the necessary route to reach destination. Therefore, inefficiency over the existing models is because of the higher redundant data. Also, in OSF, the holding time is shorter due to the successive hops towards the forwarding region. The node with higher priority fails during the packet propagation towards the destination. The fewer reception packets are compared with the transmission packets as the nodes initiate the transmission over the channel. It causes a rise in data loss and collision. The inefficiency encountered over the prevailing models leads to higher energy consumption when compared to MEA-WWO, respectively.

4.4 Average Packet Redundancy

The average packet redundancy is depicted as the total packets received at the destination with the avoidance of redundant packets to total packets generated from the network. It is computed by plotting the graph and evaluating the mathematical expression as in Eq. (14):

$$Average\ packet\ redundancy = \frac{TPR - RP}{TP} \tag{14}$$

Here, *TPR* is total packets received, *RP* is a redundant packet, and *TP* is total packets. From Fig. 6, the sustainable nature of the model over the energy efficiency is comparatively higher, where the proposed MEA-WWO model shows efficiency towards the packet redundancy (See Tab. 5). The packet forwarding region is partitioned to suppress packet transmission over hidden nodes of the source region. Tab. 6 depicts the idle energy consumed during packet size transmission (512 bytes, 1024 bytes, 2048 bytes, and 4096 bytes).

Table 5: Average packet redundancy

Number of nodes	OSF	AOR	DMR	MAE-WWO
150	1.93	1.9	1.9	1.8
200	1.93	1.92	1.9	1.824
250	1.94	1.935	1.925	1.824
300	1.948	1.936	1.925	1.836
350	1.95	1.936	1.945	1.845
400	1.95	1.945	1.945	1.850
450	1.952	1.945	1.95	1.850
500	1.953	1.945	1.955	1.856

Table 6: Idle energy (MWh)

Number of packet size (bytes)	OSF	AOR	DMR	MAE-WWO
512	9.1	9.2	9.3	7.5
1024	8.5	8.6	8.9	6.8
2048	8.8	7.2	8.5	6.5
4096	8.9	6.98	8	6.9

With the exclusion of forwarding nodes, the packets are received. The packets are broadcasted due to their mobility over the acoustic environment. Thus, the model predicts the holding time, neighbourhood nodes, and generated packets which commences from communication range after packet broadcast. Packet redundancy increases with the rise of total nodes. On the contrary, the existing OSF, AOR, and DMR models do not reduce the redundant data packets, specifically over the hidden terminals. It is not evaluated due to the lesser amount of distinctive packets. The holding time of OSF, AOR, and DMR is significantly smaller that quickly expires, which is similar to that of the re-transmission process. Fig. 7 depicts the convergence rate of the anticipated model. The cause behind this issue is the packet redundancy drawback encountered over the prevailing models.

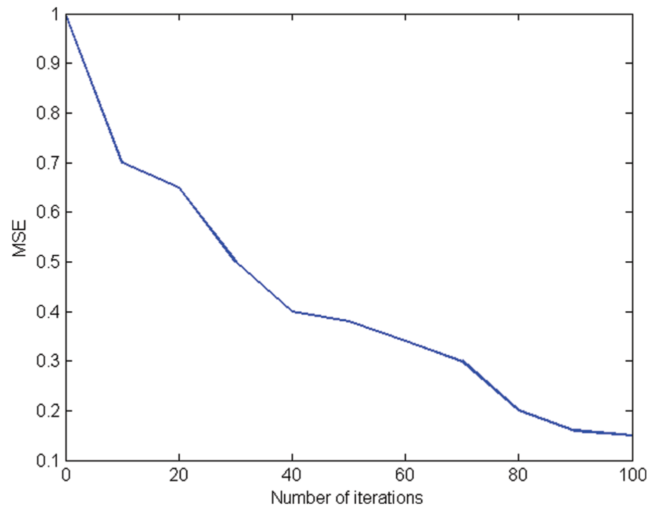

Figure 7: Convergence rate of MAE-WWO

5 Conclusion

In this research, we proposed a novel MEA-WWO model for routing with a multi-hop energy-aware model. The proposed model is analyzed with various metrics like PDR, average E2E delay, average packet redundancy, and energy consumption efficiently. The proposed model's performance is compared with three different approaches like OSF, AOR, and DMR. The multi-hop functionality is performed over 10–150 nodes, where the simulation outcomes show a slight difference in energy consumption compared with other approaches. The energy consumption of the proposed MAE-WWO is lesser than other models significantly. The performance of the proposed MAE-WWO is notably higher even when the nodes range increases.

Additionally, the proposed model reduces the computational complexity as the environment is set for simulation purpose. This complexity is still acceptable in the marine environment. The proposed model gives lesser E2Edelay, higher PDR, lesser energy consumption, and reduced packet redundancy, where it is practically applicable to the medium-scale real-time environment. The model proves the efficiency of the multi-hop energy-aware transmission efficiently with increased network lifetime. The major research constraints are the analysis with the optimization approach and simulation with sensor placement. In future, the model is further extended with practical implementation, which motivates to suit the acoustic network application with various scaling factors like (small scale, medium scale, and large-scale, respectively).

Funding Statement: The authors received no specific funding for this study.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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