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AN EFFICIENT COOPERATIVE ROUTING WITH ML BASED ENERGY EFFICIENCY MODEL FOR DISTRIBUTED UNDERWATER WSN ELECTRICITY METER WARNING SYSTEM

ZHENGANG SHI[*] TAO PENG[†] LINHAO ZHANG[‡] BO GAO[§] AND HONGXI WANG[¶]

Abstract. Underwater wireless sensor network that operates underwater, typically in oceans, lakes, and rivers. UWSNs are composed of a large number of small sensor nodes that are equipped with various sensing and communication capabilities. These nodes are deployed in the underwater environment to collect and transmit data, which can be used for a variety of applications such as environmental monitoring, oceanography, and marine biology. The Underwater WSN (UWSN) consists of sensor nodes to sense the data and transmit it to the sink node. These sensor nodes (SN) are equipped with limited batteries, which is the central issue. Therefore, the routing protocols were developed for researchers to save energy. However, the increment of network lifetime remains an open challenge. Forwarding the data to the nearest SN to the sink will reduce the network reliability and stability, draining SN's energy early. To overcome these issues, this paper focused on developing an efficient Cooperative based routing (CR) with a machine learning (ML) model to improve the network's lifetime. The cooperative routing discovers the route path from the sender to the destination. The best possible way from the sender to the receiver has been selected using the ML approach called the Self-organizing network (SON). By identifying congestion-free multi-hop transmission using CRSON, the data packet is transmitted from sender to receiver with reduced energy, increasing the network's lifetime and reliability. This model is simulated and experimented with energy efficiency, packet delivery, loss rate, latency, and throughput metrics.

Key words: Underwater WSN, cooperative routing, machine learning, Self-organizing network, energy efficiency

1. Introduction. Underwater Wireless Sensor Networks (UWSNs) are a type of network that is used to collect data and monitor the environment in underwater settings. These networks typically consist of a large number of small sensor nodes that are deployed in the water and are capable of gathering data on various environmental factors such as temperature, pressure, and water quality [4, 18]. UWSNs are used in a variety of applications, including oceanography, environmental monitoring, and underwater exploration. Because of the unique challenges posed by the underwater environment, such as limited communication range and high levels of interference, designing and deploying effective UWSNs is a complex task. However, advances in technology have made it possible to create sophisticated and reliable UWSNs that are capable of gathering and transmitting data in even the most challenging underwater environments.

UWSNs are the most significant area that supports monitoring the environment and surveillance of the military. In UWSN, the sensor nodes were connected to sink nodes, surface stations, and other nodes in the respective area [2]. Instead of radio signals, acoustic signals are used to transmit the data from the sender to the receiver since the salt water interrupts the radio signals. A de-centralized UWSN leads to a low-cost solution that deploys the sensors rapidly for parameter measurement, which will harm the marine system. The UWSN transmission while monitoring has been interrupted by a list of issues, including limited bit error rate (BER), bandwidth, high energy consumption, and propagation delay [5]. Due to the node dying of insufficient power in UWSN, the network lifetime also gets reduced. To overcome this, efficient routing protocols are needed. The primary factor in determining the routing scheme is the selection of a relay node depending on distance, number of hops, and residual energy.

The UWSNs node with the constrained battery backup and replacement are restricted in the environment. While developing a routing scheme, the node with limited battery power must be considered. The sink node,

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[*] State Grid HeBei Marketing Service Center, Shijizhuang Hebei 050000, China (`zhengangresar1@outlook.com`)
[†] State Grid HeBei Marketing Service Center, Shijizhuang Hebei 050000, China
[‡] State Grid HeBei Marketing Service Center, Shijizhuang Hebei 050000, China
[§] State Grid HeBei Marketing Service Center, Shijizhuang Hebei 050000, China
[¶] State Grid HeBei Marketing Service Center, Shijizhuang Hebei 050000, China

Sensor node, and other respective equipment are appropriately deployed to improve the network's lifetime[3]. However, the network's topology is also significant in reducing the energy of USWNs. The well-designed topology can consume less energy, and the node will die early if not adequately designed. Cooperative communication is the best solution for reliable transmission from sender to receiver, reducing data loss. Proper routing (CR) transmits the data through various routes to improve the receiving data's possible to reach its destination [17]. Some of the key challenges that need to be addressed in order to create effective UWSNs:

1. Radio waves do not propagate well underwater, which means that the communication range between UWSN nodes is limited. This makes it challenging to maintain reliable communication between the nodes and requires careful planning of the network topology.
2. The underwater environment is full of various sources of interference, such as noise from other marine animals or equipment. This can make it difficult for UWSN nodes to communicate with each other and can lead to data loss or corruption.
3. UWSN nodes are typically battery-powered, and it is often difficult or impossible to limit the communication range between UWSN nodes place or recharge the batteries once they have been deployed. This means that UWSN nodes must be designed to be highly energy-efficient and that the network must be carefully managed to conserve power.
4. The underwater environment is harsh, with high pressures, corrosive saltwater, and low visibility. This can make it difficult to design UWSN nodes that can withstand these conditions and operate reliably over long periods of time.
5. UWSNs typically consist of a large number of nodes, which can make it challenging to manage and scale the network. Designing an effective network topology and routing protocol that can handle large numbers of nodes is a key challenge in UWSN design.

In this research controlling energy usage and routing process is proposed to address few challenges of above points.

The CR methods are divided into the fixed relay node and the incremental relay node. The selected relay approaches improve data reliability through total collaboration. The relay node boosts the data before it is forwarded to the sink. The CR approaches can improve data delivery and reduce data loss. The energy and time consumption of this can make it difficult in the case of acoustic waves with limited energy. Machine learning (ML) approaches are recently the solution to address the green routing issues in WSNs[11]. The ML models provide flexibility and versatility to deal with complex data transmission with efficient routing approaches[16, 8]. To improve the network lifetime with reduced energy consumption and latency, this paper contributes the following:

1. An efficient ML-based routing model has been proposed to reduce the network's energy consumption with reduced latency.
2. This approach consists of two processes: constructing a route path using cooperating routing and optimizing relay node selection using SON.
3. Rather than directly transmitting the packets from sender to receiver, the boxes are transferred through the relay nodes using the CRSON model, which reduces the end-to-end data delivery delay and ensures network reliability.
4. The model's performance is simulated and compared with the existing models regarding energy efficiency, packet delivery rate, packet loss rate, latency, and throughput.

This paper is organized as follows: Section 2 discussed the related research of routing approaches in WSN and UWSN. Section 3 introduced the proposed system model and routing scheme. Section 4 simulates and compares the proposed model with other existing routing approaches. Section 5 concludes the proposed model with its future directions.

2. Related work. This section discusses the related literature on routing approaches. Ahmad et al., [1] developed cooperative energy-efficient routing (CEER) for UWSN to improve the network's reliability. The authors utilized sink mobility to reduce the power by removing the hotspot challenge. Wang et al.,[15] developed distributed adaptive routing with a reinforcement learning-based routing scheme for wireless multimedia sensor networks (WMSN). Based on the knowledge of the relay node and reliability, the quality of service and energy consumption of the network is improved. Sridhar et al., [12] Softmax Regressed Tanimoto Reweight Boost

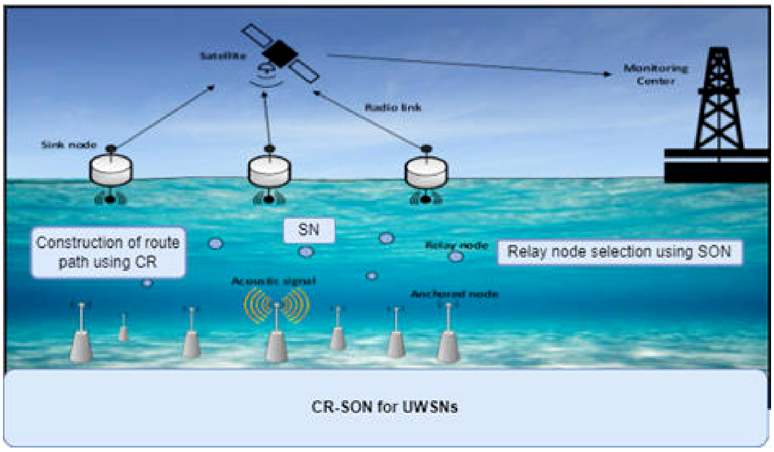

Fig. 3.1: Overview of CR-SON-based EE model

Classification (SRTRBC) method was developed to reduce energy utilization with reduced latency. This model identifies the underloaded EE nodes for data transmission.

Ullah et al., [14] developed single and multiple route path selection using minimum BER, distance to the sink node with increased residual energy. The authors obtained improved energy usage and reliable transfer of data. Due to the cooperation of nodes, the delay is raised as the disadvantage of this work. Dang et al., [13] utilized the multi-hop model to gather the data and transmission. The authors transmit the data in two ways, such as a forwarded node and relay node, using maximal radio and received signal strength models. Yum et al., [6] developed a multi-media and multi-band-based strategy for routing. Manhattan distance has been used to find the closeness of the two methods. The RSSI model has been utilized to find the distance between the sensor and the surface station. The simulation results prove that the model secured improved bandwidth and reduced delay. Qadir et al., [10] developed a based noise-aware method to decrease the latency and increase the throughput using sink mobility. The energy of the system has maximized the disadvantage. Latif et al., [7] proposed a delay-intolerant energy-efficient model using joint sink mobility with the forward mechanism. The PDR is increased with collision avoidance. The energy consumed a lot is a significant drawback. Liang et al., [9] proposed a dependence-based communication protocol for MIMO to extend the C1G2 scheme. The experimented results prove that the proposed model is improved by 40% regarding communication ratio.

Major concerns on literature discussion are as follows. It did not provide any information about the performance of the model in terms of reliability, scalability, or energy efficiency. To estimate the distance between the sensor and the surface station, which can be affected by interference and noise and may not be accurate enough for some applications. Fee papers optimized the system's energy consumption by sacrificing its performance in terms of throughput. Their approach may not be suitable for applications that require both high throughput and low energy consumption. By focusing on delay-intolerant applications and not considering applications that require low latency. Also, their mechanism consumes a lot of energy, which can limit its scalability and practicality. With existing MIMO protocols, the improvement in communication ratio they reported may not be significant compared to other existing protocols.

3. Proposed System model . The overview of the proposed network model is shown in Fig 3.1. It consists of CR-based route path discovery and SON-based relay node identification for packet transmission from sender to receiver with reduced latency and energy.

3.1. Network model. The UWSNs consist of three-dimensional is that consist of equally distributed sensors in the surveillance area. It consists of N sensor nodes (SN) as S_i, i=1,2,3,..N with the transmission range T. The data packets are denoted as P_i, i=1,2,3,..M which is forwarded to the receiver through the relay nodes called R_i, i=1,2,3,..N. The 3D UWSN is denoted as a graph of G={V,E} with N nodes. Each SN has its location information. The underwater systems have bottom-mounted nodes with its location and the anchor nodes are not deployed on the seafloor. For distribution localization, an autonomous underwater vehicle (AUV) is positioned as a reference node.

3.2. Energy model. The 3D Euclidean distance among the nodes in the UWSN is declared as a function $\gamma(a, b)$ as the distance among the node 'a' to 'b' that is stated as in Eqn 3.1

$$\gamma : N * N?\delta \ : \gamma(a, b) \tag{3.1}$$

Each node in the UWSN has the sensors to gather the data from the exterior place, which is transferred to the sink node through single or multiple hops. The sink node produces the collected data to the receiver in the communication range from R_{min} denotes the minimum transmission radius to the maximum transmit radius called R_{max}. The distance between node a and node b is bound while the distance among them with the constraint $a\left(h\right) = \gamma\left(a, b\right) = b(h)$. The two SNs have an equal minimum hop distance called h. Due to this the network density 'ρ' has an impact on the quality of the boundary. For the case of h>0 secured,

$$\lim b\left(h\right) \ - a\left(h\right) = R_{min} \tag{3.2}$$

where R_{min} is the range of SN lowest communication. The sensing model of UWSN is denoted in Eqn 3.3

$$d\left(a, b\right) = \frac{\beta}{d\left(a, b\right) k} \tag{3.3}$$

Where, $d\left(a, b\right)$ is the distance between the SN a and b and k is the parameter and β is the positive constant[4]. Assume all the SN has less battery power and that is not able to recharge after the implementation process. The network lifetime is the time when the first SN dies out of energy.

The considered simulation area is categorized into four equal sizes: upper right, upper left, bottom right, and bottom left. The sink nodes can move in the three corned paths and collect the data from the SN of each part. The SN that is randomly installed can sense the packet and transmit it to the sink node. The acoustic signal transmission can differ between shallow and deep water. The parameters such as energy, distance, and the bit error rate are considered for the selection of the receiver. The packets are directly transferred to the sink node from the neighbor node. Otherwise, the packet is sent through multiple hop. The receiver selection parameters used for packet forwarding are listed as in Eqn 3.4

$$P = \frac{Residual\ Energy}{Distance * BER} \tag{3.4}$$

The SN with residual energy and less BER is the first destination. If the BER falls below the threshold, the corresponding node has been selected as a relay node, and the sender transmits the packet to the receiver once it is formed.

3.3. Proposed CR-SON routing . This section of proposed routing scheme consists of two sub-phases: route path discovery and relay node selection.

3.3.1. Cooperative routing-based route path discovery. The discovery of route path of the candidate nodes are illustrated in Fig 3.2.

The sink node does not need that much energy since it is not move and only broadcasts its location during the startup of the transmission. The SN has the data packets with the location, relay node, source and destination, and sink node data. The S is the sender node and the remaining nodes are the receiver nodes called r1, r2, r3, r4, and r5. The packets are sent from S to sink with the minimum radius. The cosine of S and r1 is computed by r1 since r1 is located nearer to the transmitter. The forwarding packet with radius rd_i is transmitted by r2 if its cosine value is larger than 0. The radius rd_i is computed as in Eqn 3.5

$$rd_i = MIN\left\{\left(1 + \frac{\varepsilon_i^{res-ene}}{\varepsilon_i^{max}}\right).R_{min},\ R_{max}\right\} \tag{3.5}$$

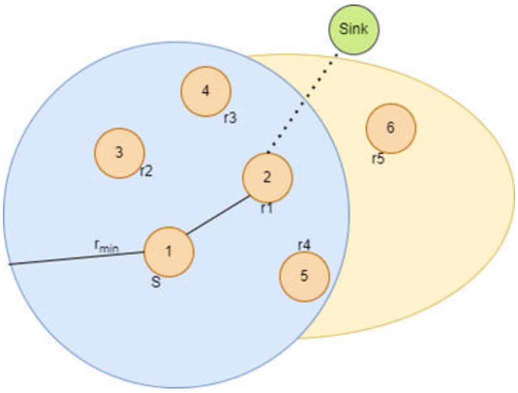

Fig. 3.2: Route discovery using CR

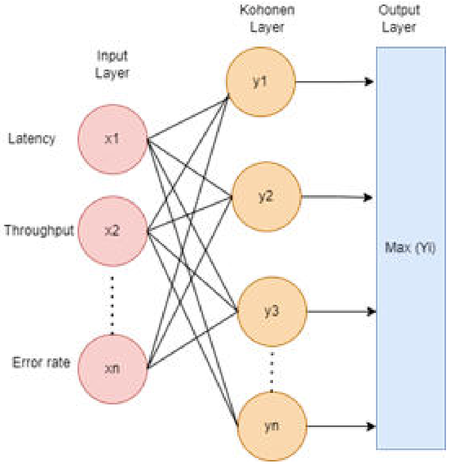

Fig. 3.3: Neural network structure of SONN

where ε_i^{max} is the SN improved energy and $\varepsilon_i^{res-ene}$ is the SN starting energy. The value of rd_i is ranged from $R_{min,}$ to $2R_{min}$. While the Forwarded packet with radius $R_{min,}$ reached S location the remaining energy of r1 is consumed. When the sink node gathers r1 packet, it extracts the residual energy and packet position. The node r3 is going to sleep mode and it does not transfer any packet for power saving since the residual energy of r3 is less than r2. The data packets are also received by r4 since it is also a receiver node. Since the radius from S to r4 and r4 to sink node is zero, it is also going to sleep mode. The node r3 is also in sleep mode since it does not receive the packets from S. Doing this transmission, the node which is in sleep mode can wake up and find its path in the communication range while the forwarding packets transfer.

3.3.2. Relay node identification using SON. SON is an unsupervised feed forward neural network proposed by Kohonen and it differs from standard neural networks with competitive learning called backpropagation. Using the geometric relationship, the SON converts the statistical data into low-dimensional space. Fig 3.3 illustrates the structure of SON which consists of an input layer to send the input data to the next layer. The second layer is the competitive layer which acts as the output node. In this layer, each neuron is connected to other neurons through inhibitory connections. To the immediate neuron, it is connected with excitatory connections. The Kohonen layer is the winner that takes all the layers. For the given input set, the output of this layer is 1 which does not need any training vector. The SON does not need an activation function or threshold, rather the output neuron is chosen as winner based on the given input pattern. That winning

Table 4.1: Parameters used for simulation

Parameters	Values
Simulation environment (W*D*H)	1000*1000*1000 m
No. of sensor nodes	500
No. of Sink nodes	20
Transmission range	550m
No. of runs	5
Packet time to live	20s
Bit rate	10kbps
Min and max speed	0 and 3 m/s

neurons are given the output. The SON enhances the understanding of data through effective visualization.

Initially, the weights of the neurons are assigned randomly. Input layer neurons are connected to all the neurons in the network. The neighbor neuron in the region is eligible to update the weight. While sending the data sample to the input layer, the Euclidean distance to all the weights is computed. The neuron weight with matching input is the best match which is adjusted toward the input. The process of SON is listed as follows:

Step 1: Initialization of network: Initialize $W_{ij}\left(t\right)$ $\left(0 = i = N-1\right)$ as the weight from the input node i to node j at time t. N is the total number of SN assigned with the weights. The radius of the neighborhood around jth node is declared as N$_j(0)$.

Step 2: Input $X_0\left(t\right), X_1\left(t\right),\ X_2\left(t\right), \ldots X_{n-1}(t)$ is initialized where $X_i\left(t\right)$ is the input from ith node at time t.

Step 3: The distance D is computed between the ith input and jth output using Eqn 3.6

$$D_j = \sum_{i=1}^{N-1} \left(X_i(t) - W_{ij}(t)\right)^2 \tag{3.6}$$

The node with minimum distance is chosen and it is the output node j called relay node for data transmission.

Step 4: The weight of j output node and its neighbor are updated using Eqn 3.7

$$W_{ij}\left(t+1\right) = W_{ij}\left(t\right) + \eta\left(t\right).X_i\left(t\right) - W_{ij}(t) \tag{3.7}$$

where, η is the learning rate in the range 0 to 1.

Step 5: Repeat the process until maximum iteration is reached.

4. Simulation and Analysis. The efficiency of the proposed CR-SON routing scheme is experimented with the simulation environment using MATLAB. The analysis is carried out using the simulation parameters listed in Table 4.1.

4.1. Evaluation Metrics. The performance of the proposed model is evaluated in terms of network lifetime, energy efficiency, latency, throughput, packet delivery rate, and packet loss rate.

1. **Network Lifetime:** It is the total time spent by the network to complete the operation.
2. **Energy efficiency (EE):** It is the proportion of output and input energy which is determined as in Eqn 4.1.

$$EE\ (\%) = \frac{E_{output}}{E_{Input}} \times 100 \tag{4.1}$$

3. **DDR**: It is computed as the ratio between the correctly delivered number of packets and the total count of sent packets which is formulated as in Eqn 4.2

$$DDR = \frac{No.of\ correctly\ delivered\ packets}{Total\ no.of\ packets\ sent} * 100 \tag{4.2}$$

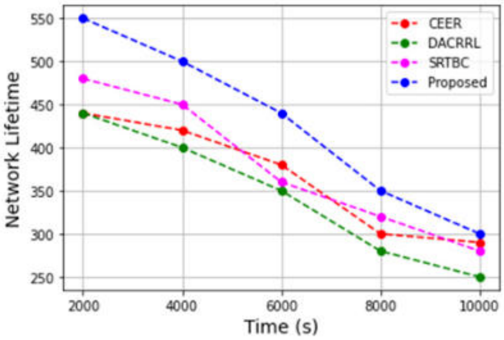

Fig. 4.1: Network lifetime comparison

4. **Latency**: It is the variation between the expected and actual arrival time of the data packets and it is denoted in Eqn 4.3

$$L\ (ms) = Actual_{AT} - Expected_{AT} \tag{4.3}$$

5. **DLR**: It is the ratio between the count of data packets that are correctly delivered and total number of transmitted packets which is denoted in Eqn 4.4

$$DLR = \frac{No\ of\ data\ packet\ delivered}{No\ of\ data\ packet\ sent} * 100 \tag{4.4}$$

6. **Throughput**: It is the amount of data packets that are broadcasted from the SN at a particular time interval which is measured using Eqn 4.5

$$Throughput\ (bps) = \frac{No.of\ transmitted\ packets}{Time\ interval} \tag{4.5}$$

4.2. Performance Analysis. The performance of the proposed model is evaluated and compared with existing routing approaches such as Cooperative energy efficient routing (CEER) [1], Distributed adaptive Cooperative routing with RL (DACR-RL)[15] and softmax regression with Tanimoto-Reweight-Boost-Classification (SRTBC) [12] routing schemes.

4.2.1. Impact on Network lifetime. Fig 4.1 illustrates the Network lifetime comparison of proposed and existing approaches in terms of time variation. It has been observed that proposed CRSON is better than other state-of-the-art approaches. The initial node of CRSON dies at 2000s which is approximately 1000s longer than other approaches. Where, the initial node of CEER, DACRRL and SRTBC die at 1000s respectively. The proposed model secured the more extended network lifetime which proves the system stability.

4.2.2. Impact on EE. The EE comparison is shown in Table 4.2. The overall EE of the proposed model is more efficient than existing approaches. As an average, the proposed model is efficient with 98.24% which is superior to other approaches such as CEER (95.54%), DACRRL (93.58%), and SRTBC (95.08%). Due to the implementation of cooperative routing and SOM, the efficiency of transmitting the packet from sender to receiver is effectively managed with reduced energy which improves energy utilization. As an average, the proposed model is 2.7% better than CEER, 4.6% better than DACRRL, and 3.16% better than SRTBC.

4.2.3. Impact on DDR. The illustration of DDR comparison between the proposed and existing approaches is shown in Fig 4.2. The X axis denotes Time in seconds and Y axis denotes the DDR in %. The observation from this fig shows that the improved performance of proposed CRSON with increased DDR than existing approaches. For the instance of 6000seconds, the DDR of proposed model is 98.3% which is better than other approaches such as CEER (96.5%), DACRRL (94.2%) and SRTBC (92.1%). The average performance of the proposed model is increased by 2.04% than CEER, 6.02% than DACRRL and 8.08% than SRTBC.

Table 4.2: Energy Efficiency (%) comparison

Time (s)	**CEER**	**DACRRL**	**SRTBC**	**Proposed CRSON**
2000	95.3	92.4	92.3	98.6
4000	94.3	93.1	95.2	98.1
6000	96.7	94.3	96.7	98.5
8000	96.9	93.6	94.5	98.2
10000	94.5	94.5	96.7	97.8
Avg performance	95.54	93.58	95.08	98.24

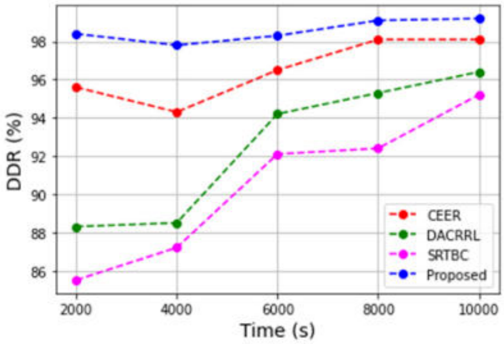

Fig. 4.2: DDR comparison

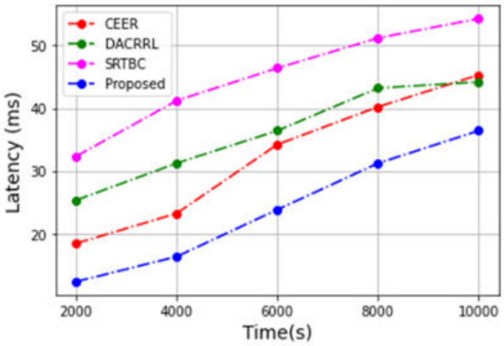

Fig. 4.3: Latency comparison

4.2.4. Impact on Latency. The illustration of latency comparison between the proposed and existing approaches is shown in Fig 4.3. The X axis denotes Time in seconds and the Y axis denotes the latency in ms. The observation from this fig shows the improved performance of the proposed CRSON with reduced latency than existing approaches. For the instance of 6000seconds, the latency of the proposed model is 23.8 ms which is reduced than other approaches such as CEER (34.2ms), DACRRL (36.4ms) and SRTBC (46.4ms). The average performance of the proposed model is reduced by 25% than CEER, 33% than DACRRL and 46% than SRTBC.

4.2.5. Impact on DLR. The illustration of DLR comparison between the proposed and existing approaches is shown in Fig 4.4. The X axis denotes Time in seconds and Y axis denotes the DLR in %. The observation from this fig shows that the improved performance of proposed CRSON with reduced DLR than existing approaches. For the instance of 6000seconds, the DLR of proposed model is 3% which is reduced than

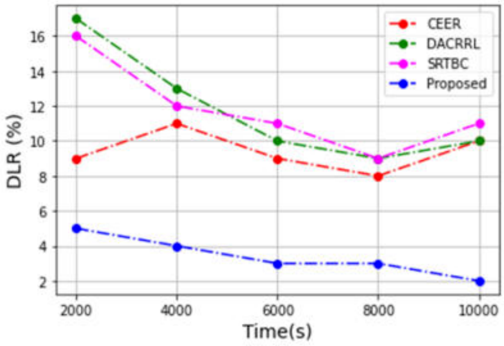

Fig. 4.4: DLR comparison

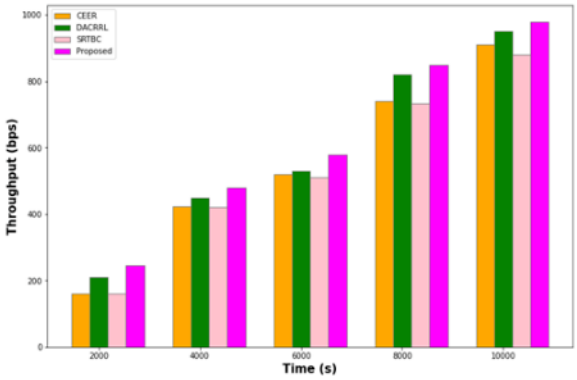

Fig. 4.5: Throughput comparison

other approaches such as CEER (9%), DACRRL (10%) and SRTBC (11%). The average performance of the proposed model is reduced by 8.4% than CEER, 8.4% than DACRRL and 8% than SRTBC.

4.2.6. Impact on throughput. The illustration of throughput comparison between the proposed and existing approaches is shown in Fig 4.5. The X axis denotes Time in seconds and Y axis denotes the throughput in bps. The observation from this fig shows that the improved performance of proposed CRSON with reduced DLR than existing approaches. For the instance of 6000seconds, the throughput of proposed model is 580bps which is improved than other approaches such as CEER (520bps), DACRRL (530bps) and SRTBC (510bps). The average performance of the proposed model is improved by 1.8% than CEER, 9.3% than DACRRL and 11.8% than SRTBC.

5. Conclusion. In this paper, presents a novel approach for routing in UWSNs that combines cooperative routing and a self-organizing network-based scheme. This proposed method utilizes a collaborative routing model to discover the optimal path for packet transmission, while also employing SON to select the most suitable relay node between the sender and receiver. It represents a significant advancement in the field of UWSN routing and has the potential to greatly improve the performance and efficiency of underwater communication networks. The simulation results and analysis in terms of energy efficiency, latency, throughput, data delivery and data loss rate, and network lifetime show an effective performance of proposed model. Compare to the existing approaches, the proposed model secured improved performance for network lifetime, energy efficiency and DDR with reduced latency and increased throughput and DLR. The efficiency of the proposed model is improved with 98.24% of energy efficiency which enhances the network stability and reliability. The proposed model was evaluated through simulation only, and its performance in a real-world deployment scenario will be checked in future research. The proposed model depends on the availability of relay nodes and the network's ability to self-organize. If there are not enough relay nodes or if the network's self-organizing capability is limited, the proposed model's performance may be affected. In future, the proposed model is enhanced with optimization-based model to enhance the congestion aware path for transmission.

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