Energy Efficient and Position Aware Routing for Auv Aided Underwater Acoustic Sensor Network

M.Ayyadurai, S.Selvakumar Raja

Abstract*: Underwater pipeline provides an economic means of oil, gas and water transportation. The underwater pipeline incurs damage due to corrosion, water pressure and mudslides. The oil and gas from impaired pipeline leak in to aquatic environment, affects aquatic eco system and loss of resources. Hence, submarine pipeline require constant monitoring. The submarine pipelines monitor by underwater acoustic sensor network (UASN). The UASN implementation has limitations in terms of bandwidth, ocean current influence on buoys node, end-to-end delay and depth. Hence, mobile Autonomous under water vehicle (AUV) deploy to route data from fixed sensor node to mobile buoys node with minimal energy consumption. The end-to-end delay of UASN depends on routing protocol and node movement due to ocean current. In this paper, we propose CAT Swarm Optimization algorithm (COA) routing in AUV to seek and track mobile buoys node and minimize end-to-end delay, energy consumption between nodes in UASN. The COA performance analyze in NS2-Aquasim environment and the same implement in 1.5x1.5 meter test bed with water for performance analysis. The COA performed better in terms of end-to-end delay and energy consumption compared to conventional routing protocols.

***Keywords* : Autonomous underwater vehicle, Underwater acoustic sensor network, multi hop, data forwarding, Cat swarm optimization.**

I. INTRODUCTION

Underwater wireless sensor network (UWSN) application has recently increased due to aqueous exploration in sea, ocean for natural gas, oil, environment monitoring, marine life monitoring, submarine pipeline, cable monitoring and underwater disaster management system. The submarine pipeline mainly employ for transportation of oil and gas. The Unites states in 1951 laid first submarine pipeline stretching 16 km from Gulf of Mexico, Cameron gas field. In 2006, china laid longest submarine pipeline up to 4000 km. The submarine pipelines classify based on type of media transmitted such as oil, gas, water and structure such as single-layer pipe and doubled-insulated pipe. The submarine pipeline has significant advantages such as increased transmission capacity, continuous oil transmission and increased economy. The foresaid application requires oceanographic sensor to be deployed in Deep Ocean. The oceanographic acoustic transceivers attach to autonomous vehicles for data gathering. The autonomous vehicle mobility improves sensor coverage region and collaborative data gathering for large area. Conventionally, oceanographic sensor deploy underwater in a fixed location to gather data. Later, oceanographic sensor recover from underwater by control center for data analysis. The conventional system suffers from scalability and data loss. The data loss occurs due to communication link disruption and physical connection failure between oceanographic sensor node and control center. Hence, routing and energy management protocols implement to gather data from underwater sensor nodes to prevent data loss and improve network lifetime. The energy consumption in underwater acoustic sensor network (UW-ASN) manages by deployment of acoustic sensor node in a predefined pattern. The acoustic sensor node computes load weight of each node for uniform energy consumption. The transmission power of acoustic sensor nodes varies dynamically to achieve specified hop sequence. The above approach overcomes sink hole problem in UWSN[1]. The Geographic and opportunistic routing protocol (GEDAR) apply in Depth adjustment based topology for communication recovery. The routing protocol analyses neighbour nodes location information for data forwarding. The energy consumption of network minimize by assigning node priority. The low priority node suppresses data transmission when a high priority node transmits data [2]. The optimal multimodal routing (OMR) algorithm with logic switch between physical layer technologies such as optical, acoustic, electromagnetic and radio frequency for data forwarding. The nodes extract information from PHY layer to avoid sinkhole problem in network [3].A dynamic protocol decides which network resource should be utilized for routing according to network conditions. The network resources include power, bandwidth, MAC and physical layer. The MAC then selects waiting time with respect to communication distance. The physical layer performs change in transmission power for communication [4]. A Depth based routing (DBR) MAC protocol and hand shaking MAC protocol increase throughput, load imbalance, energy and delay in network. The channels in network reuse during propagation delay and transmission session. The data collision during data transmission avoid by being aware of neighbor nodes transmission schedule. [5]

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Opportunistic routing protocol applies for data forwarding by exploiting neighbour nodes channel quality and nodes that received data without errors. The routing protocol geographically forwards data to nodes in upward direction from seabed to solve hidden node problem. The greedy heuristic algorithm in combination with opportunistic routing protocol identifies cluster node location with topology information [6]. The energy efficient cooperative opportunistic routing (EECOR) protocol overcome flooding technique, which affects energy, constrained sensor nodes. The EECOR make source node select relay node with respect to local depth information for multi-hop data transmission to reach surface sink. The EECOR also limits data collision by assigning holding time for relay nodes during data transmission. [7]

Adaptive energy efficient life time aware routing protocol based on reinforcement learning (QELAR) apply to spread residual energy evenly among all nodes in network. QELAR along with distributed learning agent make decision based on reward function. The reward function either positive or negative sends to agent with respect to residual energy of node [8]. E-CARP (Energy efficient channel aware routing protocol) minimizes energy consumption by eliminating the need to forward control packets to relay node and minimize sensor node data forwarding to sink node. The approach minimizes communication cost when packet size ratio between sensory data packet and control packet is large [9]. The energy consumption in routing path minimize by selecting relay node. The relay nodes select based on hop length determine by greedy minimum energy benchmark.[10]. A cross layer protocol efficiently makes use of limited energy and bandwidth in UASN. The bandwidth share effectively by monitoring underwater communications with respect to routing, MAC and Forward Error Correction (FEC) [11]. The underwater acoustic sensor node equip with pressure sensor to gather depth information. The information adds to data packet to intimate receiver node of depth difference. The data forwarding nodes select based on depth difference between transmitter and receiver nodes. The data redundancy in UASN minimize with packet holding mechanism. The sender waits a particular time before transmitting the data [12]. The routing protocol takes in to consideration parameters such as link quality, propagation delay, energy level of node, queue size and hop count to select relay node. The cross layer approach via probabilistic model determines link quality [13].

II. Methodology

The submarine pipelines require constant maintenance against corrosion and external pressure damages the submarine pipelines. The underwater acoustic sensor network (UASN) employs mobile nodes, fixed sensor nodes, and water surface gateway nodes (buoys) for continuous monitoring of submarine pipelines. The mobile nodes make with autonomous underwater vehicles, sensors and acoustic transceivers. The autonomous underwater vehicles (AUV's) navigate by control signals from fixed nodes attached to pipeline as shown in figure 1.

The AUV's gathers data from fixed nodes on submarine pipeline and transmit data to buoys nodes. The foresaid nodes work on short-range communications for data aggregation. The short-range communication limits interference problem and hidden terminals in network. Furthermore, energy consumption is uniform for nodes,below sea surfaceexcept mobile AUV node and the coverage region of UASN increase. The path loss [14] in UASN reduces by "(1)".

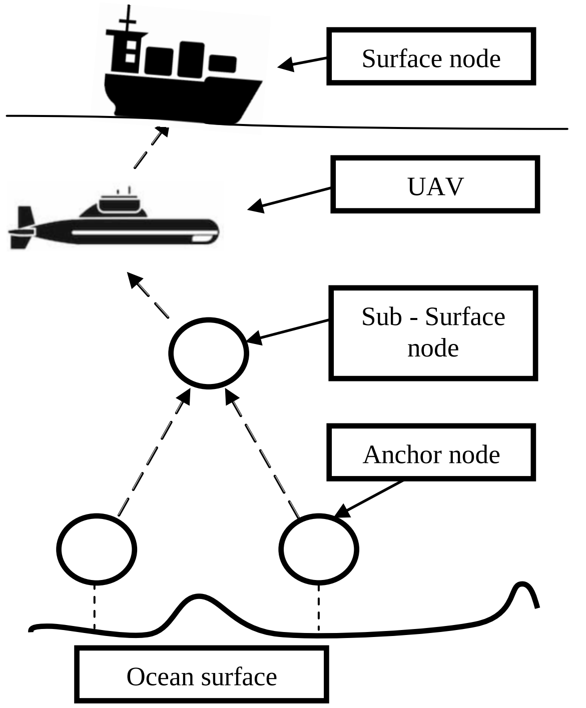

Figure 1: Submarine pipeline monitoring with AUVs.

$$P_{loss} \approx (d/n)^{\alpha} \qquad (1)$$

Where,
Ploss – overall power loss.
d – Distance.
n –hop count and α - path loss index.

In UASN, the data hop from fixed nodes on pipeline, ASN and to buoys node. Thus, the multi hop data forwarding scheme saves energy by a factor of 10αlg(n)db. The multi-hop data-forwarding scheme increase scalability and network coverage of UASN. However, the UAV's in multi hop communication encounter link disruption. The link disruption occurs due to water current, which displaces buoys nodes in network. In such cases, the data from UAVsforward to adjacent buoys nodes by CAT swarm Optimization Algorithm.

2.1. Cat Swarm Optimization Algorithm

The CAT swarm optimization (CSO) [15] algorithm is influenced by the behavior of cat. The cat is biologically curious and always monitors its surrounding environment. Although the cat may look inactive, if something suspicious happens the cat will react to the anomaly quickly. The CSO works in two modes namely seeking and tracing mode. The above modes in AUV finds link disruption among buoys node and delineate adjacent node for data transmission.

In seeking mode, the deployed cat analyzes the surrounding buoys node link. The cat is assigned with memory size - seeking memory pool (SMP). The dimension of cat deployment is provided by counts of dimension to change (CDC). The next location of cat determine by mutative ratio (MR) defined by seeking range of selected dimension (SRD).

Seeking mode:

Algorithm:

Step1: For current position 'N', copies of individual cat are made and assigned to SMP. If SPC is true then current position, assigns as a candidate.
Step 2: For 'N' copies of cat, the SRD present value is added and subtracted based on CDC to replace current value with new value.
Step 3: All candidate points are calculated fitness values.
Step 4: If fitness values does not match then select probability is calculated for each position. Else, the selected position are assigned point 1 by "(2)".

$$P_i = \frac{|FS_i - FS_b|}{FS_{max} - FS_{min}} \text{ Where } 0 < i < j. \quad (2)$$

Pi – current cat position.
FSi – Fitness value for cat.
FSmax – Max Fitness function.
FSmin – Min Fitness function.
FSb – Fmaxfor Min and Max

Step 5: A new positionis selected for movement from current position.

In tracking mode, during link disruption the cat determines movement in a particular direction. The AUV evaluates distance between adjacent buoys node. The data from AUV hop to buoys node, which require minimal transmission power.

Tracking mode Algorithm:

Step 1: For every dimension, update velocity with (3) to find target node.

$$v_{k,d} = v_{k,d} + r_1 \times c_1 \times (x_{best,d} - x_{k,d}), where\ d = 1, 2, \ldots M \quad (3)$$

Where,

$x_{best,d}$ – cat position with best fitness value.

$x_{k,d}$ - catk position.

c_1 - Constant.

r_1 -Random value [0, 1].

Step 2: If (velocity < velocity maximum)
No change
Else
Change velocity with in maximum velocity range.
Step 3: The catk position is updated according to equation.

$$x_{k,d} = x_{k,d} + v_{k,d}$$

Where,

$x_{k,d}$ – catk position.

III. PERFORMANCE EVALUATION

The CSO algorithm applies in AUV to determine next node for data forwarding during link disruption in UASN. The UASN simulate in Aquasim - NS2 environment with 1.5 x1.5 meter. Initially, the UASN form with 20 fixed nodes attached to pipeline, 6buoys nodes, 1 mobile node (AUV), and 1 control center node. The mobile node act as AUV that moves between fixed nodes on pipeline and buoys nodes. The initial energy, receive power, transmission power and distance between buoys nodes and fixed nodes are similar. The transmission, receive range of AUV and fixed nodes have similar setting. The fixed nodes on pipeline generate packets at the rate of 'p' (packets/s).The Table 1 gives the network parameters applied for UASN simulation.

The UASN evaluate in terms of throughput, Number of retransmissions, Energy consumption, packet loss ratio, packet delivery ratio, overhead, jitter, End to end delay and Bit error rate. The COA algorithm performance compare with Depth based routing protocol (DRP) and Channel aware routing protocol (CRP). The AUV sends beacon signal to buoys node and pipeline fixed nodes to initiate communication. The buoys node and fixed pipeline nodes send acknowledgement (ACK) signal to AUV. Upon successful reception of ACK signal, the data is sent by pipeline fixed node. The AUV receive data from fixed pipeline node and forwards the data to buoys node. In case, when the buoys node drift due to ocean current link disruption occur. The AUV employ COA to seek and track adjacent buoys node for data forwarding. The COA forwards data to buoys node with better link quality.

Table 1: Network Parameters

Patch	AquaSim
Number of nodes	28
Area of Simulation	1500 * 1500
Traffic Interval	0.25
Packets generated by each source	500
Size of each Packets	100 bytes
Model	Energy Model
Initial Energy	100J
Transmit Power	2 mJ
Receive Power	0.6 mJ
Protocol	CAT Swarm Optimization
MAC Layer	802.11
Operating Frequency	25Khz

The figure 2 shows throughput comparison between COA, DRP and CRP. The throughput is the measure of data transfer rate with respect to packet size. The COA has high throughput compared to conventional algorithm such as DRP and CRP. The throughput increase with COA since, the AUV evaluate link quality between buoys node for data transmission. The COA outperforms DRP and CRP during link disruption. Since, the COA algorithm determines adjacent buoys node for data transmission.The number of data retransmission in network increases with occurrence of link disruption. The DRP employs packet history buffer so each node can transmit data only once.

Each packet transmitted in network assign with unique id. However, due to volume of packet and number of data being transmitted the buffer becomes full. This causes nodes to transmit data leading to data collision and increase number of retransmissions as shown in figure 3.

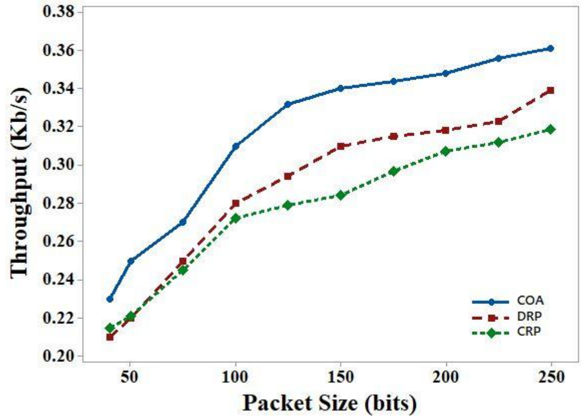

Figure 2: Throughput.

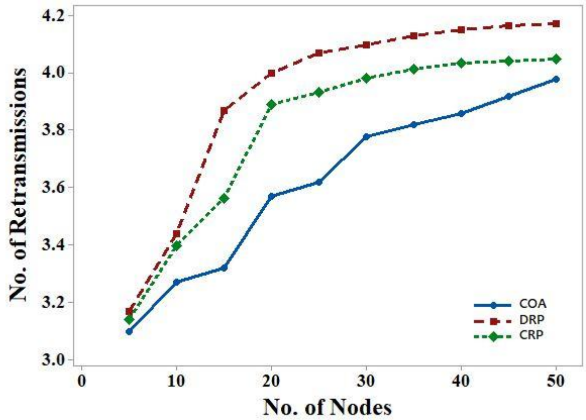

Figure 3: Retransmission in network.

Each node in DRP has a packet history buffer and priority queue. The packet history buffer comprises of sender ID, packet sequence number, and depth, which increases size of data packets. The priority queue has data about scheduled time for data packet transmission. The data packet size and frequent routing information update among sensor nodes causes higher overhead has shown in figure 4.

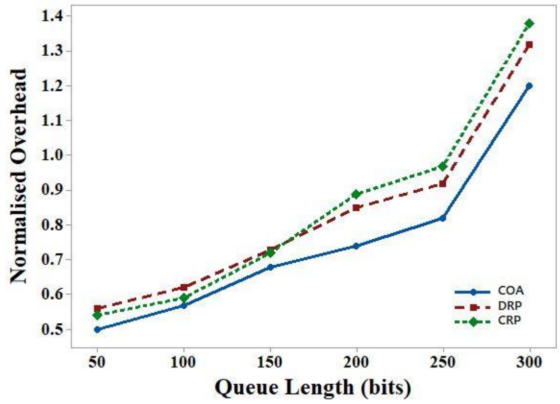

Figure 4: Overhead.

The figure 5 shows energy consumed due to data transmission and routing path information exchange. Initially, the energy consumption is uniform for all nodes in UASN. As the communication between nodes increase, the energy consumption also increase. However, COA consume less energy compared to DRP and CRP due to multi- hop data transmission and elimination of redundant data transmission has shown in figure 5 .

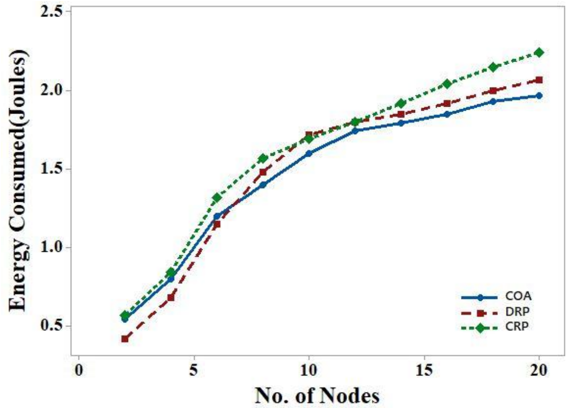

Figure 5: Energy consumption.

The packet loss ratio in network occur due to transmitted data collision among transmitter and receiver nodes. In DRP, data are transmitted as per scheduled time. The dynamic ocean environment cause AUV to arrive at different time compared to scheduled time. The natural delay and change in data routing path among sensor node cause data packet loss and packet collision among sensor nodes. The COA has minimal packet loss since COA enables data transmission with beacon and acknowledgement signals has shown in figure 6 .

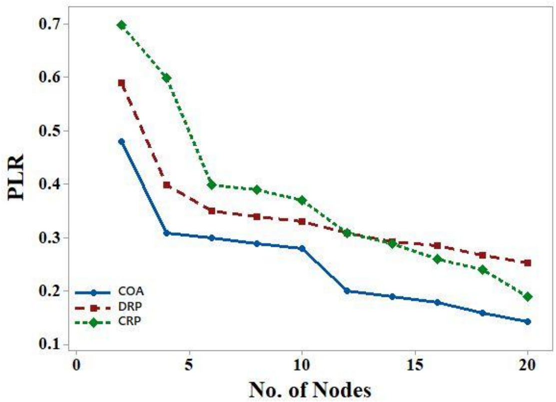

Figure 6: Packet loss ratio.

The figure 7 shows successful packet delivery ratio (PDR) comparison, defined by data successfully received at receiver with acknowledgement signal. The PDR is high for COA as expected since, the redundant data transmission eliminate in network. The end to end delay refers to time stamp difference between data transmitting time at transmitter and receiving time at receiver. The end to end delay for COA is low compared to DRP and CRP has shown in figure 8. Since, COA is adapted with seeking and tracking mode to avoid link disruption between fixed sensor nodes on pipeline and buoys node. However, in DRP and CRP the routing path information update due to link disruption, which increase delay in successful data transmission. Similarly, the jitter in UASN increase due to DRP and CRP algorithm. Since, the dynamic change in ocean environment cause the buoys node to move. The buoys movement cause data reception at different time intervals.

In COA, the data receive at regular intervals since, the link integrity maintain between AUV and buoys node in network has shown in figure 9.

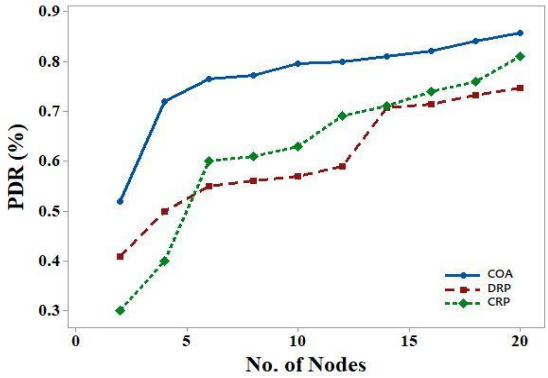

Figure 7: Packet delivery ratio.

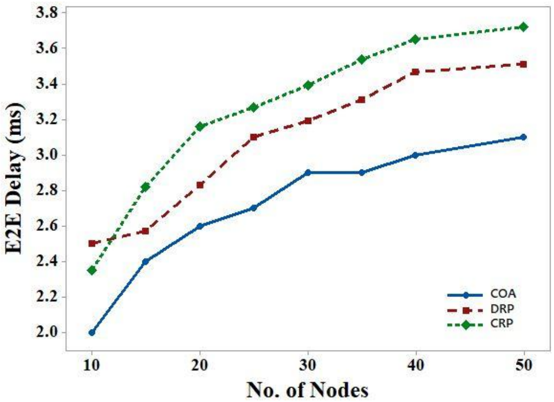

Figure 8: End to End (E2E) delay.

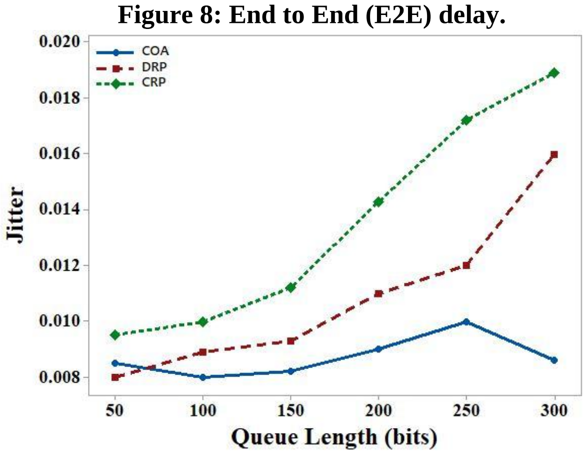

Figure 9: Jitter.

The figure 10 shows the bit error rate is low for COA algorithm since, the AUV hop data from fixed sensor node to buoys node and does not save the data for processing. In CRP and DRP the data save in buffer to avoid data redundancy. The data bit error occur when network scalability and number of data transmission increase has shown in figure 10.

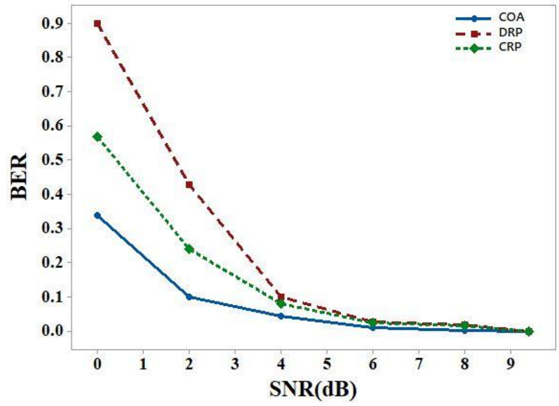

Figure 10: Bit error rate.

IV. HARDWARE IMPLEMENTATION

The COA performance evaluate in test bed with microcontroller and piezoelectric acoustic transceiver. The microcontroller with built in analog to digital conversion (ADC) function processes sensor data. The sensor data then transmit through piezoelectric acoustic transceiver. The fixed node on pipeline, mobile node (AUV) and buoys node equip with microcontroller and piezoelectric acoustic transceiver. The nodes were initially configured and placed underwater at a depth of 2 feet for data transmission. The UAV deploy to hop data from fixed node to buoys node. The COA, DRP and CRP performance with respect to node depth and number of nodes is tabulated in table 2 (a) to 2 (d). The node place at different depth to analyze node response time and power consumption. The tables show node energy consumption increases proportional to depth of node. The underwater node increase it's transmit power to successfully deliver data to receiver node.

Table 2 (a): Performance metrics for 2 nodes

	Depth	1 cm	3cm	5cm	7 cm	9 cm	10 cm
COA	Power Consumed	0.18	0.217	0.257	0.279	0.314	0.376
	Response Time	0.156	0.157	0.214	0.298	0.412	0.492
DRP	Power Consumed	0.29	0.334	0.382	0.419	0.437	0.496
	Response Time	0.182	0.20	0.245	0.326	0.453	0.554
CRP	Power Consumed	0.327	0.352	0.394	0.417	0.463	0.529
	Response Time	0.187	0.21	0.257	0.331	0.467	0.569

Table 2 (b): Performance metrics for 3 nodes

	Depth	1 cm	3cm	5cm	7 cm	9 cm	11 cm
COA	Power Consumed	0.192	0.224	0.278	0.292	0.332	0.390
	Response Time	0.237	0.242	0.324	0.408	0.442	0.512
DRP	Power Consumed	0.351	0.397	0.43	0.491	0.542	0.6
	Response Time	0.241	0.287	0.356	0.430	0.476	0.597
CRP	Power Consumed	0.354	0.402	0.447	0.517	0.551	0.628
	Response Time	0.257	0.294	0.372	0.437	0.482	0.608

Table 2 (c): Performance metrics for 4 nodes

	Depth	1 cm	3cm	5cm	7 cm	9 cm	11 cm
COA	Power Consumed	0.198	0.231	0.283	0.317	0.341	0.401
	Response Time	0.312	0.356	0.415	0.491	0.502	0.532
DRP	Power Consumed	0.380	0.411	0.463	0.509	0.572	0.687
	Response Time	0.431	0.491	0.557	0.611	0.692	0.723
CRP	Power Consumed	0.384	0.417	0.478	0.521	0.586	0.694
	Response Time	0.447	0.512	0.576	0.641	0.702	0.734

Table 2 (d): Performance metrics for 5 nodes.

	Depth	1 cm	3cm	5cm	7 cm	9 cm	11 cm
COA	Power Consumed	0.210	0.257	0.307	0.329	0.374	0.421
	Response Time	0.386	0.417	0.494	0.558	0.592	0.652
DRP	Power Consumed	0.442	0.491	0.538	0.587	0.634	0.721
	Response Time	0.478	0.515	0.598	0.642	0.719	0.772
CRP	Power Consumed	0.469	0.512	0.547	0.592	0.649	0.735
	Response Time	0.485	0.527	0.614	0.657	0.724	0.784

In summary, the COA considerably consumed less power for data transmission and the response time is minimal compared to DRP and CRP.

V. CONCLUSION

In this work, COA implement to minimize energy consumption due to data transmission, end to end delay and determine shortest routing path between AUV and buoys node. The transmission power of sender node adjust according to decisions provided by COA. The COA performance compare with DRP and CRP in both NS2-Aquasim environment and hardware test bed. The performance of algorithm evaluate at different depth in terms of network parameters such as throughput, end-to-end delay, energy consumption, power consumption and response time. From the results, it is evident that COA performs better in terms of energy consumption compared to DRP which saves data in buffer from all nodes to minimize data redundancy however, the approach cause bit error. Furthermore, the COA also adapts to network scalability. The simulation and hardware results show COA perform better compared to DRP, CRP in terms of data transmit energy consumption, throughput, and end to end delay. The COA can be implemented in UASN to determine malicious node.

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