

Minimized Delay and Improved Throughput based Geo-Opportunistic Void Node Recovery Routing Protocol for Underwater Wireless Sensor Networks

Kiruthiga V¹, Karthikeyan M², Baranidharan V³

¹PG Scholar, ² Assistant Professor, ³Assistant Professor

^{1,2}Department of Computer and Information Sciences,
Annamalai University, Chidambaram, India.

³Department of Electronics and Communication Engineering,
Bannari Amman Institute of Technology, Sathy, India.

Abstract: Underwater Wireless Sensor Networks (UWSN's) has many characteristics, that includes very slow propagation speed, high-end to end delay, very low-bandwidth, less link quality and high energy constraints. All these issues pose a very big challenge to design energy efficient routing protocol for UWSN's. In this paper, these challenges are addressed by using Geographic and Opportunistic routing with Depth Adjustment-based topology control for communication recovery for void node region (GEDAR) routing protocol with modified recovery node procedure. This routing protocol exploits to route data to the surface sonobuoys. The main contribution of the paper is to select forwarders, a novel opportunistic routing protocol is used to minimize the greedy process. The void node recovery algorithm is used to recover the void nodes based on the new depth calculation for two hops. The proposed routing protocol are to be validated by using Aqua-Sim simulator for Underwater Wireless Sensor Networks. The simulated results infer that, the modified GEDAR performs better in average energy consumption, End to end delay, and Throughput

Index Terms - Underwater Wireless Sensor Networks, GEDAR routing protocols, opportunistic routing, void node recovery algorithm, new depth calculation.

I. INTRODUCTION

The Oceans are covered in two-third portion of the earth surface. These Oceanographic environments are very important in human life because of the application such as CO₂ absorption, Earth climate regulation, Ocean monitoring, offshore oil/gas monitoring, seismic monitoring, marine military defense etc., the acoustic communication is the only feasible method for underwater wireless communication. High frequency waves and optical waves are not suitable for underwater communication due to high absorption and scattering effects [1]. Underwater acoustic channels are always introducing path loss, large delay, high noise, strong attenuation, and multipath fading results in high communication energy cost.

In this context, the geographic routing is otherwise called as position-based routing. This routing protocol is simple and scalable. This protocol is forward the data packet based on its position of nodes and sonobuoys. It does not maintain the complete route from the source to its destinations. One of the major disadvantages is route decisions are made locally. To overcome this disadvantage, the geographic routing is made to work together with opportunistic routing [2]. At each and every hop, the optimal next hop is always a very closest to the destination, is to be selected to continue forwarding the packets. By using an opportunistic routing [11], each packet is to be broadcasted to a set of qualified neighbors based on some metrics. The main disadvantages of geo-opportunistic routing protocol are void region communication problem. The Geographic and opportunistic routing with depth adjustment-based topology control for communication recovery for void node region (GEDAR) routing protocol utilizes both geographic and opportunistic routing paradigm instead of using traditional messages.

The proposed novel recovery procedure based GEDAR routing protocol is able to reduce the number of void nodes through the depth adjustment-based node recovery strategies. The proposed algorithm is based on topology control to route the packets by using Local maximum recovery procedure with incremented void node communication range using greedy forwarding strategies. This algorithm improves the packet delivery ratio, decrease end to end delay, less latency, high bandwidth utilization, less packet dropping ratio, and high throughput.

The rest of the paper is organized as follows. Section II, provides an overview of existing routing approaches and their communication void node recovery strategies. Section III and IV, provides brief overview of preliminary concepts of the proposed protocol. Section V discuss the various algorithm of Novel GEDAR. The performance evaluation of the proposed routing protocol is described in section 6. Finally, section 7 presents the conclusion and future work.

II. RELATED WORK

Geographic and opportunistic routing for underwater sensor networks [3] is an anycast, geographic and opportunistic routing protocols that route the data packets to sonobuoys at the sea surface. GEDAR switches to recovery mode procedure if the node is in the void region. Whenever the packets are gets struck, the GEDAR automatically calculate its new depth for moving void nodes. One of the major disadvantages is less throughput and less void node communication range.

Vector based forwarding [4] routing protocol. In this protocol, the packets are to be routed along a virtual route with predefined radius. When the node receives a packet, first it verifies distance to forwarding vector and continue its forwarding the packets. If the distance is less than predefined threshold value, then the packets is discarded. Depth based routing (DBR) protocol [5] is the first underwater wireless sensor network routing protocol that used node depth information for data packets routing. This protocol uses greedy forwarding strategies to broadcast the data packets towards the water surface. After receiving the broadcast packets, if the receiver is very closer to the water surface it becomes a qualified neighbor.

Resilient pressure routing protocol [6] is external depth-based routing for malicious attackers. In this protocol, the packet header and payload are encrypted with a pair of keys such as private and public keys. One of the major disadvantages only if the packets with proper signature is only accepted, otherwise the packets are discarded. Hydro cast routing protocol [7] are exploited based on their pressure (i.e. Energy) level information to greedily route the packets from the source to its destination. To avoid hidden terminal problem, a greedy heuristic approach to determine a cluster of next hop forwarder.

Void avoidance based VBF routing protocol [8] include the communication void node recovery mode. In void node recovery phase, attempts to route the packets based on the boundary of communication void node region. The void nodes are shifted by the means of back pressure method. The packets are routed back in a direction to move from the destination.

III. PRELIMINARIES OF GEDAR ROUTING PROTOCOL

3.1 SYSTEM MODEL

Consider an underwater wireless sensor network sensor equipped aquatic (SEA) swarm architecture, as shown in Fig. 3.1 In this architecture, we have a large number of mobile underwater sensor nodes at the ocean bottom sensors and sonobuoys, named as a sinks node, at the surface of the ocean. The model consists of a set $N = N_n \cup N_s$ [N_s of nodes with a communication range of r_c , so that N_n represents the set of sensor nodes, and N_s is the set of sonobuoys. The sensor nodes $N^n = \{N_1, N_2, \dots, N_N\}$ are randomly deployed in a geographic area of interest D belongs R^3 to provide (space and time) monitoring. Each node is equipped with various sensor devices and with a low bandwidth acoustic modem which is used to periodically report the sensed data to the destinations (sonobuoys).

Consider that sensor nodes can freely drift with ocean current, Drogue is a preferable candidate to be used as a sensor node. Consider the vertical movement speed and energy cost values of the depth adjustment mechanism as that work provides information about the vertical movement speed and cost. Thus, each sensor node can move vertically with velocity $v = 2.4$ m/min at an energy cost of $E_m = 1500$ mJ/m. The sonobuoys $N_s = \{S_1, S_2, \dots, S_n\}$ are special nodes randomly deployed at the sea surface.

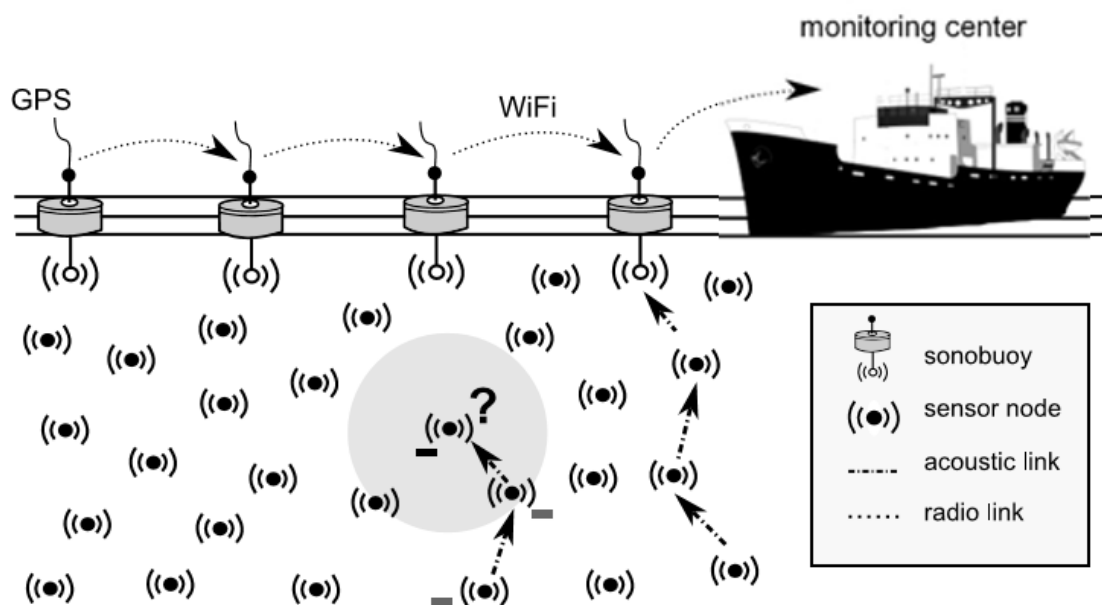


Figure. 3.1: Architecture for Sea swarm with void nodes.

Each sonobuoy is equipped with GPS to determine its position. Moreover, they are equipped with both acoustic and radio transceiver modems; each sonobuoy uses acoustic links to send commands and to receive data from underwater sensor nodes, and the radio links are used to forward the data packets to a monitoring center for future processing. Consider that if the packets arrive at any sonobuoy on the ocean surface, it can be delivered to the monitoring center [12] [13]. This assumption is reasonable for acoustic communication is harder than radio frequency communication since sound propagates (speed of 1.5×10^3 m/s in water) five orders of magnitudes slower than radio (with a propagation speed of 3×10^8 m/s in air).

3.2 UNDERWATER PACKET DELIVERY PROBABILITY ESTIMATION

The underwater packet delivery probability of m bits for any pair of nodes with distance d , which is used in the next-hop subset forwarding selection procedure of the proposed geo-opportunistic routing protocol [14-16]. The path loss, that describes the attenuation on a single, unobstructed propagation path, over a distance d for a signal of frequency f due to large scale fading, is given as:

$$A(d, f) = d^k a(f)^d \quad (1)$$

Where k is spreading factor, $A(f)$ is the absorption coefficient.

The commonly used values are $k=2$ for spherical spreading, $k=1$ for cylindrical spreading, and for a practical scenario, k is given as 1.5. The absorption coefficient $a(f)$, in dB/km for f in kHz, is described by the Thorp's formula given by:

$$10 \log a(f) = \frac{0.11 \times f^2}{1+f^2} + \frac{44 \times f^2}{4100+f} + \{ 2.15 \times 10^{-4} f^2 \} + 0.003 \quad (2)$$

The average signal to noise ratio(SNR) over the distance d is thus given as:

$$SNR = \frac{E_b}{N_0 d k a(f) d} \quad (3)$$

Where E_b and N_0 are constants that represent the average transmission energy per bit and noise power density in a non-fading additive white gaussian noise (AWGN) channel.

The probability of bit error rate can be evaluated as,

$$P_e(d) = \int_0^{\infty} P_e(x) P_d(x) dx. \quad (4)$$

where, $P_e(x)$ is the probability of error for an arbitrary modulation at the specific value of SNR.

IV. DESIGN OF GEDAR

The Novel recovery procedure based Geographic and Opportunistic routing with Depth Adjustment-based topology control for void node communication recovery is consist of three main algorithms. They are,

1. An enhanced periodic beaconing algorithm to disseminate the location of all sensors and sonobuoys to the other neighbor nodes and the sonobuoys to avoid congestion and overloading.
2. Geo-opportunistic based Neighbors candidate & Next Hop forwarder Selection algorithm to route the packet to its closest sonobuoys.
3. A novel recovery procedure based void node algorithm to improve the Throughput, Goodput, less energy consumption and less dropping ratio.

4.1 Periodic beaconing Algorithm for all sensor nodes and sonobuoys

Periodic beaconing plays a vital role in GEDAR. It is through periodic beaconing that each node obtains the location information of its neighbors and reachable sonobuoys. If each node n_i embeds its known sonobuoy locations S_{ij} together with its location, the size of its beacon message in the worst case, without considering lower layer headers, is

$$N_s \times 2(m+n) + 2m + 3n \text{ bits}, \quad (5)$$

where m and n are the size of the sequence number and ID fields, and each geographic coordinate, respectively. Given that the transmission of large packets in the underwater acoustic channel is impractical, the proposed an enhanced beacon algorithm that takes this problem into consideration. Algorithm is an enhanced periodic beaconing used by GEDAR to broadcast periodic beacons and to handle received beacons. In the beacon messages, each sonobuoy and the sensor are embedding a sequence number, its unique ID, and its X, Y location. Each sonobuoy at the surface is always equipped with GPS (ie. RF link transmission) and each sonobuoys can know its location. The algorithm is given as follows,

```

1. procedure Broadcast beacon (node)
2. msg: New beacon with seq_no
3. if beacon time expired then
   m.coordinate ← location (node)
   if node ∈ Ns then
     for s ∈ Si (node) do
       if Λs = 0 then
         msg. add. (Seq_nos, IDs, Xs, Ys)
4. Os |← 1
5. end if
6. end for
7. end if
8. broadcastmsg
9. set new time
10. end if
11. end procedure

```

Figure. 3.1: Periodic beaconing Transmission Algorithm

```

1. procedure received beacon (node, msg)
2. if msg is sonobuoys then
3. update (Si(node), msg)
4. else
5. update_neighbouring (msg.seq_no, msg.id, msg.location)
6. for s ∈ m do if seq_nb(s, msg) > seq_no (s, Si(node)) then
7. update(Si(node), s)
8. end if
9. end for
10. end if
11. end procedure

```

Figure. 3.1: Periodic beaconing Receiving Algorithm

The sequence number of the beacon does need not to be synchronized with all sonobuoys and sensors. It is used together with the ID to identify the most recent beacon of each sonobuoy. The depth information of sonobuoys is omitted from the beacon message since sonobuoys vertical movement is negligible with respect to the horizontal movement of ocean surface. Each sensor nodes have a sequence number, Sensor ID, X, Y and Z position information. The beacon messages of nodes are augmented with all the information about the sonobuoys. The ultimate aim of this enhanced beaconing algorithm is to all nodes have location information of all sonobuoys

and neighboring nodes. This message is to be broadcasted to all the neighboring nodes that may leads to unnecessary flooding in overall networks that will reduces the throughput.

4.2 Neighbor's candidate & Next Hop forwarder Selection algorithm

When the sensor nodes send the packets to qualified neighbors, it uses a greedy forwarding strategy to determine the neighbors set to continue the packet forwarding to respective reachable sonobuoys. Let N_i be the node to deliver the packet, S_i is the known sonobuoys at time t . Some packet advancement metrics are determining to forward the packet to some destination like sonobuoys.

$$C_i = S_i(t) \mid \text{Dist}(N_i, S_i) - \text{Dist}(N_k, S_v) > 0 \quad (6)$$

where S is source node, D is Destination node and C_i is the distance between the neighbor X and D .

GEDAR use opportunistic routing over the shared packet transmission, each packet is forwarded only to the qualified neighbors. It has both advantages and disadvantages in impact on network performance like decrease the amount of possible collision od packets and high latency end to end delay. The next hop forwarder set is composed with the suitable nodes from the forwarder set of candidates C_i . The Candidate set selection and Next hop selection algorithm is give below,

```

1. procedureN_hopforward_node (source  $n_i$ )
2. for  $n_m \in C_i$  do
3.    $NADV(n_m) \leftarrow \text{distance} \times p(\text{distance}^m, \text{msg})$ 
4. end for
5. order  $C_i$  with NADV nodes
6.  $j \leftarrow 1$ 
7.  $G_i \leftarrow C_i$  (where  $G_i$  is always equal to  $C_i$ )
8. while  $|C_i| > 0$  do
9.    $F_j \leftarrow \{n_i \in C_i\}$  ( $n_i$  is the node which having high priority)
10.   $C_i \leftarrow C_i - \{n_i\}$ 
11.  for  $n_u \in C_i$  do
12.    if  $D(n_i, n_u) < \frac{1}{2} r_c$  then
13.       $F_j \leftarrow F_j \cup \{n_u\}$ 
14.       $C_i \leftarrow C_i - \{n_u\}$ 
15.    end if
16.  end for
17.   $j \leftarrow j + 1$ 
18. end while
19. for  $F_j$  do
20.  for  $n_k \in G_i$  do
21.    if  $D(n_k, n_i) < r_c \cup n_i \in F_j$  then
22.       $F_j \leftarrow F_j \cup \{n_k\}$ 
23.    end if end if end for
24.  calculate the EPA for  $F_j$ 
25.  return the  $F$  with high EPA
26. end procedure

```

Figure. 3.1: Next Hop Selection Algorithm

4.3 Novel void node recovery algorithm

When the node fails to forward the data packets by using greedy forwarding strategies, the void node recovery algorithm is used to route the data packets. In traditional, message void node strategies, this algorithm have advantage of node depth adjustment technology and increased void node communication range. This algorithm is more effective in terms of data delivery, proper routing, depth adjustment and less energy consumption. During the data packet transmission, each node locally determines if it is in void region. (ie. It does not have any neighbor leading to positive progress over the void region towards the monitoring center through sonobuoys). So, at this time the nodes announce a void node announcement messages to neighbor nodes in its candidate set. This node resumes its greedy forwarding strategy and its starts calculating of new depths. After, the void node determines its new depth based on the new depth-based hop connectivity such as that it starts greedy forwarding. The novel void node recovery algorithm for Underwater Wireless sensor Networks is given as,

```

1. Procedure Recovery Void Node ()
2. node_is_void ← true
3. stop beaconing
4. omega ← 0 (Set neighbors topology control)
5. send_voidnode_announcement_msg
6. calc_newdepthvalue
7. end procedure
8. {Nvm is the void node}
9. {omega – set of next hop forwarder}
10. {D – set of the depth candidates of void node}
11. procedurecalc_newdepthvalue(time)
12. if |omega| > 0 then
13. for nu ∈ omega do
    if D (Nvm, Nv) ≤ rc then
      Du ← D (Nu, S*)
      (Xvm - Xu)2 + (Yvm - Ys*)2 + (Zvm - Zs*)2 ≥ Du2
      D ← D U {Zm2}
    else
      D ← √((Xvm - Xu)2 + (Yvm - Ys*)2)
    if D ≤ rc then
      hopcount = hopcount + 1;
      (Xvm - Xu)2 + (Yvm - Ys*)2 + (Zvm - Zs*)2 ≥ rc2
      D ← D U {Zm2}
    end if end if end for
14. Z = argmin{|Zm - Z|}
15. Nvm moves to newest depth Z
16. node_is_void ← false
17. else
18. recovery (node)
19. if |Ci| > 0
20. Fj ← {n1 ∈ Ci} {n1 is the node which having high priority} Ci ← Ci - {n1}
21. for nu ∈ Ci do
22. If D (n1, nu) < ½ rc then Fj ← Fj U {nu} and Ci ← Ci - {nu}
23. end if end for end if
24. end if
25. end procedure

```

Figure. 3.1: Void Node recovery Algorithm

V. PERFORMANCE EVALUATION

5.1 Simulation setup

The node deployment schemes are evaluated using Aqua-Sim Simulator in a 500m x 500m x 500m monitored space. The total number of sensor nodes varies from the 100 with a step size of 50 and number of sonobuoys are 5. These sensor nodes are deployed randomly in underwater scenario with different depths.

The simulation results show in the random deployment scheme of two different routing protocol scenario such as exiting GEDAR routing protocol and proposed novel recovery procedure based GEDAR routing protocols. Then, the performance metrics are evaluated in the two mentioned criteria are considered for the simulation. The results are obtained from the Aqua-Sim simulator are plotted on graphs and conclusion are drawn from them.

Table 5.1 Simulation parameters

S. No	PARAMETER	DESCRIPTION
1.	Sensor Nodes	100
2.	Sonobuoys	5
3.	Deploy region	500m x 500m x 500m
4.	Nodes transmission range	250m
6.	Data Packets payload size	19 bytes

5.2 Performance metrics

The performance metrics for novel GEDAR protocols are as follows,

5.2.1 Average energy consumption

Sensors has the capabilities of doing sensing, data processing, and wirelessly transmitting collected data back to base stations by way of multiple-hop relay. The data transmission is always consuming the more energy. The life time of node is based on overall energy consumption evaluated. The energy consumed by the nodes for listening, receiving, transmitting and sleeping. In simulation, the average energy consumption is the difference between the current value and the initial value. The energy consumption of transmitting data:

$$E_{Tx}(k, d) = E_{elec} * k + \epsilon_{amp} * k * d^2, d > 1 \quad (7)$$

Total consumed energy of nodes = $\sum ERx + \sum ETx$ So, the Total energy of nodes are equal to the sum of Total consumed energy of data receiving and total consumed energy of data transmitting.

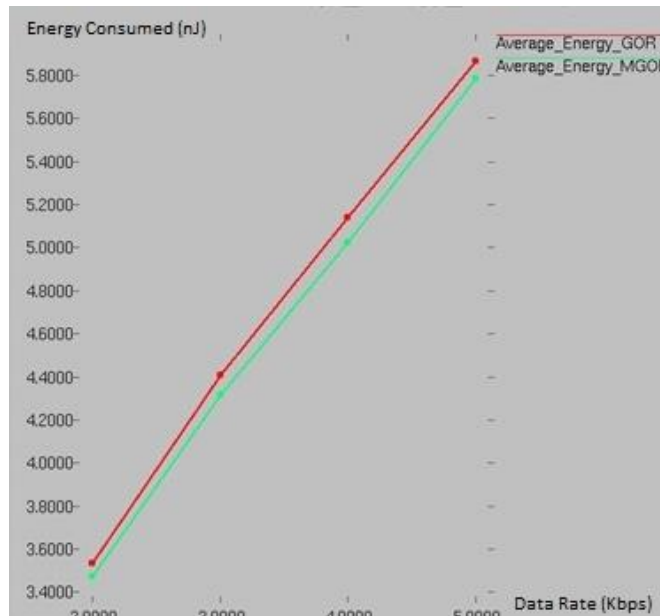


Fig. 5.1 Energy Consumption

In the Fig.5.1 shows the results for the energy consuming per received packet in per node. As expected, the energy consumption is comparatively less than the existing GEDAR routing protocol. This energy cost is always related to depth adjustment of void nodes. The network traffic increases the energy consumption will decreases.

5.2.2 End to end delay

End-to-end delay refers to the time taken for a packet to be transmitted across a network from source to destination.

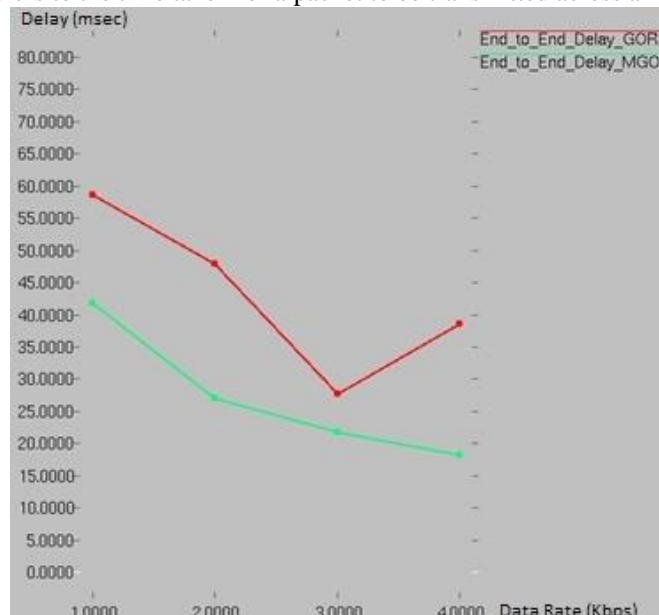


Fig. 5.2 End to end delay

Fig. 5.2 shows the results concerning the average end to end delay is comparatively very less for Novel recovery procedure based GEDAR routing protocol. This protocol use both opportunistic and geographic routing paradigm to improve the data delivery. This protocols moves the void nodes to new depth so, the packets are forwarded only to qualified neighbors. This protocol has less end to end delay compared with existing GEDAR protocol.

5.2.3 Throughput

Throughput of the network is the rate of successful message delivery over a communication channel. The data these messages belong to may be delivered over a physical or logical link, or it can pass through a certain network node of the networks. Throughput is measured in bits per second (bit/s or bps), and sometimes in data packets per second (p/s or pps) or data packets per time slot. Throughput is very essential to digital bandwidth consumption; it can be analyzed mathematically by applying the queuing theory, where the arrival rate (λ) is the load in packets per time unit, and departure rate (μ) the packets per time unit.

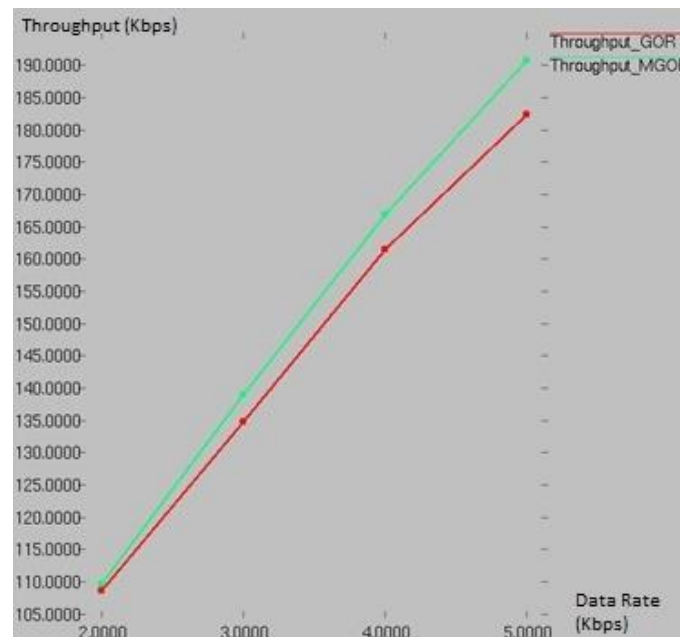


Fig. 5.3 Throughput

Fig 5.3 shows the throughput of Novel recovery procedure-based routing protocol. In existing protocol, all geographical nodes are used to transmit and route the packets so it has large throughput. But in proposed Novel GEDAR the packets are to be transmitted to set of qualified neighbors which is very closest to its destination, the throughput is better compared with existing GEDAR.

VI. CONCLUSION AND FUTURE SCOPE

The paper evaluates the existing GEDAR and the proposed novel recovery procedure based GEDAR routing protocols performance in underwater. More specifically, this paper reveals that void node recovery procedure based GEDAR routing protocol outperforms than the existing GEDAR in terms of decrease average energy consumption, less end to end delay and improve its throughput. This shows that Recovery procedure based GEDAR is a primary choice for most of practical applications to date, the results are expected to shed some light on the design of UWSN in the near future. The future work can be extended on Network layer to improve its residual energy consumption by clustering based back pressure routing protocol in UWSN.

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