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A Novel Underwater Packet Scheduling based on Modified Priority Backpressure and Peak Age of Information approach

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Abstract

Objective: To develop an effective underwater packet scheduling algorithm considering the freshness of information. Underwater Communication has gained interest in recent days and Energy consumption, Freshness of information is considered to be an important metric. Applications include defense-based applications, environmental monitoring, pollution detection, and ocean study. This paper works on the Age of Information-based concepts to ensure that information's freshness is sustained. Peak AoI is used as an important metric to assign priority to the packets resulting in less packet delay and loss. Congestion is reduced as it works on the principle of backlog. And normalized class-based AoI helps in giving importance according to the importance of packets. As the value of information reduces over time, the proposed technique helps to maintain freshness. By varying the number of nodes and speed of nodes simulation results are shown, and delay, throughput, packet delivery ratio, and energy consumed are calculated. Energy consumed is almost reduced to two third and as Information freshness is given importance, packet loss and delay are reduced.

Keywords: Backpressure, Peak AoI, Priority, Underwater

1. Introduction

For a better understanding of the sea world, underwater communication is essential. Increasing demands for real-time status update has led to Age of Information (AOI) -based scheduling. Applications like Tsunami based data, underwater monitoring, etc. demand the Age of Information to be less with less packet delay and loss. Finding out the minimum achievable AoI is also an important question (Jaya et al. (2021)). The time elapsed since the generation of the latest successfully received information is considered an AoI measure (Roy D. Yates et al.(2021)). The difference between the current time and the time when the last received information was

generated is $t - \tau$. To be a minimum AOI, packets must be transmitted often, and delays in packets have to be reduced (Xingran Chen et al. (2022)).

Estimation error might increase if there is a delay in packets. By minimizing the Age of Information, errors can be reduced to a great extent (X. Zhang et al. (2021)) (X. Chen, X. Liao & S. Saeedi-Bidokhti (2021)). Pre-processed data is preferred to make sure that the transmission is easier. But it might affect the freshness of information (C. Xu et al. (2019)).

Peak AOI is a factor considered in the Age of Information Concept. Concepts are based on replacing the old packet when a new packet arrives. This can be helpful to minimize the age of the information to some extent so that the freshness of information can be increased.

Several scheduling algorithms are available that help to decrease packet loss and increase throughput etc. One such algorithm is Backpressure Algorithm (BPA), which is apt for underwater-based communication as it helps to reduce congestion to a greater extent. BPA works on the principle of backlog. Hence, packet loss can be reduced and the timeliness of information can be taken care of. The problem with the BPA is that the smaller queue might be made to suffer, so special consideration to the priority queue is a must. The backpressure algorithm takes care of traffic and congestion control. The priority queue concept will help manage real-time packets so that important packets will not suffer packet delay.

To avoid smaller queues from getting affected, the Queue Length Stabilizer technique is used. After a timespan, the number of packets serviced is noted, and the average is found. If a queue has a smaller number of packets scheduled, the queue size is increased virtually. This might help in the smaller queue to be scheduled too.

Active priority is helpful, as it's not static like most of the priority algorithms. The priority value is based on its priority, TTL, and delay. As the information freshness parameter is important, the AoI-based metric is also used to find the packet's priority. The Metric used here is Peak AoI. Peak AoI represents the worst-case AoI. It is the maximum time elapsed since the preceding piece of information was generated.

Stale information is generally not needed to be transmitted. Here, the source node manages to discard the packets that are not needed. A peak age metric is suggested, which can help know the max-age value before an update.

Underwater Pragmatic Routing Approach through Packet Reverberation mechanism (UPRA-PR) (SHAHZAD ASHRAF et al. (2020)). Considers the thorp propagation mechanism for rummaging and rejection of unavoidable noises and allows only litigate packets to minimize the route failure probability.

In our proposed method, packet loss, delay, and Age of Information are controlled, thereby minimizing energy usage.

The adaptive traffic control algorithm works based on the BPA. This helps in reducing congestion. It is based on accurate real-time traffic information and global traffic information. Results show that it decreases the average vehicle traveling time (Arnan Maipradit et al. (2021)).

In our proposed method, a modified Backpressure technique is suggested with QLS, so even shorter queues are also not affected and congestion is also in control.

A low-complexity algorithm, which helps in minimizing AoI is suggested by (Igor Kadota et al. (2019)). A randomized policy, MaxWeight Policy, Drift-plus-Penalty, and Whittle Index policy are suggested and algorithms are simulated. It is based on reducing undesirable states. Lyapunov optimization.

In our proposed method, with the help of the undesirable effect of Peak AoI, a threshold is created and active priority is assigned based on it.

The query age of information (QAoI) metric, an adaptation of the AoI concept for pull-based scenarios, is considered in (Tahir Kerem et al. (2022)).

To avoid failures, separating loads dynamically and allocating them to be scheduled is proposed by (Reshma Sultana S et al. (2020)). Priorities based on deadlines are suggested. Consideration of the value of information is not done.

Our proposed method works on Active priority with consideration to TTL, its Priority of it, Freshness of Information.

Priority-based Edge scheduling algorithms are proposed in (Arkadiusz Madej, Nan Wang, et al. (2020)). Three levels of priority 50%, 35%, and 15% are assigned, thereby low-priority process doesn't starve.

Our proposed method works on the principle of Age gain and QLS thereby avoiding starvation and packet loss.

In priority-based applications, measures are not taken to increase the freshness of information. Here, in the proposed method, a novel way of Peak AoI is used as a threshold to gain momentum.

The organization of the paper is as follows,

To avoid traffic congestion, a backlog-based technique is used to find the optimal commodity,

PeakAoI is calculated which can be used to deal with the freshness of Information.

PeakAoI value is normalized as different packets have different importance with respect to information freshness.

To the Active priority scheduling algorithm, PeakAoI is added as one of the metrics to denote the priority of the packet to be scheduled and packets are scheduled accordingly.

The proposed method helps in keeping the time-critical information fresh using a normalized PeakAoI approach and the active priority scheduling algorithm helps

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A.C. Mary, A. V. S. Kumar, etc/ Int. J. Systematic Innovation, 7(5), 56-63(2023)

in less packet loss, energy, and delay which makes it suitable for real-time underwater-based applications.

2. Methodology

2.1. Age of information (AoI)

The freshness of information is an important metric to be addressed. AoI is a new metric used to denote information's freshness. In real-time-based applications, the latest state information only matters. In health-based applications, natural calamities-based applications, etc. timeliness of the information plays a major role. The status updates packet comes with a timestamp to denote the time at which the packet was generated. The old information seems to have no value, once the new information comes in. When the receiver is interested in the timeliness of information, the Age of Information has its importance.

$\Delta(t) = t - U(t)$. (1)

Age of Information is the time elapsed since the last received packet was generated.

Packets are selected such that, minimization of age happens. Usually, fixed threshold or adaptive threshold measures are used.

Peak AOI

AOI measures are generally based on the frequency of generation of packets too, and not just the delay of the packet. Peak AoI metric represents the worst-case AoI. It denotes the maximum time elapsed since the previous information was generated.

Delay time can be denoted as $T_i = r_i - t_i$. (Basel Barakat et al. (2019)) (2)

ti => Time at which the status was updated or the packet was generated at the source

ri = > Denotes the time at which the packet reached the destination.

Xi = > Denotes the time between the generation of updates.

$X_i = t_i - t_{i-1}$. (3)

Peak Age of Information value of the particular update => $PT = (1 / n - 1) \sum_{i=1}^{n-1} X_i + T_i$ (Basel Barakat et al. (2019))
(4)

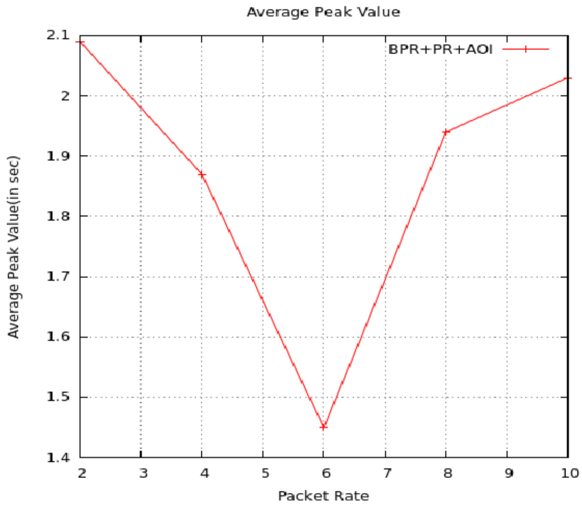

Fig 1. Denotes the average peak AOI value.

AoI metrics are based on Packet rates too. So, the packet rate is varied and the Average PeakAoI is calculated as shown in Fig. 1.

2.2. Congestion control with backpressure algorithm

The backpressure algorithm is effective in scheduling packets. Especially it helps in avoiding traffic in networks. The backpressure algorithm works on the principle of Backlog. The optimal commodity is found based on the backlog (Zhuo Lu, Member, IEEE, Yalin E. Sagduyu, Senior Member, IEEE & Jason H. Li, Member, IEEE (2016)). $\boldsymbol{Q_a^{(c)}(t) - Q_b^{(c)}(t)}$.

Backpressure algorithms can be used to Multi commodity Networks. Based on the optimal commodity, a flow is selected for transmission. It provides high throughput. But there might be delays, especially in the case of smaller queues.

Wab(t) = max [Qa (t) - Qb (t)] (Zhuo Lu et al.(2016)) => Weight calculation (5)

Transmission matrices are created and the link is selected.

The problem with the Backpressure Technique is that the smaller queue might suffer. It might be difficult for the smaller queues to be scheduled before the deadlines or before facing issues like packet delay.

2.3. AoI with priority

Our ultimate goal is to ensure that real-time and non-real-time packets are scheduled effectively. To achieve this queue length and stabilizer queues can be used. Where, if a particular queue is unattended based on a threshold value, the queue size can be virtually increased, so that the queue might get a chance to be scheduled.

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A.C. Mary, A. V. S. Kumar, etc/ Int. J. Systematic Innovation, 7(5), 56-63(2023)

Dynamic priority is considered to be useful in the real-time congestion of the network (Bo Hu et al. (2020)).

Real-time packets or high-priority packets must be made sure to reach the destination without packet loss or delay. So, it's better to include a priority queue, where real-time packets are given first preference to be scheduled. When added to the Backpressure technique, this solution is beneficial as important packets never suffer. Based on TTL and delay, the priority can be updated to make sure that Packet loss and delay are less. This active priority technique adds strength to the proposed algorithm.

AoI measures help to make sure that the freshness of information is sustained. In addition to priority technique parameters like TTL, and Delay, the AoI metric namely Peak AoI is also considered to determine the priority of packets.

When the rate of communication varies, the Age of Information varies too. When the Rate increases, AoI decreases based on the resources available too. A threshold value is set based on the value obtained from the PeakAoI. If the threshold is met, the priority of the packet is increased from the current level, as the packet might turn out to be less valuable because of the timeliness.

When the new packet arrives, and if the old packet is still in transmission, the old packet is dropped as it does not have any value compared to the new packet.

Simulation results prove that packet loss, delay, energy, routing overhead, etc are reduced and the packet delivery ratio, throughput, etc. have been improved using the above method suggested.

Algorithm 1 PeakAoI

1. Using the priority of the packet, TTL, and Delay constraint assign the priority of Packets.
2. Calculate PeakAoI.
3. Calculate the threshold value based on PeakAoI obtained.
4. Using the Threshold value, make changes to the priority of packets if needed.

2.4 Class-based normalized PAoI

Based on the priority of packets, TTL, and delay allocate classes for the packet. Let us consider that there are 3 classes of Priority, High, Medium, and Low. Assign High priority packets to 10 and 20,30 for medium and low-priority packets.

By considering priority and TTL, have 3 classes. 1. High Priority with less TTL, 2. Medium Priority with medium TTL, 3. Low priority with high TTL.

AoI metric is used to measure the freshness of information. But the freshness of information will have its importance according to the information, so this class-based PAoI will help find the exact or needed PAoI.

Table 1. Normalized PAoI

	PAoI value	Normalized PAoI
High Priority with less TTL	10	10
Medium priority with medium TTL	10	7.5
Low Priority with high TTL	10	5

When a scheduling algorithm has to schedule the packets based on AoI, this normalized PAoI will better solve the purpose of the freshness of information according to the packet. As every packet are different, their values over time will be different too. Important packets will lose their value more, over time when compared to low-priority packets. Keeping this in mind the PAoI value is normalized accordingly. This method can help keep emergency and most critical application data fresh.

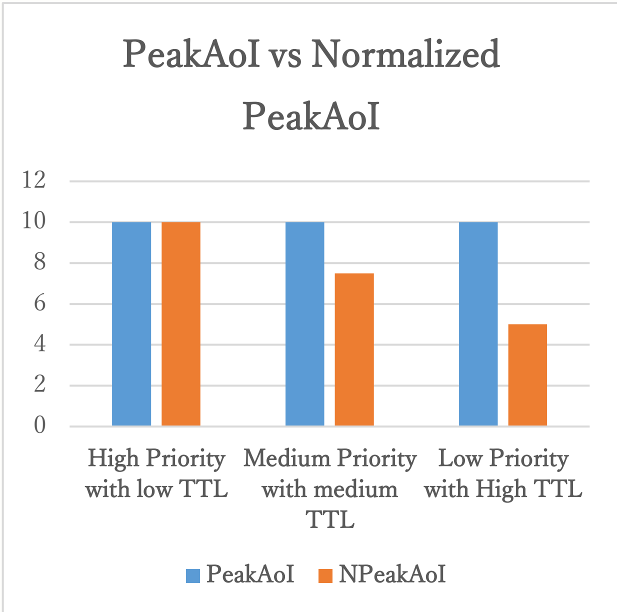

Fig 2. Normalized PeakAoI

Normalized PeakAoI helps in giving importance to time-critical packets where Information freshness is vital.

2.5. Modified priority backpressure algorithm with consideration to real-time packets and AOI

Algorithm 2 Modified Priority

Assign priority of packet based on the packet's importance

If TTL < then

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Upgrade the priority of the packet to the next level End if

Use Backpressure Algorithm to schedule the packets by calculating the optimal commodity and weight

Make sure that smaller queues are not affected by larger queues by adjusting the queue size

Calculate PeakAoI

Normalize the obtained PeakAoI value according to the importance of the packets

Calculate the threshold value

If AoI >= threshold value of Normalized Peak AoI

Reassign the priority of the packet End if

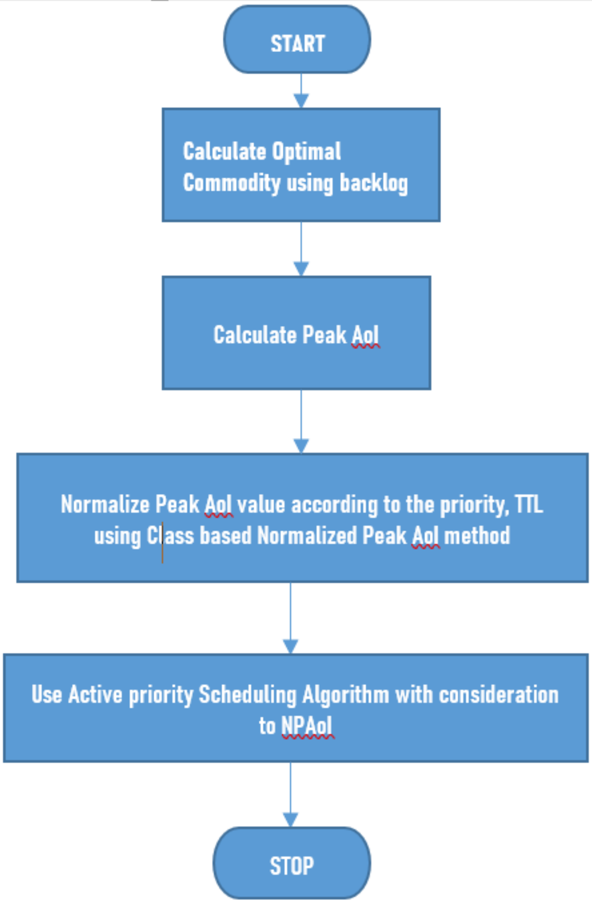

Fig 3. Flowchart representing the Proposed Algorithm

3 Results and discussions

3.1 Simulation results

Simulation is carried out in NS3 and results are found. 2 Parameters, Number of nodes, and speed of node in the Network are varied to find out the working of the proposed algorithm under such circumstances.

(a) Results by varying No. of Nodes in the Underwater N/W

(b) Results by varying the speed of Nodes in the Underwater N/W.

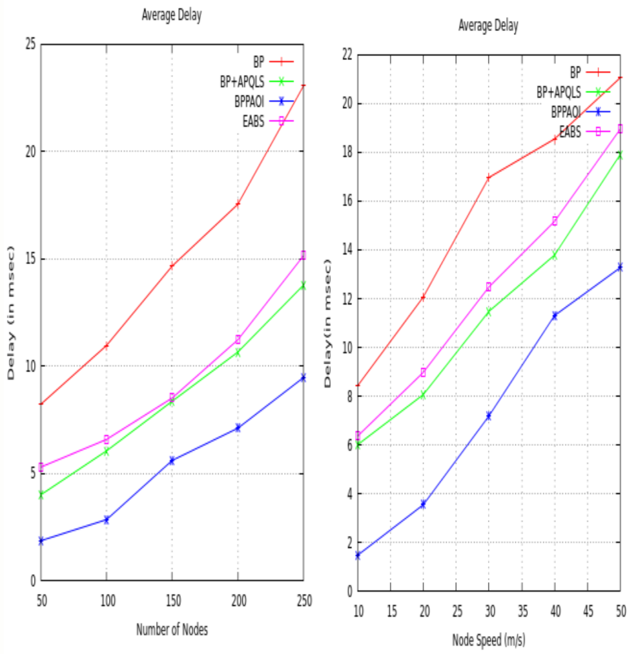

Fig 4. Delay in an underwater Network is calculated by (a) varying the number of nodes and (b) Varying the speed of nodes.

It can be seen from Fig. 4 that the Backpressure algorithm with priority and AOI-based technique [BPPAOI] outperforms the rest of the algorithms. The delay is much reduced when compared to traditional backpressure, EABS (Tie Qiu et al.(2018)), and the BP + APQLS Technique (A Caroline Mary et al.).

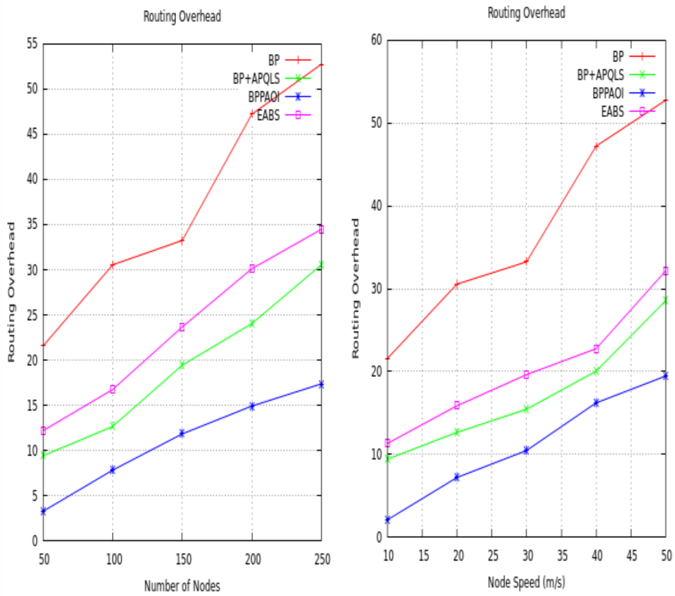

Fig 5. Routing Overhead in an underwater Network is calculated by varying the number of nodes and speed of nodes.

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It can be seen from Fig. 5 that the Backpressure algorithm with Active priority and AOI-based technique [BPPAOI] outperforms the rest of the algorithms in terms of Routing overhead.

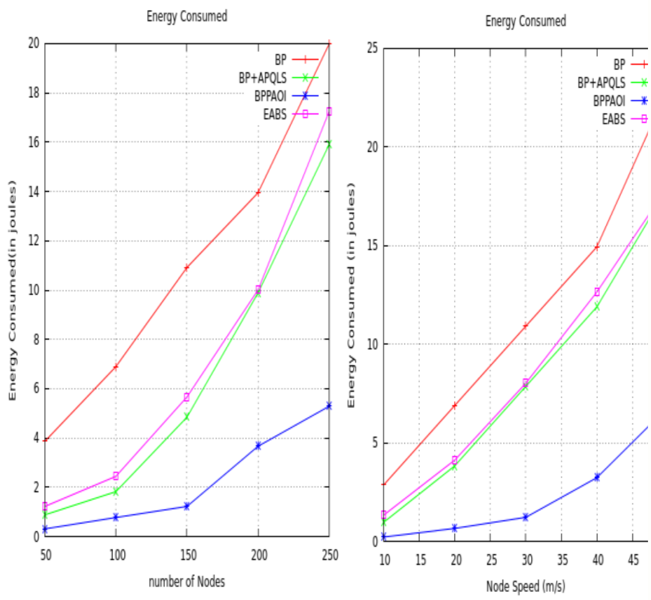

Fig 6. Energy consumption in an underwater Network is calculated by varying the number of nodes and speed of nodes.

Fig. 6 shows that the Backpressure algorithm with priority and AOI-based technique [BPPAOI] outperforms the rest of the algorithms in terms of Energy consumption. The initial energy of 50 Joules is assumed for all nodes and the final energy consumption is noted.

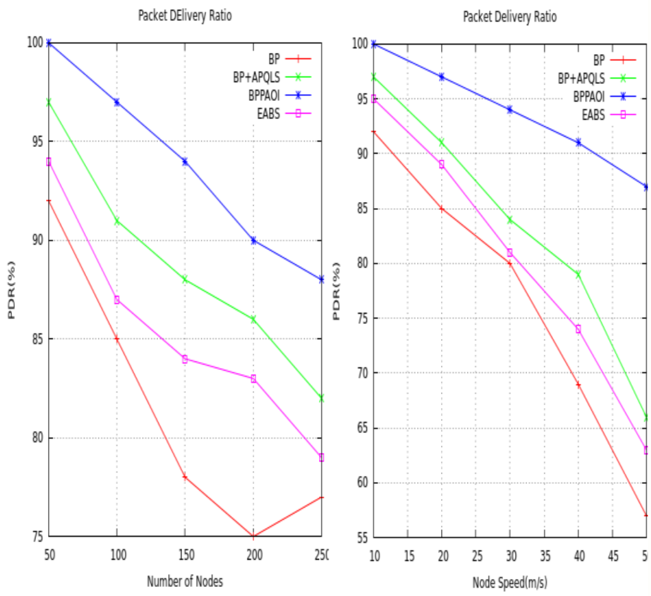

Fig. 7. The Packet Delivery Ratio in an underwater Network is calculated by varying the number of nodes and speed of nodes.

It is found that the BPA with Priority and AOI-based technique [BPPAOI] outperforms the rest of the algorithms in terms of packet delivery ratio as seen in Fig. 7 and in Table 2.

As smaller queues and high-priority real-time packets are given importance and as the Freshness of Information is maintained, the proposed algorithm results better. The use of peak AoI as a metric in considering the priority of the packet has improved the scheduling algorithm in terms of Packet delivery ratio, and energy consumption as shown in Figure 6. Normalized Peak AoI helps in treating time-critical applications with utmost importance. The use of active priority which adapts dynamically to the needs of the network has yielded better results. Energy plays a vital role in underwater Networks, as of the proposed algorithm energy consumption is less and Information freshness has yielded less packet loss and delay.

Table 2. Comparison of Existing and Proposed Algorithms

	BP	BP+ APQLS	EABS	Proposed with AOI BPPAOI
Congestion	Taken care of using Backlog based technique (Arnan Maipradit, Tomoya Kawakami, Ying Liu1 Juntao Ga & Minuro Ito (2021))	Taken care of using Back-log based technique and Active priority	Taken care of using Backlog based Technique	Taken care of using Backlog based tech-nique and Active pri-ority
Freshness of Infor-mation	Not considered	Not considered	Not considered	PeakAoI acts as an im-portant metric as shown in Figure 1.
Priority	Not considered	Based on its priority, TTL and delay	Based on the im-portance of packets	Based on its priority, TTL, delay, Freshness of Information

4. Conclusions

This study proposed a new method that is suitable for scheduling real-time packets in an underwater environment, which demands the freshness of Information, less delay, and less loss. The inclusion of Normalized class-based Peak AoI in assigning priority to the packets is a novel technique. Simulation results prove that almost one-third of Packet delay is reduced and the packet delivery ratio is more than around 90% which helps in reducing energy consumption. Other AoI-based metrics like the Freshness ratio of Information can be considered to improve the energy consumption and delay in future works. Underwater networks are vulnerable to security threats and malicious attacks. Added security can be considered in future works to avoid malicious attacks in underwater networks.

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