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## **A COLLISION AWARE PRIORITY LEVEL MEDIUM ACCESS CONTROL PROTOCOL FOR UNDERWATER ACOUSTIC SENSOR NETWORKS**

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### **ABSTRACT**

The Underwater Acoustic Sensor Network (UASN) plays a significant role in many application areas like surveillance, security, commercial and industrial applications. In UASN routing, propagation delay and collision are perennial problems due to data transfers from various sensor nodes to the Sink Node (SN) at the same time. In this paper, we propose a Collision Aware Priority Level mechanism based on Medium Access Control protocol (CAPL-MAC) for transferring data from the Sensor Head (SH) to the SN. In the proposed protocol, we use Parallel Competition Scheme (PCS) for high channel utilization and energy saving of battery. In each Competition Cycle (CC), the data packet produced by each SH in a different time slot can join in CC for data packet transmission in parallel with high channel utilization. In CAPL-MAC, each SH is assigned with a different Priority Level Number (PLN) during every CC. Instead of broadcasting, each SH sends its respective PLN to each SH with the help of the nearest SH to save battery energy. Based on the highest PLN, each SH communicates with SN without collision, and it will also reduce propagation delay as well as improve timing efficiency. Finally, Quality of Service is also improved.

We adopt the single-layer approach with the handshaking protocol for communication. We carried out the simulation utilizing Aqua-Sim Network Simulator 2. The simulation results showed that the proposed CAPL-MAC protocol achieved the earlier stated performance rather than by existing protocols such as Competitive Transmission-MAC and Channel Aware Aloha.

**Keywords:** Underwater acoustic sensor network, medium access control protocol, handshaking protocol, channel aware aloha, quality of service.

## INTRODUCTION

Underwater Acoustic Sensor Networks (UASNs) play essential roles in collecting data in underwater environments for a plethora of applications, such as water quality monitoring, military operations, underwater exploration monitoring and habitat monitoring. The primary objective of this study is to avoid collisions in an acoustic sensor network using the Collision Aware Priority Level-Medium Access Control (CAPL-MAC) protocol. The research scope of this study covers the impact of factors, such as throughput, propagation delay and energy efficiency, on the quality of service and the effects of collisions. The aim of the study is to improve Medium Access Control (MAC) protocol using our proposed protocol. Sonar sensors consist of a small device and a battery. In a UASN, all types of sensor nodes are used for collecting data and sending them to the surface station. Data are also transmitted to a satellite and offshore sink. When the data packet is sent to the surface station or sink node, there will be possible collisions in the network due to multiple sensor nodes communicating with the sink node (Luo, Pu, Peng, Zhou, & Cui, 2015). Many existing MAC protocols that were proposed in the past were based on contention-based protocols (CBPs) and contention-free protocols (CFPs).

CFPs can be divided into Code Division Multiple Access (CDMA) based on time slots. Frequency Division Multiple Access (FDMA) is based on frequency and CDMA is based on code. CBPs are divided into ALOHA, Multiple Access with Collision Avoidance (MACA) and Carrier Sense Multiple Access (CSMA). Traditional MAC protocols are not suitable for all applications, especially when a long propagation delay occurs in a UASN (Li, Xu, Diao, Wang, & An, 2016). In conventional MAC, the Ready to Send (RTS) and Clear to Send (CTS) protocols are used from the source to the destination. The RTS and CTS are used for collision avoidance. However, these protocols will reduce the energy and throughput efficiency for some applications, such as a commercial sensor network in a UASN. The end-to-end delay will also be

very high during collisions in a UASN for some applications. The underwater depth is also one of the essential factors in our proposed model. Under Water Sensors (UWSs) are placed at great depths under water. Due to the propagation delay, the time efficiency of deep UWSs is very high (Bharamagoudra, Manvi, & Gonen, 2017).

An ultrasonic sensor is a device that can measure the distance of an object using sound waves in a UASN. The ultrasonic sensor always sends the sound waves to detect any object in a UASN. There will be multiple waves that are received from different directions in the water. Due to the various waves, invariably, there will be propagation delays that occur when signals from multiple sensors collide with each other as they approach the sink node (Azad, Hasan, Nandi, & Pathan, 2015). In our paper, we do not consider space-time issues and power allocation. Our proposed model concentrates only on the data link layer of the International Organization for Standardization (ISO). All incoming and outgoing data are processed based on the UWSs and SHs. If data processing takes more time, then battery life is reduced (Alfouzan, Shahrabi, Ghoreyshi, & Boutaleb, 2019). Our proposed CAPL-MAC model uses small battery power during the transmission of the Priority Level Number (PLN) and data packets. In this article, we used SHs only to transmit data from a group of UWSs to a SN. At the same time, we used the parallel Competition Cycle (CC) mechanism for CAPL-MAC to allow the SH to quickly participate in a new round of competition cycle before the old round is completed.

## **RELATED WORK**

Luo et al. (2015) proposed a new MAC protocol called CT-MAC. In this work, the authors considered a multi-user uplink to the sink node. The authors improved energy and channel utilization by using parallel competition. This improvement was confirmed using two different approaches. The authors used a random priority level for the user in an acoustic sensor network. Based on the highest priority, the node could communicate with the sink node. A MATLAB simulation was used for its proposed model. Li et al. (2016) suggested that the DBR-MAC protocol should be used for improving energy costs and fairness. These authors used the handshake protocol for their proposed method. The handshake protocol depends on the cross-layer approach, and it forwards data packets from the source hub to the sink hub in a UASN. These authors used Aqua-Sim for the simulation. They compared DBR-MAC with three protocols, namely, the M\_FAMA, DOTS and S-FAMA. The authors proved that DBR-MAC produces high energy, high throughput with low delay. Chen, Cheng, Yuan, Su, and Ma (2018) predicted round trip times using Bayesian

linear models and the adjusted recovery time objective with the expected value. These authors compared the model with Karn's algorithm and proved that it increased throughput in an underwater acoustic sensor network.

Li et al. (2016) proposed a new MAC protocol with the full-duplex mode for collision avoidance using long propagation delay in an acoustic sensor network. These authors considered complete duplex collision avoidance to increase both spatial and temporal reuse, and they used the handshake process for their proposed MAC protocol. These authors proved that the new MAC protocols were more efficient using an Aqua-Sim simulation. Tang, Shi, and Dong (2018) explored the power assignment system for the control part of the hand-off convention and time-exchange hand-off convention. The observed improvement in the time-exchange was because of the transfer convention by breaking down streamlining capacity. The power-allotment issue could be converted into a raised effect. Finally, these authors proposed time-exchange transfer, control exchange hand-off, information transmission and energy transmission conventions for acoustic sensor organization. These authors proved the results using a simulation.

Yang, Ssu and Yang (2015) investigated the likelihood of an impact between any two-sensor data node transmissions in a UASN. These authors considered the recreation rate, and the results proved that an adequate information rate helped in preparing the arrangement of a UASN. In light of the demonstrated outcome, the delay aware energy efficient protocol (DEEP) was proposed. This method incorporates vitality with various parameters in which the 3-dB transmission capacity determines the separation of data between any two-sensor nodes. The DEEP is utilized to avoid impact and to decrease the number of crashes in a UASN system. The DEEP also incorporates end-to-end postponement and acquired higher information rate and low vitality by using additional available transmission capacities. The result has been proven through a simulation using an NS2 based on the underwater module. Morozs, Mitchell, and Zakharov (2017) proposed the two-Macintosh convention, the Accelerated TDA-MAC and Transmit Delay Allocation MAC (TDA-MAC) to the sensor nodes to eliminate clock synchronization, which is centralized. Propagation delay and data transfer rate are reduced in the simulation of the sea bed. As far as the propagation delay and energy efficiency are concerned, the proposed model outperformed the conventional MAC protocol that is based on contention and the T-LOHI protocol in a UASN.

Dhongdi, Nahar, Sethunathan, Gudino, and Anupama (2017) proposed the cross-layer three-dimensional protocol stacks for acoustic sensor nodes. These authors mainly considered the energy and overall performance of the existing research. The proposed protocol is used for ocean column monitoring, and it combines data link, physical, network, application, and transport

layers with power management, clustering and time synchronization. This protocol was effectively implemented via the open-source acoustic sensor arrangement using an untersim simulation. In this work, various parameters were considered while analyzing network performance, the power levels of cluster head nodes, and the dimension of a column and the duty cycle of TDMA MAC. Muthukumaran, Chitra, and Selvakumar (2018) investigated the improvement of energy-efficient clustering based on a power dynamic and hierarchical routing at the node level. The proposed routing protocol provides three different routing schemes, namely, the hierarchical path using multi-hop (HRMH), hierarchical routing using multilevel and hierarchical routing using cluster identification (HRCI). The HRMH assigns cluster heads at each level over the entire network. The analysis outcomes and experimental results proved that the HRMH is more energy-efficient than the other two proposed protocols.

Nowsheen, Karmakar, and Kamruzzaman (2016) proposed data delivery with path reliability awareness for reliable data transfers so that there is delay tolerance in a UASN. These authors mainly considered the high error rate and long propagation delay in a UASN. Data transfer reliability is meaningfully enhanced by optimizing reachability to gateways, coverage likelihood using probabilistic estimation and the next hop forwarder based on its link dependability. These authors proved the results using a simulation and confirmed that the proposed protocol improved performance with increased energy efficiency and low overhead. Fan, Chen, Xie, and Wang (2013) suggested a hybrid reservation-based MAC (HRMAC) protocol. To reduce the number of collisions, spectrum spreading technology was applied and found to be very useful. Simultaneously, a channel could be reserved using several data nodes to dispatch data packets. After making such a reservation, the data nodes dispatched their data in a specific sequence. The nodes improved channel efficiency, and the simulation results showed better performance based on high throughput, propagation delay, and energy efficiency.

Mohamed, Zainudin, Sulaiman, Perumal and Mustapha (2018) made a proposal based on studying specific human activity(s). The sensors for accelerometers were fixed in smartphones. Multiclass classification (MC) is a general purpose classification method. These authors reduced the multi-label classification build time using the Label combination method. This method outperformed the existing MC protocol. Nasir, Ku-Mahamud, and Kamioka (2019) proposed adapting the parameter values for an Ant Colony System (ACS) and practically validated its performance. These authors used every thinkable parameter value within a specific range. Every parameter's best possible value that improved power consumption, latency and throughput was experimentally determined. Shanmugasundaram, Mohmed, and Ruhaiyem

(2019) proposed an algorithm for minimizing Equal Error Rate (EER). This algorithm serves as a performance measure in biometric authentication. It is known as the Hybrid Improved Bacterial Swarm (HIBS). Finally, the authors optimized priority-based biometric authentication. Cheng and Li (2017) found a strategy for replicating data that are required in the data grid of a wireless sensor network. This strategy has to consider the decay of data files, their exponential growth and how they are interrelated with each other. OptorSim is employed to obtain the simulated output.

Bharamagoudra, Manvi, and Gonen (2017) devised a routing protocol based on an energy efficient and multipath channel and depth-based agent. When an event occurs, the event initiates a dynamic clustering process. The cluster head enables the collection and aggregation of data through data sensor nodes where the event occurred. A mobile agent and its clones are utilized by the data cluster heads to start the routing. This routing leads to a surface gateway via different paths. The method is based on channel quality, energy, propagation delay and hop count. Finally, the authors proposed an agent-based dynamic traversal algorithm to achieve better reliability and network environment. Rani, Ahmed, Malhotra, and Talwar (2017) proposed a chain based routing protocol with better energy efficiency for a UASN. Various features are considered in this protocol, such as the cluster head, network topology, cluster coordinators, node mobility, relay nodes and underwater dynamics, during data transmission. To maintain the nodes' loads, stated features are considered after a period. Location-aware data nodes form the distance-based communication criterion. This criterion is useful during the steady state to oversee domains. However, in its dynamic counterpart, data communication irrespective of node location is imperative. Obviously, hop to hop type relay node communication improves the process. Relay nodes upgrade the data to be much more reliable. The energy and data packet delivery, and the proposed protocol are superior to the cache array routing protocol. The authors validated this protocol using a MATLAB simulation to prove the improved node communication costs and network lifespan.

Darabkh, Wala'a, Hawa, and Saifan (2018) formed a Modified Threshold-based Cluster Head Replacement (MT-CHR) protocol. This protocol changes a general node in any round to be a CH based on a new probability. This assumption is in fair agreement with the LEACH protocol. These authors recommended a fresh expression for energy at the threshold. Here, attention is given to avoid data packet losses and the first node's death. The evaluation is performed by measuring network lifespan, live data nodes, and various performance metrics of network utilization. The stated protocol is superior to T-LEACH and LEACH protocols based on comparisons. In the context of a UASN, the mentioned protocol is well-suited and appropriate,

since it lengthens a network's lifespan. Azad et al. (2015) examined different topology-based routing metrics' functioning in a UAN-architecture. Here, instead of active probing-based routing metrics, topology-based routing metrics were chosen, since in UASN many nodes depend on batteries. A new routing metric named the Cubic Minimum to Average Signal-to-Noise Ratio (CMAS) was designed. This metric is compared with other topology-based routing metrics in a UASN. The simulation results showed that the method provides increased throughput compared to other methods.

Cheng and Li (2017) proposed a couple of integrated algorithms for collecting data. The first algorithm relates to Autonomous Underwater Vehicle (AUV) operations. The second algorithm is for multi-hop transmissions. This algorithm, in turn, minimizes power consumption due to imbalances and time delays of an extended period. A way to find the data's importance is determined. Then, the needed delay periods are set. However, this is accomplished without domain knowledge. In other words, with a reasonable delay, based on data priority, the data is delivered to the sink node. The results validated the mitigation effectiveness of the proposed mechanism with respect to priority-based propagation delay, optimal power utilization and longer network lifespan. Zhu, Zhang, Jin, Qin, Xin, and Wang (2016) designed an underwater practical MAC protocol (UPMAC). Based on the network's load conditions, the protocol must adapt. To adapt, the protocol has both low and high modes. The protocol is centered on switches between the various loads that are present. There is a noticeable decrease in the overhead in a period due to turn around. The piggyback system decreases control packet corruption. A method that is based on the receiver is employed by UPMAC during higher loads. This method is helpful in multi-hop and single hop conditions, resulting in a substantially lower data collision rate. Repeated simulations supported the improved performance of UPMAC in a Sea Swarm network and a general network.

Feng, Wang, Han, Qu, and Chen (2018) proposed the Distributed Receiver-oriented Adaptive Multichannel MAC (DRAMAC) for a UWSN. The DRAMAC has a couple of key innovations. One innovation reduces collision probability, and the other innovation selects the channel according to the length of a packet and the load conditions in the receiver network. Existing device performance is improved with these innovations. This method yielded a reduced propagation delay, a better packet generation rate and higher utilization. Alfouzan et al. (2019) suggested a new protocol for a UWSN to conserve power that includes a depth-based layer that is free from collisions. This protocol addresses the issues of effects due to being near or far, uncertainty in spatial or temporal regions and problems in open or unseen terminals. By using layering and a clustering algorithm, this protocol

schedules transmissions and receipts in an efficient way. Each sensor node is assigned a time slot to access the channel and avoid collisions using TDMA. The simulations proved that this method’s performance is superior to others in terms of packet generation rate, energy conservation, packet losses due to different traffic rates and packet delivery ratio.

Chen et al. (2018) designed a model for positioning multilayers in an underwater network. The Poisson distribution centered protocol, which has a varying interval ALOHA, is used to analyze the causes of packet collisions. This protocol is minimized by the addition of random space-time. The evaluation of the results of the effects of localizing in both variable and equal time intervals are performed by comparing data packet loss, localization time and coverage. A huge influence on localizing was exhibited by the MAC protocol when simulations were carried out. In addition, the varying type was 20 percent better than the equal type. Zhuo, Qu, Yang, Wei, Wu, and Li (2019) proposed a MAC with a delay and queue aware adaptive scheduling type protocol for a UASN. This combination minimizes the number of handshaking packets by transmitting using adaptive scheduling, improves throughput of the network, minimizes average power dissipation, reduces propagation delay and improves transmission fairness. Even with varying traffic loads, this protocol is better than conventional protocols. Bouabdallah, Boutaba, and Mehaoua (2018) suggested a multi-channel MAC protocol for underwater acoustic sensor networks. This protocol is found to have better energy efficiency and can transmit without collisions. The single slotted control channel avoids data loss at the receiving end. The multiple channels increase the throughput. This protocol employs two methods for assigning slots: one method is grid-based, and the other method is based on a quorum. The simulation validates a better packet generation rate, lower power consumption, and lower propagation delay. Table 1 summarizes the related work.

Table 1

*Summary of Related Work*

<b>Author &amp; Year</b>	<b>Proposed Technique</b>	<b>Advantage</b>	<b>Disadvantage</b>	<b>Gap</b>
Luo et al. (2015)	CT-MAC	Improved energy and channel utilization	SH is not used	Time efficiency is not considered
Li et al. (2016)	BBR-MAC	Improved throughput, energy & time efficiency	Not incorporated multiple sensor & SH	Chance to observe collision

(continued)

<b>Author &amp; Year</b>	<b>Proposed Technique</b>	<b>Advantage</b>	<b>Disadvantage</b>	<b>Gap</b>
Chen et al. (2018)	Adaptive RTO	Improved throughput, energy & time efficiency	Not incorporated multiple sensor & SH	Chance to observe collision
Li et al. (2016)	FDCA Protocol	Improved throughput, use of handshaking, propagation delay is reduced	Not incorporated multiple sensor & SH	Chance to observe collision
Tang et al. (2018)	Throughput Analysis	Improved throughput & energy efficiency	Not incorporated multiple sensor & SH	Energy efficiency is very low
Yang et al. (2015)	Deep protocol	Improved energy efficiency & collision is reduced	Cluster head is absent	Time efficiency is very low
Morozs et al. (2017)	TDA-MA	Improved propagation delay and throughput	SH is absent	Time efficiency is not effective
Dhongdi et al. (2017)	Cross-layer Protocol	Energy efficiency alone is considered	Collision and propagation delay not accounted	Time efficiency is not effective
Muthu-Kumar et al. (2018)	ENEFC	Improved energy and increased network lifetime	A few sensors are present	Energy efficiency to be improved
Nowsheen et al. (2016)	PRADD protocol	Improved delay tolerance in underwater traffic	Used only in the hop to hop	Reduce delay
Fan et al. (2013)	Hybrid reservation MAC	Collision is reduced	SH is not used	Propagation delay occurs
Rani et al. (2017)	Energy effective protocol	Improved data is not considered	Propagation delay effective	Time Efficiency is not efficient
Azad et al. (2015)	High throughput routing metric	Contains more sensor	SH is not used	Collision occurs
Cheng et al. (2017)	Data gathering technique	Reduced delay and more energy efficient	Propagation delay is neglected	Time efficiency is very low
Zhu et al. (2016)	UPMAC protocol	Network load condition is considered	Only timing efficiency is considered	Collision occurs
Feng et al. (2018)	DRAMAC	Reduced collision & delay, improved channel	SH is not used	Propagation delay occurs
Alfouzan et al. (2019)	DL-MAC	Improved throughput & energy, reduced packet loss	SH is not used	Chance to observe collision

(continued)

Author & Year	Proposed Technique	Advantage	Disadvantage	Gap
Chen et al. (2018)	VI-ALOHA	Proved VI-ALOHA observe is 20 % better than EI-ALOHA	SH is not used	Chance to observe collision
Zhuo et al. (2019)	Delay and queue aware	Improved delay bandwidth & time variation	SH is not used	Chance to observe collision
Bouabdallah et al. (2018)	MC-UWMAC	Improved energy & throughput, reduced delay	SH is not used	Timing efficiency not considered

## DESIGN OF COLLISION AWARE PRIORITY LEVEL MECHANISM BASED ON MAC PROTOCOL

In this section, we discuss topics, such as the methodology of CAPL-MAC, architecture, communication diagram, level diagram, transmission cycle and transmission scheme.

### CAPL-MAC Methodology

Figure 1 represents the flow of our proposed model. This model is divided into four levels. The first level represents the UWS. This level is used to detect any underwater object using sound waves and sends the data to the SH. The second level is the SH. This level shows the incoming data process and how the data is sent to the sink node with the help of the CAPL-MAC. The third level contains the proposed CAPL-MAC, which performs the key processing work from the SH to SN. This level performs the communication from the SH to the SN. The fourth level is the SN, and it processes incoming data from the SH and sends them to the satellite and server. The proposed CAPL-MAC architecture is illustrated as follows.

Figure 2 shows the 3-dimensional architecture based on the SHs and UWSs. Here, three underwater depths are considered for our model. Each level is at a depth of 10 meters and has a static SH. This model uses the full-duplex mode and the handshake protocol. The SH is attached to three UWSs at each level. This model has nine SHs. Each SH is stored with a PLN. The CAPL-MAC is more suitable for handling data in underwater situations where the depth is in the order of several tens of meters. The data can be easily received or sent; depending on whether it is an SN or SH. The communications will be very fast, and collision-free data packet transmissions are possible. Additionally, the maximum data rate is produced by the SHs and sent to the SN. The end-to-end delay will be reduced. Power is conserved in the battery, and QoS is improved.

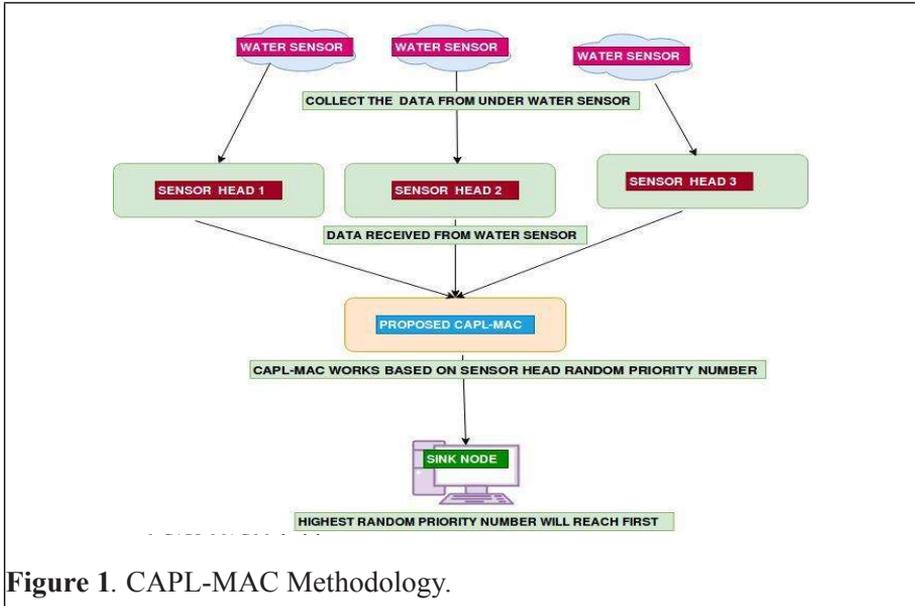


Figure 1. CAPL-MAC Methodology.

### Proposed 3-Dimensional Architecture for CAPL-MAC

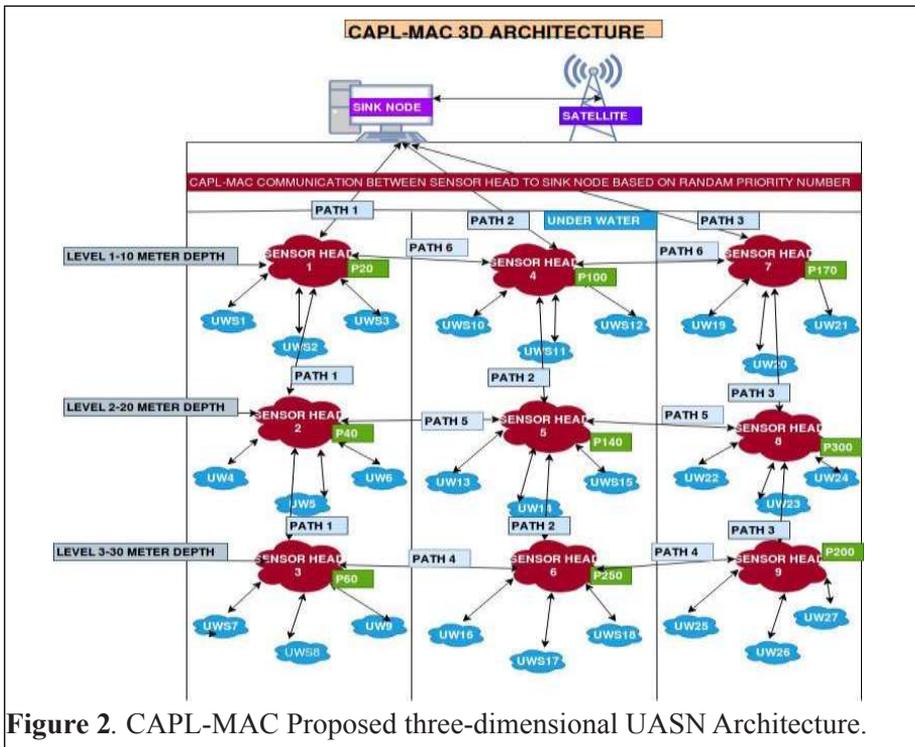


Figure 2. CAPL-MAC Proposed three-dimensional UASN Architecture.

### CAPL-MAC Communication Model

Figure 3 shows a communication pattern between SHs to the SN. The SHs generate a PLN for each CC. Here, six tracks are used for SH communications, and each SH can travel on any route. Every SH receives the PLN and sends it to the neighboring SH. It can reach all possible SHs. In our proposed model, the SHs will start to communicate based on the highest PLN from the SHs to the SN. Similarly, each SH follows the same procedure. If a SH does not have any data to send, then, its priority number will be set to zero.

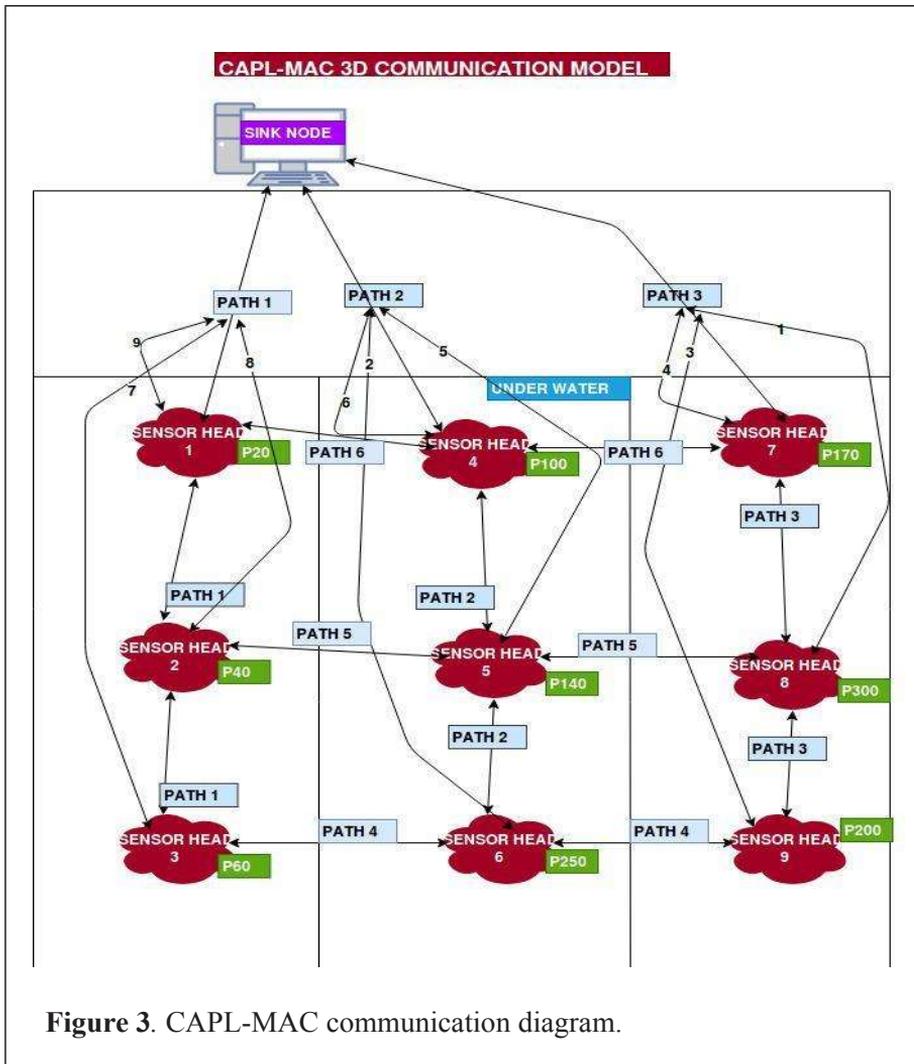


Figure 3. CAPL-MAC communication diagram.

### The probability for CAPL-MAC Total Outcome

Based on the binomial formula, Figure 3 has nine SHs, and the number of outputs to the SN is 9. The likelihood of individual success is denoted as P. The general formula for binomial probability is denoted by b as Equation 1.

#### General formula

$$b(x,n,p) = {}_n C_x * P^x * (1-P)^{n-x} \quad (1)$$

Where

n : Total Sensor Head=9

x : Total Output=9

P : Individual Success=1/9

$$\begin{aligned} B(9, 9, 1/9) &= ({}_9 C_9) * (1/9)^9 * (1-1/9)^{9-9} \\ &= 1 * (1/9)^9 * (8/9)^0 \\ &= 1 * (1/9)^9 * 1 \\ &= (1/9)^9 \end{aligned}$$

According to Equation 1 in our proposed CAPL\_MAC model, the model is communicating with the SN using 1/9 SHs. Therefore, out of the 9 SHs each time, only one SH is communicating with the SN without a collision. The power 9 implies that only one SH is communicating with the SN each time. This communication can be repeated 9 times. Each SH is assigned a PLN. Any SH that does not have data has its PLN number initialized to zero. In Equation 2, we obtained 8 or 9 waiting states. Therefore, in each CC, the remaining SHs in the waiting state are communicating with the SN one by one, according to the CAPL-MAC.

### The probability of each outcome based on priority level number for CPAL-MAC

Here, according to Equation 2, the probability of each outcome based on the PLN for the CAPL-MAC output is one, which follows the probability concept.

$$P_{PLN} = X * Y = 9 * 1/9 = 9/9 = 1 \quad (2)$$

Where

- PPLN : Probability of each outcome based on PLN
- X : Number of total outcomes from SHs.
- Y : Probability of each outcome from SHs using CAPL-MAC

Therefore,

$$X = 9$$

$$Y = 1/9$$

### Transmission cycle for CAPL-MAC

To avoid a collision, only M out of N SHs with the highest PLNs are allowed to send their data in the transmission cycle. Figure 4 shows the priority level transmission arrangement in CAPL-MAC where red, black and blue represent newly produced PLNs, overhead PLNs from the nearest neighbors and past PLNs, respectively. Here, three SHs are used for CAPL-MAC protocol. Each SH has three CCs that are used for transmissions in this diagram. In each CC, different types of PLNs are produced and sent to all SHs. Data transmission will take place based on the PLNs. Each time, a different PLN is produced in each CC. If all SHs communicate, then it will start a new CC to produce the PLNs.

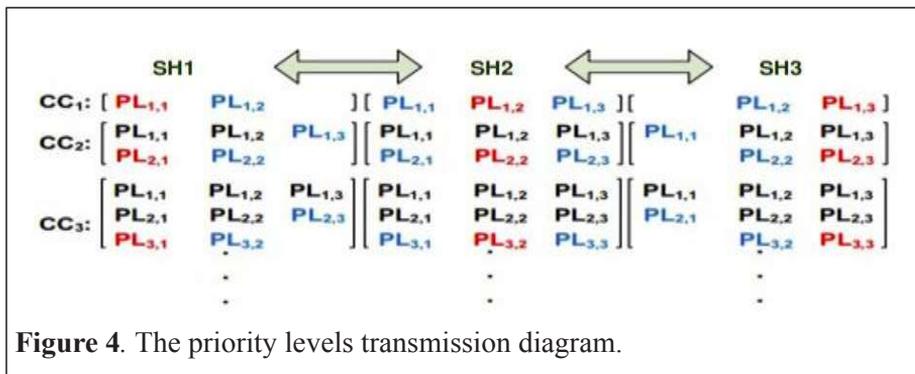


Figure 4. The priority levels transmission diagram.

Equation 3 shows that different types of PLNs are produced for every SH in each CC. Based on this observation, the communication will take place in our proposed CAPL-MAC protocol.

$$CC = \sum_1^n PLN \tag{3}$$

Where

CC : Competition Cycle  
PLN : Priority Level Number

### Data transmission schemes

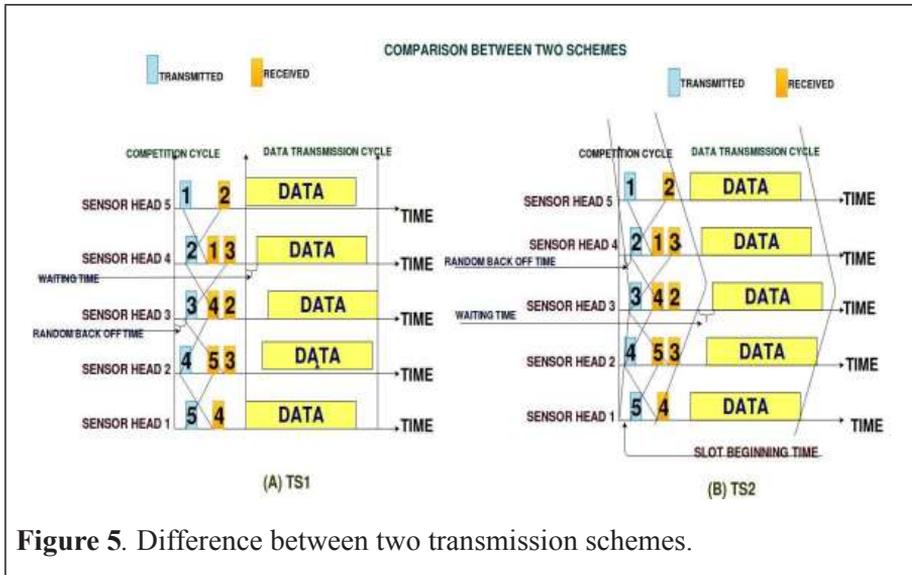
In Figure 5, the Transmission Scheme 1 (TS1) has all SHs starting at the same time slot. The SN will receive each packet from different SHs at the same time. SHs with the shortest distances between their SH and SN ( $D_s$ ) should wait for the one with a long  $D_s$  before transmitting their packets. With reference to Figure 3, SH1 has the smallest  $D_s$ . The waiting time is substantially less for SH1. In Transmission Scheme 2 (TS2), all SHs start at different time slots. The SN will receive each packet from the different SHs at a different time. The SHs with the largest  $D_s$  should wait for the one with the small  $D_s$  before transmitting their packets.

In TS2, since SH1 does not start in the same time slot, the CC may stand a chance to have overlapped data transmissions. Therefore, we need to ensure that there is no collision between the SHs and the SN in our proposed model. In Equation 4, the distance between the SHs and SN is equal to the length of a CC in the Data Transmission Cycle (DTC).

$$D_s = L_{cdc} + L_{dtc} \quad (4)$$

Where

$D_s$  : Distance between SH and SN  
 $L_{cdc}$  : Length of the competition data cycle  
 $L_{dtc}$  : Length of the data transmission cycle



**Figure 5.** Difference between two transmission schemes.

## CAPL-MAC PROTOCOL

According to this protocol, it is presumed that the proposed architecture is a three-dimensional and time-based one. We present how the CAPL-MAC functions in a three-dimensional full-duplex system.

### Three Dimensional Full-Duplex Networks

This standard three-dimensional network has a vertical bus topology in which SHs are deployed and arranged vertically, as shown in Figure 5. In the protocol, the division of the time slot has the same length as that of the others. Each time slot has a DTC and a CC.

#### *Competition cycle*

At the CC, every SH performs the following three tasks before the communications.

- (1) Each time, the SH generates a random PLN and then sends it to all SHs.
- (2) The PLN is sent to all SHs with the help of the nearest SH, thus avoiding transmissions to all SHs and conserving power.
- (3) In the case that an SH gets a PLN that is sent by the nearest SH coming from the preceding CC, it relays the present CC.

At a specific CC, if all the SHs know the PLNs of all other SHs, then all SHs decide to send data packets independently by comparing their value with those of other SHs. In the conventional MAC protocol, it works based on underwater sensor inputs. However, the time consumption of all sensors would be very high.

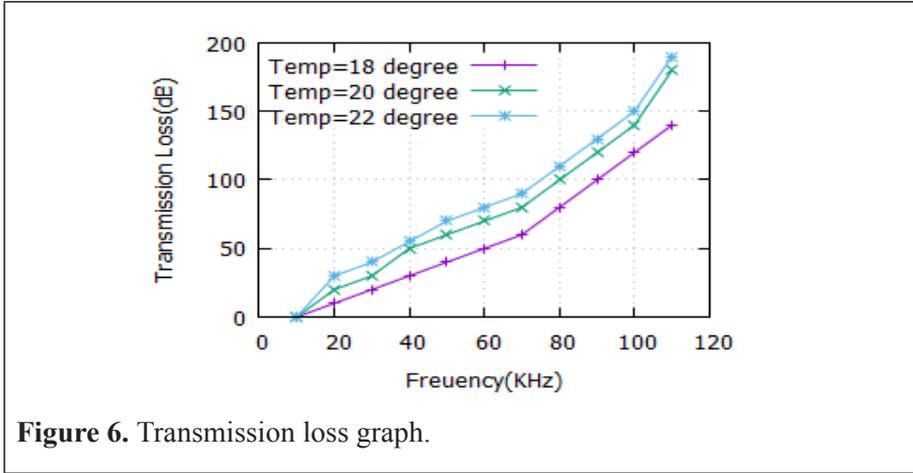
### ***Deep water channel for underwater acoustic sensor network***

One modeled channel can be considered for the proposed three-dimensional network. The channel analysis of utilization modeling is presented in Equation 5 in the case of the proposed three-dimensional network. For example, Total Depth (TDu) = 2100 m, Range (Ru) = 15 m, and Each level (Elu) = 700 m.

$$\text{Transmission loss (R, F, T, D, C)} = k10\log R + \alpha (F, D, T, C) \times R \times 10^{-3} \quad (5)$$

The term  $k$  represents the spreading factor;  $\alpha$  represents the absorption coefficient, and its unit is in dB/km;  $r$  represents the range in meters;  $f$  represents the operating frequency in kHz;  $D$  represents depth in meters and  $T$  represents the water temperature in °C. The term appearing first in Equation 5 represents the spreading loss, and the next term represents the absorption loss. The spreading factor  $k$  accounts for geometrical spreading. The spreading factor  $k$  denotes the acoustic energy that spreads due to the expansion of the wavefront. There are two types in geometric spreading. If  $k=1$ , it is cylindrical, denoting shallow water communication; and if  $k=2$ , it is spherical, and it is in deep water.

Figure 6 depicts the communications that take place at a depth of 1000 m. In addition, this figure shows data transmission losses ranging from 50 m to 200 m. This loss occurs while the frequency range varies from 120 kHz to 20 kHz. Here, loss constant due to pH is set at 8, and salinity is considered to be 35 percent. The graph is drawn for different temperatures. When the operating frequency increases, the transmission loss increases. Such loss occurs even when the communication distance is long. This aspect is specifically observed in transmissions in a UASN. The bandwidth of the usable range gets restricted.



**Figure 6.** Transmission loss graph.

For the acoustic frequency  $f$  in kHz, the absorption coefficient  $\alpha$  can be determined in dB/km as Equation 6:

$$\alpha = (A_1 B_1 C_1 C^2) / (C^2 + C_1^2) + (A_2 B_2 C_2 C^2) / (C^2 + C_2^2) + A_3 B_3 C^2 \quad (6)$$

The term appearing first in (8) represents the absorption effect of boric acid, and the next term represents magnesium sulfate's refer old absorption loss. The final term stands for pure water absorption loss. The transmission loss in deep water can be calculated using Equations 5 and 6.

### Algorithm

In Algorithm 1, the first step is to generate the PLN for each CC and then send the PLN to all SHs with the help of their nearest neighbors. Then, in step 5, if an SH is empty, it will be assigned a value of zero, and it will not be communicated to the SN. In Step 8, the SHs check with the corresponding PLN. If the PLN of the SH is greater than those of all other SHs, it will communicate with the SN. Steps 1 to 10 will be repeated in each CC.

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#### Algorithm 1: CAPL-MAC Protocol Algorithm

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Step 1: **Input:**

Step 2: Generate Random PLN for each Completion Scheme (CS).

Step 3: **Begin:**

Step 4: Send PLNs to all SHs.

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(continued)

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Step 5: An SH sends its PLN to all the SHs using the nearest neighbors of the SH.  
Step 4: end  
Step 5: **if** SH is Empty  
Step 6: **Then**, Set SH= 0  
Step 7: end  
Step 8: **while** SH > PLN from all SHs  
Step 9: **do** SH decides to send their data individually with the data transmission cycle by associating it with the corresponding PLN.  
Step 10: end  
Step 11: Steps 1 to 9 will continue for each CS

---

## EVALUATION OF COLLISION AWARE PRIORITY LEVEL MECHANISM BASED ON THE MAC PROTOCOL

We implemented our simulation model on Aqua-Sim, which is based on NS2, according to Li, Xu, Diao, Wang, and An (2016), and it is shown in Table 2. We deployed our model for a UASN. We measured the average energy efficiency, throughput efficiency and delay reduction as functions of the packets.

Table 2

### *Simulation setup and parameters*

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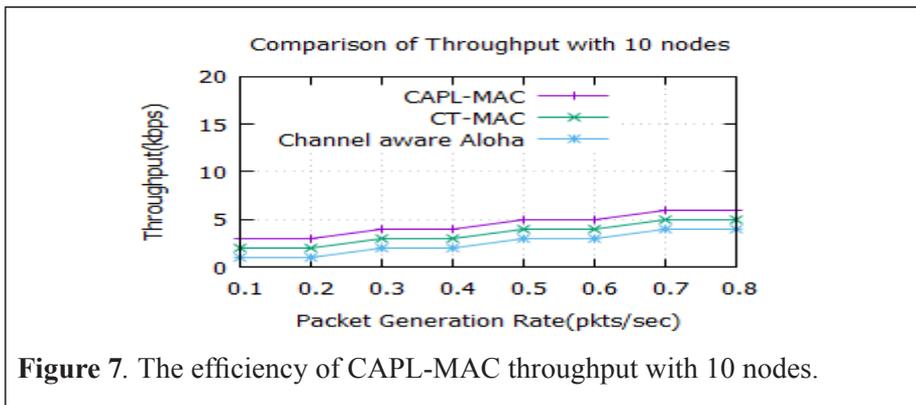
<b>Parameter</b>	<b>Value</b>
Operating system	Ubuntu 16.4
Simulator name	Aqua-Sim extension package based on network simulator2
Network size	500 m*500 m*500 m
Number of nodes	100
Simulation rounds	1000
Bandwidth	10 kbs
Maximum transmission range	50 meters
Energy efficiency	2 watts
Receiving	100 mv
Idle state	10 mv
Data packet size	256 bytes
Control packet size (RTS/CTS/ACK )	16 bytes
Size of buffer queue of each node	20 k bytes

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## SIMULATION RESULTS

Earlier methods did not provide proper emphasis to these factors. In addition, previously, when the effects of collisions were included, the QoS was greatly affected. For a detailed explanation, please refer to Table 1. We compared two existing protocols, namely, the CT-MAC and CAA, and the results proved that our proposed CAPL-MAC gave 45 to 65 percent improvement in terms of energy efficiency, throughput and delay reduction. Graphs that mapped the results of CAPL-MAC, CT-MAC, and CAA are generated.

Figure 7 shows that the proposed CAPL-MAC has high throughput compared to the existing CT-MAC and CAA protocols. When the throughput is increased, the packet deliveries from the SHs to the sink node will also be very high. In this graph, we conducted testing using 10 nodes and proved that the throughput increased in each CC during data transmissions. In the proposed CAPL-MAC protocol, a 25 percent data transmission rate improvement is observed compared to the existing protocols.



**Figure 7.** The efficiency of CAPL-MAC throughput with 10 nodes.

Figure 8 shows that we tested the throughput using the Aqua-Sim simulator, which is based on NS2. In this graph, we tested 30 nodes. We obtained a high throughput compared to the existing CT-MAC and CAA protocols. For the plotting, we tested 30 nodes and proved that the throughput is very high in each competition cycle during data transmission. In the proposed CAPL-MAC protocol, a 35 percent improvement in the maximum data rate is observed compared to the existing protocols.

Figure 9 shows that the energy consumed with 10 nodes is very low. In each CC, we used the PLN for each SH during data transmissions from the SHs to the SN. Based on the PLNs, we observed that the collisions are entirely avoided in our proposed CAPL-MAC. This protocol used a very low energy level for each sensor battery compared to the existing CT-MAC and

CAA protocols. In our proposed CAPL-MAC protocol, a 45 percent energy efficiency improvement is observed when compared to the existing protocols.

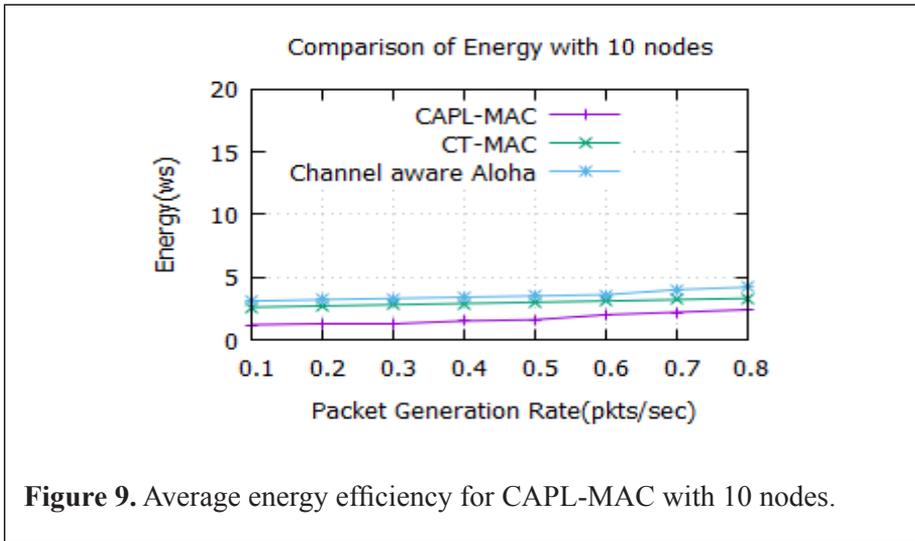
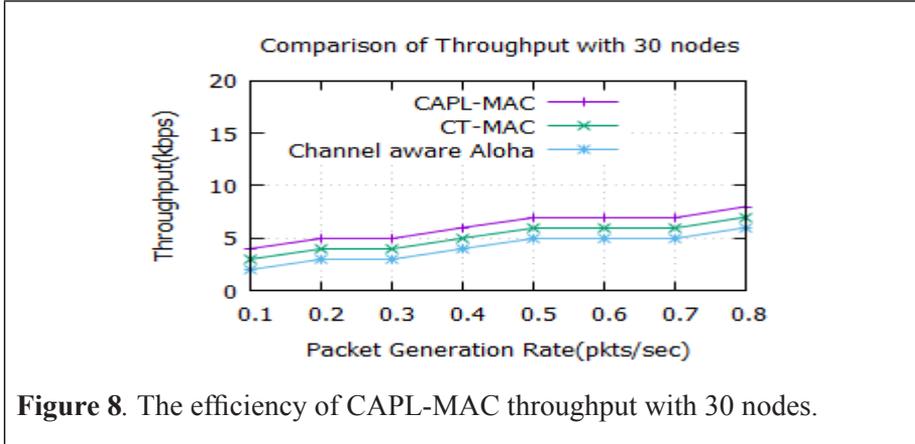
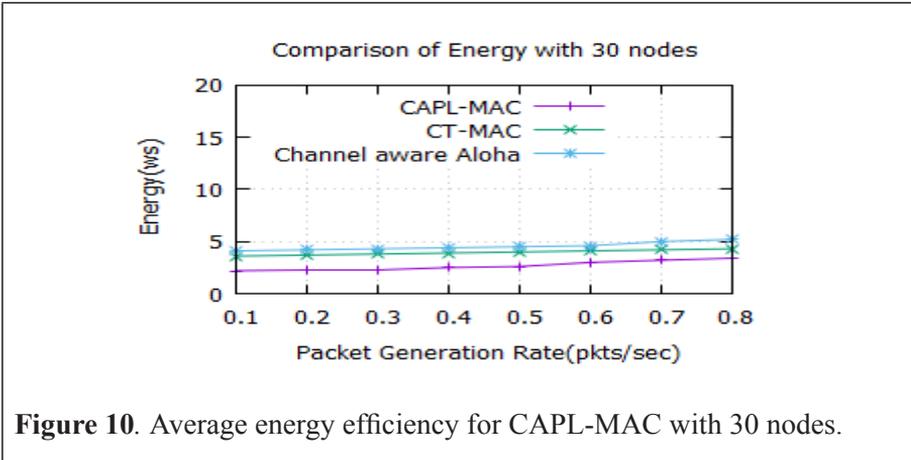
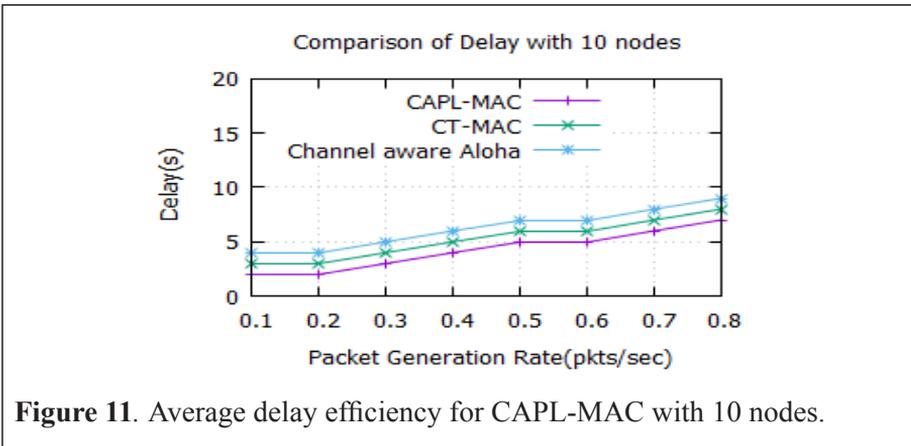


Figure 10 shows the results using 30 nodes. In this graph, the energy utilization of 30 nodes is very low compared to the existing CT-MAC and CAA protocols. The proposed CAPL-MAC works based on the PLN values, and collisions are completely avoided. In each CC, the energy utilization for a sensor battery is very low compared to the existing CT-MAC and CAA protocols. In the proposed CAPL-MAC protocol, a 40 percent energy efficiency improvement is observed when compared to the existing protocols.



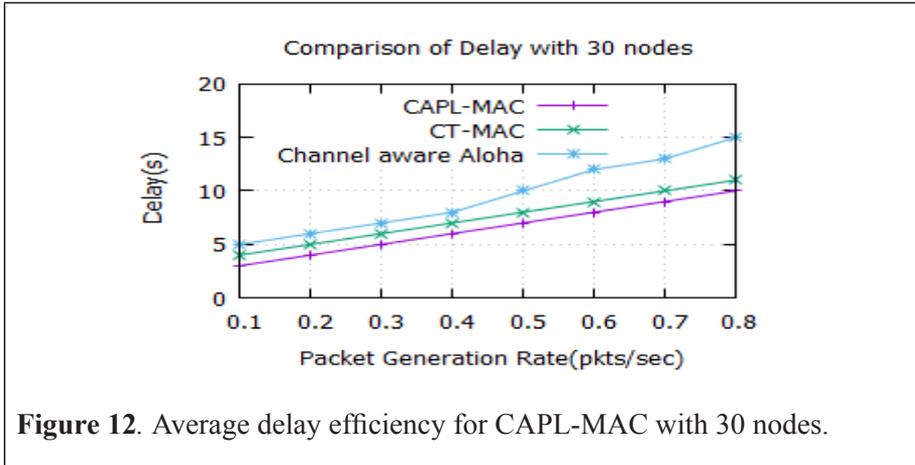
**Figure 10.** Average energy efficiency for CAPL-MAC with 30 nodes.

Figure 11 shows the results of testing a delay in our proposed CAPL-MAC model with 10 nodes. Here, the delay is very low compared to the existing CT-MAC and CAA protocols. We used the PLNs value for all SHs. Therefore, the delay is decreased in our CAPL-MAC and, in each CC; the data are transmitted without collisions. In the proposed CAPL-MAC protocol, a 60 percent decreased delay is observed when compared to the existing protocols.



**Figure 11.** Average delay efficiency for CAPL-MAC with 10 nodes.

Figure 12 shows the results of testing a delay with 30 nodes. We compared our CAPL-MAC with the existing CT-MAC and CAA protocols. We proved that our CAPL-MAC results in a low delay compared to the existing CT-MAC and CAA protocols. We concentrated mainly on avoiding collisions completely in our proposed CAPL-MAC and proved that the delay is very low for 30 nodes using the simulation. In the proposed CAPL-MAC protocol, a 55 percent decreased delay is observed compared to the existing protocols.



With reference to Table 1, many of the existing work did not consider SHs, timing efficiency, energy efficiency and propagation delay. This omission would lead to a high number of collisions during data forwarding from underwater sensors to the SN. In CAPL-MAC, we compared the existing CT-MAC and CAA protocols using simulations. In CT-MAC, they considered only the sensor node, which would lead to propagation delay and lower timing efficiency. The CAA MAC was also not suitable for a UASN due to the high propagation delay. To solve these issues, we proposed the CAPL-MAC protocol for a UASN. We used SHs for communicating to the SN in CAPL-MAC. We used PLNs for all SHs. Based on the highest PLN for each SH, they could communicate with the SN without a collision. The PLNs were also used to reduce propagation delay and increase throughput and energy efficiency. In addition, timing efficiency and QoS were also improved.

## CONCLUSION AND FUTURE WORK

In this study, we proposed a Collision Aware Priority Level-MAC (CAPL-MAC) for a UASN. Usually, in a UASN, the propagation delay can be very high due to collisions. Since collisions occur in the MAC protocol, we concentrated our work on the ISO data link layer alone. The important factors of CAPL-MAC, such as energy efficiency of the battery, collision-free data transfer, and long propagation delay, were carefully considered. Finally, the performance of CAPL-MAC was evaluated using Aqua-Sim NS2. Especially in the high traffic packet generation scenario, the CAPL-MAC performance was approximately 80 to 90 percent better than existing CT-MAC and CAA protocols, respectively. In conclusion, compared to the CT-MAC and CAA,

our proposed CAPL-MAC has higher throughput with collision-free data transmissions. Moreover, the energy efficiency of the battery is also very high compared with the other two protocols. In addition, the propagation delay is also very low compared to the other two protocols and this method improves timing efficiency and QoS. Since we analyzed only one specific layer where collisions occur, in future, we plan to extend testing using a cross-layer approach that will make real-time applications possible.

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