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Underwater Cross Layer Protocol Design for Data Link Layer : Stochastic Network Calculus

M SARAVANAN[1], RAJEEV SUKUMARAN[2]
Directorate of Learning and Development, SRM Institute of Science and Technology, Kattankulathur, Chengalpattu, Tamilnadu, India 603203
Corresponding author:M Saravanan (e-mail: saravanan.be88@gmail.com).

ABSTRACT Nowadays, the research in underwater coral farming development is increasing due to the incremental demand for a source of medicines. The coral farms are located in the depth of the seabed and physically monitoring the coral farms is not an easy task in an underwater environment. At the same time, wired communication makes massive deployment and maintenance costs. The terrestrial wireless communication protocols in air and their approaches cannot be directly implemented in underwater communication scenarios as seawater is a highly saline medium. The protocol design in underwater acoustic communication for coral farms is a challenging research domain. This paper proposes the Scheduled Process Cross Layer Medium Access Control (SPCL-MAC) protocol design using stochastic network calculus. The fundamental idea of this protocol is to schedule the handshaking communication during the reserved process cycle and coordinate the process among the physical and network layer in underwater wireless communication. Performance analyses for frame delivery ratio, end-to-end delay, and energy consumption of both transmission and reception are carried out. The proposed mathematical models are also evaluated for its accuracy using discrete event simulation studies.

KEYWORDS Underwater Acoustic Wireless Communication, Synchronization, Medium Access Control, Stochastic Network calculus, Scheduling, Cross Layer.

I. INTRODUCTION

The Scientific research activities in oceans have rapidly expanded in recent years. Many sensors, actuators and autonomous vehicles have been deployed for research and commercial purposes. Thus, underwater wireless communication becomes an important key area for the real world's uncovered problems. Like terrestrial communication, the MAC protocols are significant for reliable data transfer in the underwater environment. The underwater applications include military surveillance, underwater agricultural farming, natural disaster monitoring, oil companies, mining, and device monitoring and control. Researchers are seeking for novel approaches suitable for underwater coral farming due to the demand in medicine industry, etc.,. Due to unique characteristics of underwater acoustic channel, such as low bandwidth, long propagation delay, and extensive time-varying multi-path effects, designing effective protocols for each layer in underwater acoustic networks encounters great challenge [1]. In recent years, many MAC protocols have been proposed for UAWNs to improve performance. These protocols consider unique characteristics of underwater acoustic channel. It coordinates communication via handshaking, scheduling, severe packet collisions and throughput insufficiency. It is worth noting that other layers like network layer and physical layer activities. To decrease cost of route discovery in UAWNs with long propagation delay, limited energy, and routing protocols are studied to forward packets based on location information without dedicated route discovery [2]. Moreover, Orthogonal Frequency Division Multiplexing (OFDM) as a multi-carrier modulation technology, has been widely studied in underwater acoustic networks with advantages of its high spectrum efficiency, strong resistance to multi-path interference, and convenient realization. Although these studies improve underwater acoustic networks performance from their own perspective, it introduces the additional problems for MAC protocols, due to complex interactions between each layer. Most existing MAC protocols are does not concentrating on the coordination between the physical and network layer activities because sender can not know the exact next-hop in such stateless routing design. The existing protocols such as geo-routing protocols can combine with Broadcast MAC, multiple next-hop candidates are easy to lead severe collisions. Meanwhile, most existing MAC protocols based on OFDM are designed for centralized networks, which are not suitable for sparse distributed UWANs, and difficult to deal with dynamic change of nodes and environments [3]. Therefore, it is necessary to design an efficient MAC protocol that smoothly integrate with network layer protocols and orthogonal Frequency Division Multiplexing in physical layer to avoid the collisions.

Figure 1. The illustration of underwater coral farm structure

The coral farm enable numerous marine animals to spawn in natural settings for lengthy periods. The view of the coral farm is illustrated in the Figure 1. In addition, the coral farm facilities are often located in deep and provide optimal conditions for coral farming. However, physically supervising coral farms is a time-consuming operation for humans [4], [5]. Therefore, coral farming may be more effective and inventive by using remote control, such as a UWAN acoustic communication system to track the growth rate [5]. The buoy is used to periodical monitoring of coral farming using wireless acoustic communications. It is the most effective technique for monitoring coral growth between 500 to 1500 meter a distance [6]. The UWAN is suited for transferring data between nodes distributed to base station. Cooperative handshaking operations (RTS, CTS) between the sensor nodes to avoid data loss to maintain reliability. The energy usage and life of a battery are also some of the necessary consent for underwater application implementation. The energy usage of a node should be minimum to ensure the life of a node. The communication between the sensors nodes should be an energy-efficient one to increase the lifetime of a node [7]. In such situations, the cross layer MAC protocols play an essential role in making the control instructions to use the standard communication wireless channel and debug the disagreement among the sensor nodes [8]. The sections are ordered as follows. The related work is discussed in section II.The System Model and working of the SPCL-MAC are elaborated in Part III. In Section IV, The working principles of the SPCL-MAC protocol overview in underwater coral farming are discussed. SNC Model is derived in Section V. The performance analysis of the proposed model is elaborated in Section VI. The result analysis of the system model and SNC model is analyzed in Section VII. Equivalent innovations in underwater works are discussed in Section VIII. Finally, section IX concluded and stated the future work.

II. RELATED WORK

The MAC Layer components are categorized into three parts. (1) Operation cycle (2) Medium Access Unit and (3) MAC mechanism. The components are listed in the Figure 2. In addition, the work flow between the MAC Components is illustrated in the Figure 3. Sensor node executes the MAC mechanisms and runs medium access units based on time slots. Therefore, the number of MAU applicable for OC based on the MAC protocol design may vary based on the protocol design. The basic operation of mechanisms/schemes are classified based on the multiplexing and MAC Mechanisms summarized in Table 1.

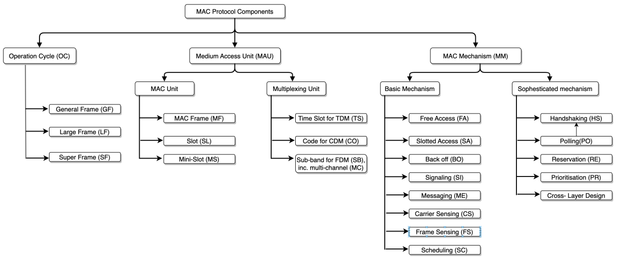


Figure 2. MAC Components

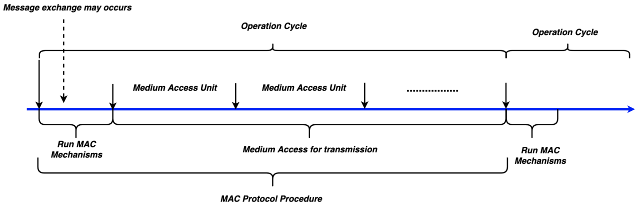


Figure 3. Executon of MAC protocol Components

The MAC layer protocol design in underwater using SNC is not developed completely. The primary goal of MAC protocol is allowing underwater nodes to access shared media effective and only if reception is effective. Conflict at the receivers is the most frequent cause of reception failures and how to prevent such conflict is the primary responsibility of each MAC protocol.

Table 1. Characteristics of MAC Mechanisms and Multiplexing schemes

Scheme	**Operation**	**Strength**	**Weakness**
Schemes based on multiplexing			
TDMA	It is Time Synchronized operation	Comparatively simple to understand and implement	Bandwidth wastage are high and Propagation delay is directly proportional to guard time
CDMA	Synchronization is widely utilized in pre-emptive multitasking setup	High bandwidth utilization and it performs simultaneous operation without collision. Communication security high in CDMA	Implementation difficulty is high, it is affected by neat-far effects
FDMA	Frequency used for sender receiver sync.		Bandwidth wastage is high. Frequent bottleneck issues occurs in MC
Multi Channel			

Table 2. MAC protocols comparison based on RWN-MAC Mechanisms

MAC Protocols	**Operation Cycle**	**MAU**	**MAC Mechanisms**												
			FA	SA	SI	CS	ME	FS	SC	BO	HS	PO	RE	PR	Sim/Ana
ALOHA	General Frame	MAC Frame	✓												Sim/Ana
S-ALOHA	General Frame	SLOT		✓											Sim/Ana
CSMA	General Frame	MAC Frame				✓									Sim/Ana
CSMA/CA	General Frame	MAC Frame				✓				✓					Sim/Ana
MACA	General Frame	MAC Frame	✓				✓	✓		✓					Sim/Ana
FAMA	General Frame	MAC Frame	✓			✓	✓	✓		✓					Sim/Ana
IEEE 802.11 DCF	General Frame	MAC Frame				✓	✓	✓		✓					Sim/Ana
IEEE 802.11 PCF	Super Frame	MAC Frame				✓	✓	✓		✓					Sim/Ana
IEEE 802.15.4	Super Frame	MAC Frame, SLOT				✓	✓	✓		✓					Sim/Ana
HyperLan	General Frame	MAC Frame			✓	✓	✓	✓		✓					Sim/Ana

Table 3. Comparative analysis of MAC protocols based on Model Availability

Protocols	**Mode**	**Year**	**DNC model Availability for WN**	**SNC Model Availability for WN**	**Deterministic Model Availability for UWCN**		**SNC Model Availability for UWCN**		**Layer**	**Topology**	**Sync**
					Ana	**Sim**	**Ana**	**Sim**			
OFDMA [9] [10]	FDMA	2009	Y	N	N	Y	N	N	MAC	centralized	Y
UW-OFDMAC [11]	FDMA	2011	Y	N	N	Y	N	N	MAC	distributed	Y
ACMENet [12]	TDMA	2006	Y	N	N	Y	N	N	MAC	centralized	Y
ST-MAC [13]	TDMA	2009	Y	N	N	Y	N	N	MAC	Multihob	Y
DSS [14]	TDMA	2011	Y	N	N	Y	N	N	MAC	centralized	Y
ERMAC [15]	TDMA	2008	Y	N	N	Y	N	N	MAC	centralized	Y
WA-TDMA [16]	TDMA	2009	Y	N	N	Y	N	N	MAC	Multihob	Y
UW-FLASHR [17]	TDMA	2008	Y	N	N	Y	N	N	MAC	distributed	Y
STUMP [18]	TDMA	2009	Y	N	N	Y	N	N	MAC	distributed	Y
CDMA - B [19]	CDMA	2009	Y	N	N	Y	N	N	MAC	Multihob	Y
POCA-CDMA [20]	CDMA	2011	Y	N	N	Y	N	N	MAC	Multihob	Y
S-ALOHA [21]	RA	2006	Y	N	N	Y	N	N	MAC	distributed	Y
ALOHA-CS(AN) [22]	RA	2007	Y	N	N	Y	N	N	MAC	distributed	N
UWAN-MAC [23]	RA	2007	Y	N	N	Y	N	N	MAC	distributed	Y
T-Lohi [24]	RA	2007	Y	N	N	Y	N	N	MAC	distributed	N
DACAP [25]	HS	2007	Y	N	N	Y	N	N	MAC	distributed	N
MACA-MN [26]	HS	2008	Y	N	N	Y	N	N	MAC	Multihob	N
RIPT [27]	HS	2008	Y	N	N	Y	N	N	MAC	Multihob	N
R-MAC [28]	HS	2007	Y	N	N	Y	N	N	MAC	Multihob	N
UMIMO [29]	HS	2011	Y	N	N	Y	N	N	MAC	Multihob	N
CUMAC [30]	HS	2012	Y	N	N	Y	N	N	MAC	Multihob	Y
HSR-MAC [31], [32]	HY	2010	Y	N	N	Y	N	N	MAC	Multihob	Y
H-MAC [33], [34]	HY	2007	Y	N	N	Y	N	N	MAC	Centralized	Y
P-MAC [35]	HY	2010	Y	N	N	Y	N	N	MAC	Centralized	Y
UW-MAC [36], [37]	HY	2007	Y	N	N	Y	N	N	MAC	distributed	Y
PLAN [38]	HY	2007	Y	N	N	Y	N	N	MAC	Multihop	N
U-TDMA [5]	HY	2022	Y	N	N	Y	N	Y	MAC	Centralized	Y
WN- Wireless Networks, UWCN - Underwater Wireless Communication Networks, DNC-Deterministic Network Calculus, SNC-Stochastic Network Calculus RA-Random Access, HS- Hand Shaking, HY-Hybrid, Y-Yes, N-No											

To avoid collisions efficiently, the receiver node must adopt a MAC decision then only it can understand whether the new communication is free from the collision at reception or not [39]. As a result, synchronization between transmitters and receivers is required to make MAC decisions by protocol overhead. It includes combinations of the basic mechanisms and cross-layered design. (a) Handshaking (HS): It combines messaging with frame sensing, and the recipient must respond to the sender. It enables nodes to communicate explicit data via a predetermined protocol. RTS/CTS is the common format used by MACA and FAMA. (b) Polling (PO): In addition to this, it adds messaging with frame sensing such that a central node may poll the intended nodes; however, only a node that has been polled can send data. It works well with a star topology and can provide quality service effectively. (c) Reservation (RE): The node has to send the RTS to the nearest nodes. It is receiver-centric MAC protocol activity. So the receiver node decides to continue the communication. With support for QoS, it can cut down on the complexity of message exchange and regular file transfer. (d) Prioritization (PR): It attempts to priorities nodes in media access control by configuring a longer jamming time or a shorter back-off time for nodes with a higher priority. (e) Cross-Layer Design: It attempts to increase MAC performance and minimize energy usage by utilizing functionalists and/or information accessible on the physical layer, and higher layers UWAN MAC systems commonly use physical-layer methods such as Multi-Input Multi-Out, Orthogonal Frequency Division Multiplexing (OFDM), and power control [40].

Many of the MAC Layer based applications have been undergone in the deterministic analysis. At the same time, the stochastic network calculus model has not yet been created for underwater MAC layer protocols activities except our U-TDMA [5]. The continuation with our previous model, we have extended our works to cross layer activities for data link layer. This section provides a quick examination of the underwater MAC protocols. We have compared the the RWN based derived MAC protocol suitability is compared in the Table 2. and due to some unique features of the underwater environment, the newly designed mac layer protocols needs the specific changes to minimize the energy utilization of the other nodes. The MAC Layer protocols are compared based on the mathematical model availability and listed in the Table 3. Thus we have conclude that the most of the MAC layer protocols have not implemented with Stochastic network calculus except U-TDMA [5]. The stochastic network calculus model available for the land based communication. Due to the peculiar features of the underwater the same protocol operation can be implemented directly. This paper concentrate on the development of SNC model continuation with our previous work [5] for SPCL-MAC for underwater environment and results have been compare with relevant features exiting protocol such as UWAN and HSR MAC for the correctness verification. Hence we have concluded that the SNC model is not completely developed for the all the layers in underwater environment. In this paper, We have concentrated on the cross layer activities with stochastic network calculus and compared with the existing models such as UWAN and HSR MAC Protocols. The abbreviations are listed in the Table 5.

III. SYSTEM MODEL FOR UNDERWATER WIRELESS COMMUNICATION IN CORAL FARMS

The main goal of this paper is to use SNC to formalize the scheduled process cross layer MAC Protocol (SPCL-MAC) for underwater coral farming applications to achieve the effective performances while considering the other vital metrics such as throughput and reliability. First, we considered the communication structure shown in Figure 4 for the underwater coral farming application. The deployment of nodes placed at every aqua cage. Every aqua cages have a minimum of one sensor node. The aqua cages located at the middle and bottom layer of the ocean. The sensor nodes are communicated by horizontal or cross-flow communication and linked as groups. The surface communication occurs through the Root Node, always deployed at the middle layer aqua cage. Due to the high energy consumption, the bottom layer sensor nodes do not consider the Root Node. Instead, one Root Node (RN) is selected from among the Linearly Deployed Nodes (LDN) in a given region, and one Conventional Gateway (CGW) is established between 2 groups. Furthermore, a buoy Node at the upper level called Surface-Station (SS) is responsible for receiving sound waves from the RN through the Vertical communication sensor Node (VCN), which translates the acoustic signal into a radio transmission. The LDNs are 50 meters apart from their RN (the maximum distance is 200 meters). The RNs are separated from respective VCNs by 500 meters (maximum). A 500-meter gap separates the surface station from VCNs. Therefore, communication can appear between the LDN and RN, RN and VCN, VCN and SS, and RN and CGW. Let's assume that the VCN is used to forward the data between the SS and RN.

The actual deployment underwater can vary based on the depth of the water level. More than one intermediate VCN can be deployed between SS and RN if the depth is high. Therefore, the LDNs energy utilization for sensing in the network is considered homogenous. Every node has buffer elements that follow the queue concept to process the incoming frames on FCFS. Therefore, data frames arrival in LDN is independent, and distribution has equal loads to all nearby nodes. Following the underlying MAC protocol rules, an LDN with a busy frame queue competes with nearby nodes to deliver frames to RN. The VCNs use a different media access technique to pass the gathered data frames to the SS, and it helps to monitor underwater coral farming.

The SPCL-MAC protocol is modeled to resolve the contention-based media access among the nodes by scheduled process cycle reservation. Therefore, the model is suitable for underwater coral farming monitoring applica-

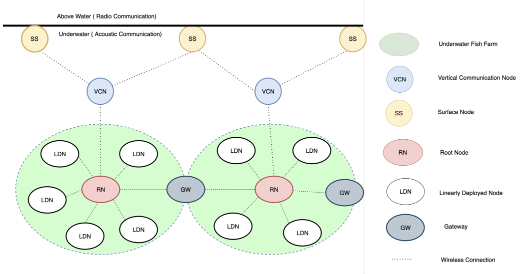


Figure 4. The overview and node setup of underwater coral farming

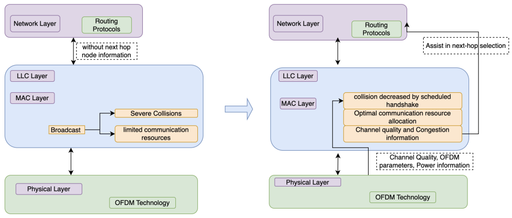


Figure 5. SPCL-MAC design model for the cross layer activities

tions.The illustration of the sensor nodes deployment structure is shown in the Figure 4. The proposed SPCL-MAC activities concerning the activities of physical and network layer activities have illustrated in the Figure 5. It determines the distribution sequence and prepares a shared transmission plan using request frames from possible sources. Different applications required distinct operations for the MAC layer activity. This research paper is shown the MAC layer protocol design for submerged coral farming monitoring applications. The monitoring requires a finite number of nodes, a process cycle for duty operation to manage and organize the network activity. These are standard requirements to model make maximum frame delivery, less end to end delay and energy-efficient underwater coral farming applications. The following assumption is incorporated in the protocol design and simulation works. (a) The sensor nodes are deployed in the coral farms and also it is assumes as immovable. (b) RN selection is taken care of by the centralized Low-Energy Adaptive Clustering Hierarchy procedure from the group of nodes. (c) Every RN and LDN node communicates using the half-duplex mode to save energy consumption. (d) Every node has a liberated rate of frame arrival and delivery ratio. (e) Buffer queue elements of the node follow the FIFO basis. (f) The process cycle is fixed in size. (g) All nodes follow synchronous communication mode and allow one data frame for one process cycle.

IV. SCHEDULED PROCESS CROSS LAYER MAC PROTOCOL OVERVIEW FOR UNDERWATER CORAL FARMING

The SPCL-MAC is a scheduled process and collision-free MAC protocol. The process cycle is reserved for a particular node that can perform the operations in the scheduling phase. The LDN nodes are organized into groups, and the MAC protocols manage the access of the nodes within the group by the shared communication medium. The basic idea in this model is that the RN obtains the desire for communication from all ready state devices. First, the RN arranged the successful reception of RTS requested nodes identification number on a transmission schedule FCFS basis. Then, the RN broadcasts the transmission schedule to all nodes in groups. The intended node waits until its schedule. Finally, the idle node notes the communication channel's busy period by reading the transmission schedule. When the transmitter node sends the frames to RN during its slot, the remaining nodes go to sleep until it comes. The node is being an active state during its scheduled transmission time. Once the ACK is received for current transmission, then the node sleeps.

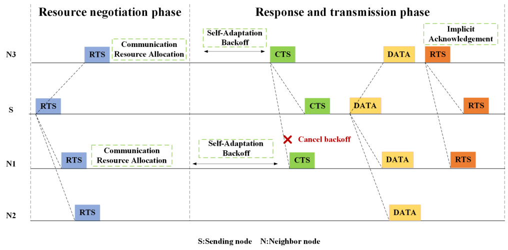


Figure 6. The Handshaking operation and communication between the nodes for SPCL-MAC

The SPCL-MAC protocol proposes the scheduling of frame slots for the contented nodes and reserves the channel for the communication. It avoids the unwanted waiting and collision of frames during the transmission. The transmission is organized in a fixed process cycle, and arrangement has been made for the next cycle. The initialization occurs at the beginning state. Repeated initialization does not happen during the other process to avoid energy consumption. It consists of three sub-stages to complete the initialization process. (a) The node deployment in underwater coral farming (b) Localization identification. (c) Root node selection among the group of nodes within the region. The sensor node's life is significantly less, so more than one node deployment helps us monitor the coral without trouble. One sensor node is getting active until the energy is lost. Once the node is dead, the next node gets active for further communication by sharing the beacon frame. There are many localization algorithms available in various surveys [32] [34]. For example, the hierarchical localization technique [41] is suitable for the underwater coral farming application, shown in Figure 4. In this application, the nodes are deployed inside the coral farming cages. So the movement of the sensor node is comparatively less than the random deployment.

In resource negotiation phase, the sender node issues a transmission request, and potential next-hop assign appropriate communication resource. In response and transmission phase, next-hop candidates reply allocation scheme based on self-adaption back off mechanism. the process is shown in the Figure 6. Then the sender transmits a data packet based on allocation decision, and next-hop adopts an implicit acknowledgment method to respond the sender. OFDM allows multi-user access to improve performance of UANs. Selecting appropriate parameters by OFDM based MAC protocols is paramount importance [3], [42]. In this paper,following parameters are considered in SPCL-MAC,

$$\left.\begin{aligned} P_b = \frac{\sqrt{M}-1}{\sqrt{M}\log_2\sqrt{M}}\operatorname{erf} c\left(\sqrt{\frac{3\mathrm{SNR}\log_2 M}{2(M-1)}}\right) \\ +\frac{\sqrt{M}-2}{\sqrt{M}\log_2\sqrt{M}}\operatorname{erf} c\left(\sqrt{\frac{3\mathrm{SNR}\log_2 M}{2(M-1)}}\right) \end{aligned}\right\} \tag{1}$$

Let $M = 2,4,8,16,64 etc.$, and $\operatorname{erfc} c(\cdot)$ is the complementary error function denoted as follows:

$$\operatorname{erfc}(\mu) = \frac{2}{\pi}\int_{\mu}^{\infty} e^{-t^2}\,\mathrm{d}t. \tag{2}$$

For a given SNR, BER becomes larger as the increase of M value. However, larger M can improve transmission rate for a modem. Subcarrier spacing: If bandwidth B and subcarrier spacing Δf of a channel is given, number of subcarriers N can be calculated as follows:

$$N = \frac{B}{\Delta f}. \tag{3}$$

In OFDM based system, transmission rate gets higher with more subcarriers. Nevertheless, to guarantee orthogonality between subcarriers, Δf is required to be larger than Doppler Shift caused by relative movement between sender and receiver. Otherwise, Inter-Carrier Interference (ICI) will occur and lead to performance degradation. Acoustic signal propagation information can be obtained with these models by solving wave equation. For simple harmonic process, wave equation can be denoted as follows:

$$\nabla^2\psi - k_0^2 n^2\psi = 0. \tag{4}$$

Let n is refractive index, k is wave number of sound source denoted as w/c_0. Specifically, c_0 is corresponding sound speed and ω is angular rate. ∇ is Laplacian which can be presented as follows:

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}.$$

Solution of wave equation can be calculated as follows:

$$\psi(x,y,z) = A\left(x, y_1 z\right) e^{ik_0 P(x,y,x)}, \tag{5}$$

Amplitude function denoted as $A(x,y,z)$, and $P(x,y,z)$ is phase function. Then we substitute 5 into 4, and separate real and imaginary parts as follows:

$$\begin{gathered} (\nabla P)^2 - \frac{\nabla^2 A}{Ak_0^2} - n^2 = 0, \\ \nabla^2 P + \frac{2(\nabla P\nabla A)}{A} = 0. \end{gathered} \tag{6}$$

For high frequency sound source, there is $\frac{\nabla^2 A}{Ak_0^2} \& n^2$, and (4) can be simplified as follows:

$$(\nabla P)^2 = n^2, \tag{7}$$

The intensity equation (5) is used to determine sound intensity.

We can also obtain the Signal to Noise Ratio (SNR) can be derived as follows:

$$\mathrm{SNR} = 10\lg\frac{P_{\mathrm{x}}}{\mathrm{N}(f)} - TL, \tag{8}$$

Power P_n is used for transmit the frame, $N(f)$ is ambient noise, and f is transmitting frequency. As for ambient noise, we design wave noise N_t, ship noise N_s, wind noise N_w, and thermal noise $N_t h[34]$ as follows:

$$\left\{\begin{array}{l} 10\lg N_t(f) = 17 - 30\lg_g f \\ 10\lg N_s(f) = 40 + 20(5-0.5) + 26\lg g - 60^0(f+0.03) \\ 10\lg N_s(f) = 50 + 7.5w^{0.5} + 20\lg f - 40\lg(f+0.4) \\ 10\lg N_{tk}(f) = -15 + 20N_g f \end{array}\right. \tag{9}$$

Service s is shipping activity factor, and w is wind speed. Then the total ambient noise can be calculated as follows:

$$N(f) = N_t(f) + N_s(f) + N_{\mathrm{s}}(f) + N_{\mathrm{th}}(f). \tag{10}$$

In our observation scenario, nodes will carry various sensors which can provide marine environment information. Taking advantage of this information resource, channel quality can be predicted with our propagation model [43].

V. STOCHASTIC NETWORK CALCULUS MODEL FOR SPCL-MAC

For analytical purposes, the following assumption has been considered.(a) One process cycle is allotted for one process at a time. (b) Each node has its independence to receive the frame. (c) All nodes have a finite FIFO queue Each process has a finite execution state based on the buffered data at the queue, such as ready, active, and sleep. C can be the capacity of the queue of each node. State numbering starts from 0 to C. zero symbolizes the unfilled queue, and C symbolizes the entire queue memory is full.

A. THE ARRIVAL OF FRAMES AT NODE

The data link layer deals with frames that arrived [44] at the node M lies (t) and T denoted as $D_f(\mathrm{t},T)$, the service of the $S_f(\mathrm{t},T)$, and frame departure is expressed as $D_f(\mathrm{t},T)$also a bi-variate stochastic process. The frame departure of M completely depends on the input and outgoing frames of the system (M). $A_f(T)$ is arrival of the frames at interval $(0,T)\cdot A_f(T)$ can be denoted as $A_f(0)=0$ and occurs in the non-negative time. $A_f(\mathrm{t},T)=A_f(T)-A_f(\mathrm{t})$ denotes the time interval in arrival between $\mathrm{t}+1$ and T from Eqn.11

$$D_f(T) \geq \min_{\in[0,T]} \{A_f(\mathrm{t}) + S_f(\mathrm{t},T)\} =: A_f \otimes S_f(T). \tag{11}$$

The $S_f(,T)$ is the service [45] of node M_s within the time interval between T >= t >= 0. The service occurs between the time interval $[t+\ 1,T]$ such that,

$$D_f(T) = D_f(\mathrm{t}) + S_f(\mathrm{t},T). \tag{12}$$

Let, $\mathrm{t}=\mathrm{t}'$ is the active state before T. Then the frame departure of the node is denoted as,

$$D_f(T) = A_f\left(\mathrm{t}'\right) + S_f\left(\mathrm{t}',T\right). \tag{13}$$

Since t' is unknown, we can use the common departure state of a machine,

$$D_f(T) \geq \min_{\mathrm{t}\in[0,T]} \{A_f(\mathrm{t}) + S_f(,T)\} \tag{14}$$

Consider the two dynamic nodes $M_1\left(\mathrm{t}',T\right)$, $M_2\left(\mathrm{t}',T\right)$, then the arrival of the frames at the node M_2 is equal to the Departure of the M_1. The Associativity of the nodes are,

$$\begin{aligned} D_{M2}(T) \quad &\geq \left(A_{M1}\otimes S_{M1}\right)\otimes S_{M2}(T). \\ &= A_{M1}\otimes\left(S_{M1}\otimes S_{M2}\right)(T). \end{aligned} \tag{15}$$

The main outcome of the stochastic node are

$$S_M(\mathrm{t},T) = S_{M1}\otimes S_{M2}(\mathrm{t},T)$$

$$S_{M1}\otimes S_{M2}(\mathrm{t},T) := \min_{v\in[\mathrm{t},T]} \{S_{M1}(\mathrm{t},v) + S_{M2}(v,T)\} \tag{16}$$

$$S_{M_{net}}(\mathrm{t},T) = S_{M1}\otimes S_{M2}\otimes\ldots\otimes S_{Mn}(\mathrm{t},T). \tag{17}$$

let, $S_{M\_i}(\mathrm{t},T)$ the time interval is T >= t >= 0. For better understanding purposes, the hereafter nodes refer from i to j. The probability of arrival A_i of frames from the node, i to j denoted as P_{ij}. The empty queue turned to a nonempty queue after A_i. If the queue is full, then the arrival of frames drops automatically. The dropped frames are retransmitted during the next transmission cycle. t is negligible for queue-level processing.

The queue turned from empty to non-empty state i then the transition probability is denoted as

$$P_{0,i}(T) = A_i(T); \quad i \leq C-1, \quad 0 \leq T \leq T_{ls}. \tag{18}$$

The conversion from an unfilled memory state to busy state C then the probability is denoted as

$$P_{0,C}(T) = A_{i\leq C}(T); 0 \leq T \leq T_{ls}. \tag{19}$$

The probability (q) of the node wins the contention to transmit the frames i to i-1 is denoted as

$$P_{(i,i-1)}(T) = qA_0(T); 0 \leq T \leq T_{ls}. \tag{20}$$

In transmission, i=1,2,3, ...,C. and i to $i-1$ represents that only one transmission cycle remains for transmission. The probability of the node wins the contention, but there are no frames available to transmit denoted as

$$P_{(i,j)}(T) = 0. \tag{21}$$

$j \leq i-2; \quad i = 1,2,3,\ldots,C \quad ;0 \leq T \leq T_{ls}$. The transition cycle is expired for the current transmission; then, the frames are queued for the next transmission cycle denoted in the Eqn.21.

$$P_{(i,j)}(T) = qA_{j-i+1}(T) + (1-q)A_{j-i}(T). \tag{22}$$

consider i=0,1,2,3, ..., c-1, j=i, ..., c-1. If the oldest frame does not win the contention, then it is denoted as

$$P_{(i,C)}(T) = qA_{c-i+1}(T) + (1-q)A_{C-i}(T). \tag{23}$$

B. CONTENTION OF CHANNEL ALLOCATION POSSIBILITY OF NODE

The possibility of winning contention (P) by m nodes is denoted as P_{wsm}. In the group of networks, there is m number of nodes competing for the contention windows (WS). So m should be less than $(n-1)$. The m nodes winning the contention window for duty cycle reservation are denoted as

$$P_{wsm} = \sum_{i=1}^{ws} i * \frac{1}{ws} * \left(\frac{ws-i+1}{ws}\right)^m. \tag{24}$$

m=0,1, ł. If the window is not allocated to a node. There is a time is called back-off window time (T_{bwd}). It is required for energy consumption.

$$T_{bwd} = \frac{1}{P_{wsm}} \cdot \sum_{i=1}^{ws} i * W * (S)^m. \tag{25}$$

let, W $= \frac{1}{ws}$, S $= \frac{(ws)-i+1}{(ws)}$, m $= 0,1,\ldots,$n $-$ 1. M nodes competing to win the medium (P_{cm}) and the exclusive fixed delivery $(\boldsymbol{U})$ is given by

$$P_{cm}(\boldsymbol{U}) = \left(\begin{array}{c} \boldsymbol{n-1} \\ \boldsymbol{m} \end{array}\right) (\mathbf{1}-\boldsymbol{U}_.)^{\boldsymbol{m}} \boldsymbol{K}^{(\boldsymbol{n-1-m})} \tag{26}$$

m =0,1, ..., n-1; K $= \boldsymbol{U} = \mathbf{\Pi_0}$. $(\boldsymbol{\pi} = \boldsymbol{\pi}_0, \boldsymbol{\pi}_1, \ldots\ldots \boldsymbol{\pi}_{\boldsymbol{i}})$. The distribution function is written as

$$P_{cm}\left(\boldsymbol{\pi}_0\right) = \frac{\boldsymbol{exp}^{(-\lambda T)}(\lambda\boldsymbol{T})^m}{m!}. \tag{27}$$

$\mathrm{m} = 0, 1, \ldots, \mathrm{n}-1$; $\lambda =$ arrival rate, the information proportion is directly relative to λ. Each node winning contention (q) is calculated by

$$q = \sum_{m=0}^{n-1} P_{cm}\left(\boldsymbol{\pi}_0\right) \cdot P_{wsm}(T). \tag{28}$$

Sub Eqn. 24 and Eqn. 26 in Eqn. 28 then we get,

$$q = \begin{pmatrix} n-1 \\ m \end{pmatrix} (\mathbf{1}-\boldsymbol{\pi}_0)^m \boldsymbol{K}^{(n-1-m)} . \sum_{i=1}^{ws} \frac{1}{ws}\left(\frac{ws-i+1}{ws}\right)^m \tag{29}$$

Again substitute Eqn. 26 in Eqn. 29

$$q = \frac{\exp^{(-\lambda T)}(\lambda T)^m}{m!} \cdot \sum_{i=1}^{ws} i * \frac{1}{ws} * \left(\frac{ws-i+1}{ws}\right)^m \tag{30}$$

The contention winning probability can be derived as q_w and q_f is failed to transmit the data. Total probability $q = q_w + q_f$. the winning and failure ratio occurs frequently, then the total probability is

$$q_w + q_f = 1, \tag{31}$$

$$q_w = 1 - q_f, \tag{32}$$

$$q_f = 1 - q_w, \tag{33}$$

1) Success probability for transmission

Let m nodes are available, then the success probability q_{sm} is calculated by

$$q_{sm} = \sum_{i=1}^{ws} \frac{1}{ws}\left(\frac{ws-i+1}{ws}\right)^m . \tag{34}$$

Back-off window contention winning time can be derived as T_{bwds}

$$T_{bwds} = \frac{1}{q_{sm}} \cdot \sum_{i=1}^{ws} i * W * (S)^m . \tag{35}$$

Success probability (q_s) defined as

$$q_s = \sum_{i=1}^{n-1} P_{cm}\left(\boldsymbol{\pi}_0\right) * q_{sm}. \tag{36}$$

Sub Eqn. 27, Eqn. 34 in Eqn. 36 and we get

$$q_s = \frac{\exp^{(-\lambda T)}(\lambda T)^m}{m!} \sum_{i=1}^{n-1} \sum_{i=1}^{ws} \frac{1}{ws}\left(\frac{ws-i+1}{ws}\right)^m \tag{37}$$

2) Probability for the failure of transmission

The probability of failure (P_{fl}) occurrences of the m nodes out of $\mathrm{n}-1$ modes. It is denoted by (P_{flm})

$$(P_{flm}) = \sum_{i=1}^{ws} \frac{1}{ws} * \left(\frac{(ws-i+1)-(ws-i)}{ws}\right)^m \tag{38}$$

The winner of the contention including the failure can be calculated by,

$$P_{wsm}(T) = P_{ck} + P_{flm} \tag{39}$$

$$P_{flm} = P_{wsm}(T) - P_{ck} \tag{40}$$

i.e.,

$$P_{flm} = \frac{1}{ws} \tag{41}$$

The back-off waiting time concerning window size of the processing node and experiences the collision data loss. It is denoted as (T_{cbw}). and derived from Eqn. 38

$$T_{cbw} = \frac{1}{P_{flm}} \sum_{i=1}^{ws} i * W * (R)^m \tag{42}$$

$\mathrm{R} = \frac{(ws-i+1)-(ws-i)}{ws}$

$$T_{cbw} = \sum_{i=1}^{ws} i * (R)^m \tag{43}$$

The probability of frame failure can be derived as (P_{ff})

$$P_{ff} = \sum_{m=1}^{n-1} P_{cm}\left(\boldsymbol{\pi}_0\right) * P_{flm} \tag{44}$$

Sub Eqn(15) and Eqn(28) in Eqn.(31) then

$$P_{ff} = \sum_{m=1}^{n-1} \cdot \begin{pmatrix} n-1 \\ m \end{pmatrix} (1-\boldsymbol{\pi}_0)^m \boldsymbol{K}^{(n-1-m)} * \frac{1}{ws} \tag{45}$$

Sub Eqn(16) in Eqn (32) then

$$P_{ff} = \frac{1}{ws} * \frac{\boldsymbol{exp}^{(-\lambda T)}(\lambda T)^m}{m!} \tag{46}$$

From Eqn. 46, frame failure probability can be derived.

C. ENERGY UTILIZATION FOR TRANSMISSION AND RECEPTION

The energy-related performance metrics are energy consumption data-carrying capacity concerning throughput, reliability, and delivery probability. Energy ingestion is calculated by the overall energy utilized by different node states over the simulation time [41]. The distinguished situations are (transmission, reception, idle, sleep, waiting, and ready). Let $E_{tfd} =$ transmission of frames, $E_{rfd} =$ Receivable of frame, $T_{\text{frame}} =$ transmission Time of data frame.

Every node plays different roles, such as successful dispatcher, successful recipient, unsuccessful recipient, and not involvement nodes in transmission. The energy consumption of every node is calculated concerning the role/states. The probability of different roles are,

- Successful Transmitter

$$P_{TS} = (\mathbf{1} - \boldsymbol{\pi}_0)\, P_S,$$

- Successful Receiver

$$P_{RS} = (\mathbf{1} - \boldsymbol{\pi}_0)\, P_S,$$

- Unsuccessful Transmitter

$$P_{TU} = (\mathbf{1} - \boldsymbol{\pi}_0)\, P_f,$$

- Unsuccessful Receiver

$$P_{RU} = (\mathbf{1} - \boldsymbol{\pi}_0)\, P_f,$$

- Not involved nodes

$$P_{\text{nin}} = (\mathbf{1} - \mathbf{2}\,(\mathbf{1} - \boldsymbol{\pi}_\mathbf{0})\,(P_f + P_s)$$

The energy utilization of nodes in different states can be calculated. For Successful Transmitter, the energy utilization is defined as

$$\left.\begin{aligned} E_{fts} &= E_{txf}\,(T_\gamma + T_\partial) \\ &\quad + E_{rxf}\,(T_\delta + T_\alpha + 4T_{Prob} + T_{BWDS}) \end{aligned}\right\} \quad (47)$$

For Successful Receiver, energy utilization is defined as

$$\left.\begin{aligned} E_{frs} &= E_{rxf}\,(T_\gamma + T_\partial + 3T_{Prob} + T_{BWDS}) \\ &\quad + E_{rxf}\,(T_\delta + T_\partial) \end{aligned}\right\} \quad (48)$$

For an unsuccessful Transmitter, energy utilization is defined as

$$E_{ftu} = E_{txf}\,(T_\gamma) + E_{txf}\,(T_\delta + 2T_{prop} + T_{BWDS}) \quad (49)$$

For not-involved node transmitter E_μ and frame E_φ, the energy utilization is defined as

$$E_\varphi + E_\mu = E_{rxf}\,(T_\gamma + T_{BWDS}) \quad (50)$$

Energy consumption in data transmission is defined as

$$\left.\begin{aligned} E_{dataframe} &= (P_{TS} * E_{fts}) + (P_{RS} * E_{frs}) \\ &\quad + (P_{TU} * E_{ftu}) + (P_{RU} * E_{fru}) \\ &\quad + (P_\varphi + P_\mu) * (E_\varphi + E_\mu) \end{aligned}\right\} \quad (51)$$

Sleep state energy consumption can be written as

$$\left.\begin{aligned} E_{sleep} &= (P_{TS} * E_{sfts}) + (P_{RS} * E_{sfrs}) \\ &\quad + (P_{TU} * E_{sftu}) + (P_{RU} * E_{sfru}) \\ &\quad + (P_\varphi + P_\mu) * (E_\varphi + E_\mu) \end{aligned}\right\} \quad (52)$$

Nonsleep node energy consumption is defined as

$$\left.\begin{aligned} E_{non-sleep} &= (P_{TS} * E_\zeta) + (P_{RS} * E_\vartheta) \\ &\quad + (P_{TU} * E_\psi) + (P_{RU} * E_\xi) \\ &\quad + (P_\varphi + P_\mu) * (E_\varphi + E_\mu) \end{aligned}\right\} \quad (53)$$

The energy consumption during RTS scheldule transmission and reception energy consumption can be written as

$$\left.\begin{aligned} E_f &= \tfrac{(E_{trf} * T_{\delta 2} + E_{rxf}(T_{\delta 1} - T_{\delta 2}))}{n_\delta} \\ &\quad + \tfrac{(E_{txf} * T_{\delta 1}(n_\delta - 1))}{n_\delta} \end{aligned}\right\} \quad (54)$$

Energy spent on normal operation, RTS, transmission schedule, frame collision is defined as

$$E_{nor} = E_\delta + E_{dataframe} + E_{sleep} \quad (55)$$

The energy depletion in the active stage is defined as

$$E_{active} = E_f + E_{dataframe} + E_{nonsleep} \quad (56)$$

The overall energy utilization can be deliberate as

$$E_{total} = E_{nor} * N_\delta\,(n_{active} - 1) + (E_{active} * N_f) \quad (57)$$

The average rate of the power utilization in the active state can be noted as

$$E_{avg} = \frac{E_{nor*} N_\delta\,(n_{active} - 1) + (E_{active} + N_f)}{N_\delta + n_{active}} \quad (58)$$

A node throughput of effectively distributed within specified time. The throughput is expressed as,

$$\mp = \frac{\sum \text{ Transferred frames } \times \text{ Size of the Frame}}{\text{Time}} \quad (59)$$

$$\mp = \frac{N\,(1 - \pi_0)\, p_s D_s}{T} \quad (60)$$

The Frame Delivery Ratio (FDR) is calculated from the difference between the number of frames received and frames transmitted. The FDR expressed as

$$FDR = \frac{\sum \text{ frames received}}{\sum \text{ frames transmitted}} \quad (61)$$

$$FDR = \frac{(1 - \pi_0)\, p_S}{\lambda t T} \quad (62)$$

Consider this scenario λ is arrival proportion ;p_s is the possibility of every node can effectively transmitting a frame, T is the duration, and $(1 - \pi 0)$ is the possibility of each device having a frame.

VI. SYSTEM MODEL VALIDATION AND SPCL-MAC MODEL OUTCOMES ANALYSIS

This section covers the simulation results, preceded by Riverbed discrete event simulation [46] metrics of the SPCL-MAC in assessing and validating the mathematical framework. The research mainly focuses on the frame delivery ratio, delay [47], and energy conception. The performance measures aim to determine the power consumption in terms of data rates, assuming that all interactions are performed on linear topology. The sensor nodes perform both procedural transitions between the sleep and active phases where the mathematical model performance metrics are compared with the discrete event simulation for correctness.

Simulation experiments apply a linear topology configuration to validate the proposed stochastic model. The sensor nodes deployed for the coral farming application simulation, each node having a specific communication and data rate. The LDNs and RNs have a maximum transmission distance of 100 to 200 meters. The VCN node is distinguished from the other nodes 500 to 600 meters range. The LDN's are 150 to 200 meters separately from their root nodes. Each root node is 100 to 150 meters apart from the others. The number of hop lengths is fixed, and the transmission rate varies. Simulation purpose the nodes are set up with omnidirectional, and half-duplex communication is allowed to save energy consumption. The data traffic is equally distributed to all nodes. The node setup parameters are listed in Table 1. and the simulation setup is shown in the Figure 8. The node deployment is illustrated in the Figure 7. The performances are compared with UWAN-MAC protocol and Hybrid HSR MAC protocol for verification purposes. These protocols have chosen based on the characteristics of underwater performances and related to this application.

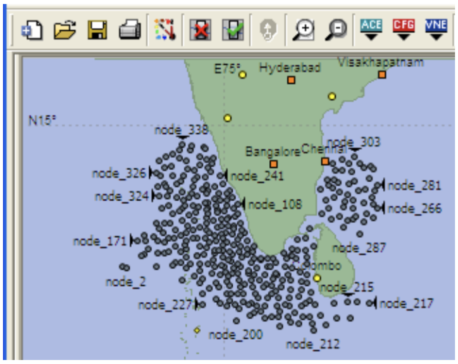
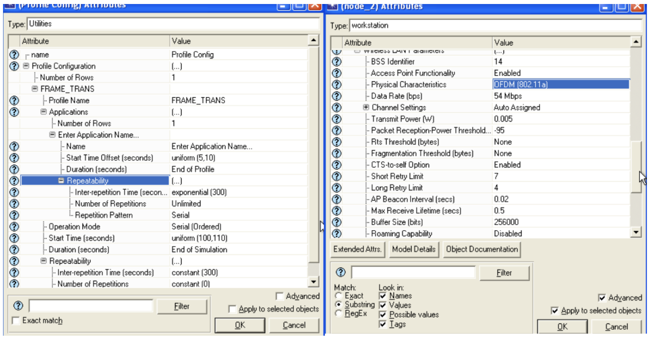


Figure 7. overview of underwater node deployment



(Profile Config) Attributes

Type: Utilities

Attribute	Value
name	Profile Config
Profile Configuration	(...)
Number of Rows	1
FRAME_TRANS	
Profile Name	FRAME_TRANS
Applications	(...)
Number of Rows	1
Enter Application Name...	
Name	Enter Application Name...
Start Time Offset (seconds)	uniform (5,10)
Duration (seconds)	End of Profile
Repeatability	(...)
Inter-repetition Time (secon...	exponential (300)
Number of Repetitions	Unlimited
Repetition Pattern	Serial
Operation Mode	Serial (Ordered)
Start Time (seconds)	uniform (100,110)
Duration (seconds)	End of Simulation
Repeatability	(...)
Inter-repetition Time (seconds)	constant (300)
Number of Repetitions	constant (0)

☐ Advanced
☐ Apply to selected objects
☐ Exact match

(node_2) Attributes

Type: workstation

Attribute	Value
BSS Identifier	14
Access Point Functionality	Enabled
Physical Characteristics	OFDM (802.11a)
Data Rate (bps)	54 Mbps
Channel Settings	Auto Assigned
Transmit Power (W)	0.005
Packet Reception-Power Threshold...	-95
Rts Threshold (bytes)	None
Fragmentation Threshold (bytes)	None
CTS-to-self Option	Enabled
Short Retry Limit	7
Long Retry Limit	4
AP Beacon Interval (secs)	0.02
Max Receive Lifetime (secs)	0.5
Buffer Size (bits)	256000
Roaming Capability	Disabled

Match: ○ Exact ● Substring ○ RegEx
Look in: ☑ Names ☑ Values ☑ Possible values ☑ Tags
☑ Advanced
☑ Apply to selected objects

Figure 8. The node setup parameters for communication nodes

The frame distribution relation calculated for linear topology. The simulation and SNC model outcomes of frame delivery ratio are plotted in Figure 9. It's worth noting that the frame delivery ratio is high when the number of nodes less numbers with less hop communication. The frame delivery ratio is reduced due to the incremental level of hop communication between the nodes when the number of nodes is raises. Compared to the UWAN-MAC and hybrid HSR-MAC protocol, the SPCL-MAC's frame delivery ratio rises as well. Due to this, the data rate rises, the channel is engaged, and the access points forward all the incoming

Table 4. Node setup parameters

Parameters	Specifications
propagation model	Underwater acoustic
Number of nodes	350 Nos
Frame size (bytes/pec)	100
Type of transmission	Constant bit rate
Traffic rate (kbps)	0.5 to 1000
Simulation Time (in a sec)	1200
Distance (in a Meter)	1500
Frame transmission execution (in a sec)	0.25
Idle power (watt)	0.31
Forwarding energy (watt)	0.175
Reception energy (watt)	0.85
Distribution energy (watt)	2.5
Initialization energy (Joule)	10 to 100
Communication mode	Half duplex

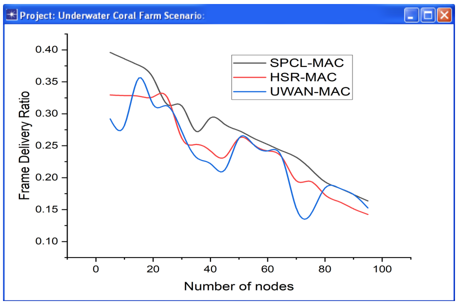


Figure 9. The Frame Delivery Ratio vs Number of Nodes

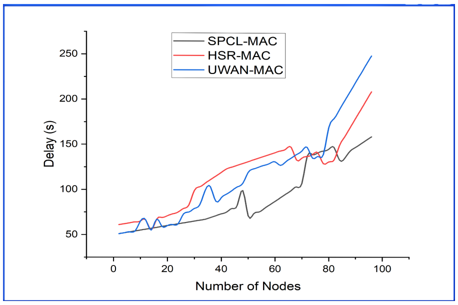


Figure 10. The Delay vs Number of Nodes

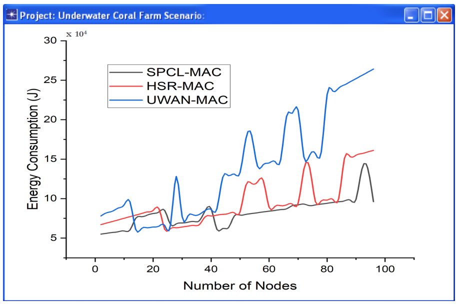


Figure 11. The Energy Consumption vs Number of Nodes

data transmission frequently. As a result, the node remains active for the duty cycle duration. It validates that the SPLC-MAC modeling of frame delivery ratio behaviors is valid. The SPCL-MAC's ability to deliver all incoming data traffic. The frame delivery ratio is inversely proportional to frame arrival (λ). The frame arrival rate directly influences the data rate. As a result, while the data rate is low, the frame delivery leftovers persistent as the data rate rises. The distance and natural factors affects the time that is referred as delay. The frame delay for transmission is increasing gradually when the number of nodes and hop communication increased. The delay of the SPCL-MAC, HSR-MAC and UWAN-MAC have showed in the Figure 10. Comparatively, the SPCL-MAC have less delay than HSR-MAC and UWAN-MAC protocol.

The transmission and reception energy consumption is a fundamental parameter for the MAC layer protocol design. Therefore, we measure the energy utilization concerning data rate in transmission, reception, active state, idle state, and sleep state. The simulation and stochastic model results concerning the total energy utilization in Eqn.[59]. The SNC based SPCL-MAC protocol total energy utilization are obtained and plotted as shown in Figure 11. It is noticeable that the SNC modeling outcomes of the SPCL-MAC protocol's energy usage are less than the HSR-MAC and UWAN-MAC. It's worth noting that when the number of nodes raises, the SNC based SPCL-MAC's energy usage rises as well and less in energy consumption compared to HSR-MAC and UWAN-MAC. The energy consumption rises when the access points engaged with the incoming data or transmission of frames frequently. As a result, the node remains active for the duty cycle duration, consuming more energy in the active phase.

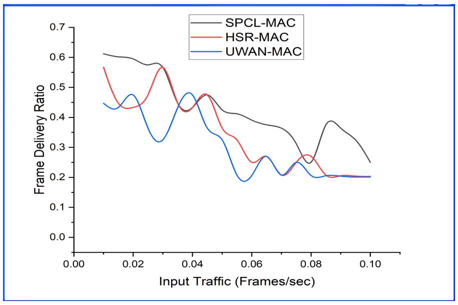


Figure 12. The Frame Delivery Ratio vs Input Traffic

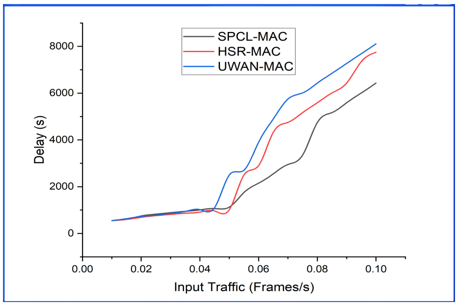


Figure 13. The Delay vs Input Traffic

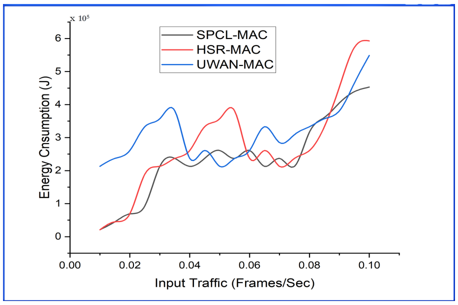


Figure 14. The Energy Consumption vs Input Traffic

The frame delivery ratio of the SNC based SPCL-MAC are plotted with respect to Input Traffic and compared with the HSR-MAC, UWAN-MAC. The results are plotted in the Figure 12. The frame delivery ratio of SNC based SPCL-MAC is considerably deliver more frames compared with HSR-MAC and UWAN-MAC. All the nodes sent the data in the reserved schedule so that other nodes won't transmit the data during that time. The transmission occurs without collision to process in the scheduled time, and data transmission without collision raises performance as well. It may be inferred that when the incremental ratio of the transmission, the overall work done of both procedures rises as well and eventually stabilizes after some time. The frame delivery between the nodes encounters the delay while delivering the frames due to the incremental size in input traffic. The end to end delay variations of the SNC based SPCL-MAC, HSR-MAC, UWAN-MAC is compared with respect to the Input Traffic. The results of the delay variations with respect to the frame size is plotted in the Figure 13. The delay variations of SNC based SPCL-MAC is considerably less compared with HSR-MAC and UWAN-MAC. The delay of SNC based SPCL-MAC coincide with HSR-MAC and UWAN-MAC in certain places and comparatively the SPCL-MAC is lower than the HSR-MAC and UWAN-MAC.

The energy consumption parameters are fixed for validation, as mentioned in Table 1. we could observe that the SNC based SPCL-MAC uses less energy than UWAN-MAC. The proposed SPCL-MAC protocol spent less energy on synchronizing nodes and prepared the reserved scheduling for other nodes regarding the RN. The energy consumption (derived in Eqn. 59.) the idle, transmission, and reception state concerning the input traffic is plotted in Figure 14. Compared with the UWAN-MAC protocol, the usage of the proposed protocol used less energy in the lazy state, transceiver state. The collision-free transactions reduce the energy consumption for SPCL-MAC than HSR-MAC and UWAN-MAC. The inference of this part is that SPCL-MAC utilizes less energy and also coincide in certain places of HSR-MAC and UWAN-MAC shown in the Figure 14.

The frame delivery ratio concerning with frame size is plotted in the Figure 15. It is worth to noted that the

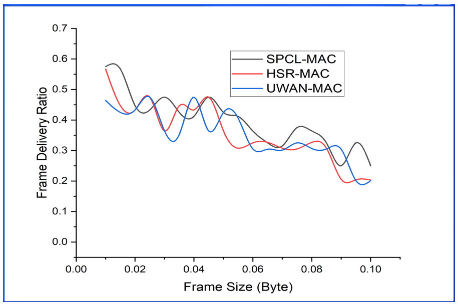


Figure 15. The Frame Delivery Ratio vs Frame Size

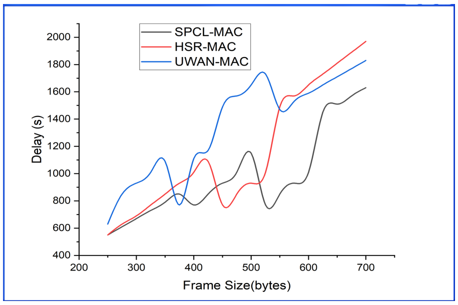


Figure 16. The Delay vs Frame Size

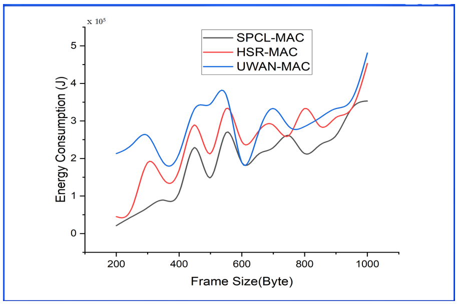


Figure 17. The Energy Consumption vs Frame Size

SNC based SPCL-MAC protocol coincide with HSR-MAC and UWAN-MAN but considerably better than the other two protocols. The data rate is significant for underwater wireless acoustic communication. Therefore, the comparison of delay and energy consumption with respect to frame size is affected by the hops and natural factors in an underwater environment. Delay with respect to frame size have been compared in the Figure 16. The end to end delay variation have the significant difference between the SNC based SPCL, HSR, UWAN-MAC Protocol.

The energy consumption with respect to the frame size is plotted in the Figure 17. The energy utilization is decreased in SPCL-MAC and the hop communication occurs between LDN and SS through the RN and VCN. Hence the SPCL-MAC protocol performance is better than HSR-MAC and UWAN-MAC in underwater environments for coral farm construction. End-to-end delay is increased when the hop count is increased, the comparative analysis shows that the end-to-end delay is less in the SPCL-MAC protocol than the UWAN-MAC protocol. The node's energy-saving purpose should have less than a 5 hop count for the long life of the node and the accuracy of the communication. The abbreviations with its expansions are have listed in the Table 5.

VII. CONCLUSION

In this paper, a scheduling based cross layer model was developed for underwater coral farming application. The proposed SPCL-MAC protocol design includes frame delivery ratio, end to end delay, energy utilization, frame size, and the input ratio. Furthermore, the SPCL-MAC protocol prepares the communication schedule based on the RTS frame received from various nodes. Based on the schedule, the channel is reserved for the particular node for Time T. It reduces the handshaking operation for every data transmission. Due to the minimal activity in the handshaking, the energy consumption is reduced for every node.The SPCL MAC shared the information to upper layer for routing purpose and lower layer for OFDM activities. The next hob routing information shared to the next transmission to avoid the collision occurrences. The performances were analyzed using stochastic network calculus and discrete event simulation for its accuracy. As a result, the SPCL-MAC model performs better in energy utilization, less end to end delay, and frame delivery ratio without collision. In future, we will concentrate on network Layer routing actives with Stochastic Network Calculus Design.

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Table 5. Notations and abbreviations used in the derivations

Abbreviation	Meaning
E_{avg}	Average energy utilization
D_f	The departure of the frame at node
S_f	Service of a frame at node
A_f	The arrival of frame at node
t'	Busy time before current time T
$P_{0,i}$	Probability of queue turned from empty to nonempty
$P_{0,c}$	Probability of queue turned from empty to state C
$P_{i,i-1}$	Probability of contention to transmit the frame i to i-1
$P_{i,j}$	Probability of no frames available to transmit
$P_{i,c}$	The probability of the frame with contention
P_{wsm}	Contention window for m-nodes
T_{bwd}	Back off window time
P_{cm}	Competing to win the medium
π_0	Stationary distribution
λ	Arrival rate at the distribution q Wining contention
q_w	Contention winning probability
q_f	Contention failure probability
q_{sm}	The success probability of node m
T_{bwds}	Back off window extension for the success node
q_s	Success probability
P_{fl}	Probability of failure
P_{flm}	Probability of failures for m-nodes
P_{wsm}	Probability of winning contention, including failure
T_{cbw}	Contention back off window winner
P_{ff}	Probability of frame failure
E_{tfd}	Energy consumption for transmission of frames
E_{rfd}	Energy consumption for the reception of frames
T_{frame}	The transmission time of the data frame
P_{TS}	Successful transmission probability
P_{RS}	Successful reception probability
P_{TU}	Probability of unsuccessful transmission
P_{RU}	Probability of unsuccessful reception
P_{nin}	Probability of not involved nodes
E_{fts}	Energy utilization for successful transmission
E_{frs}	Energy utilization for successful reception
E_{ftu}	Energy utilization for unsuccessful transmission
E_{μ}	Energy utilization for not involved frames
POCA-CDMA	Path-Oriented Code Assignment CDMA
T-Lohi	Tone -Lohi
DACAP	Distance Aware Collision Avoidance Protocol
MACA-MN	Multiple Access Collision Avoidance -Multichannel
UMIMO	Underwater Multi-In Multi-out MAC
CUMAC	Cooperative Underwater Multichannel MAC
ST-MAC	a Spatial-Temporal MAC Scheduling protocol
UWAN-MAC	Underwater Acoustic Wireless Networks
R-MAC	Reservation based MAC
BiC-MAC	Bidirectional concurrent MAC
DTMAC	Delay Tolerant MAC
DOTS	Delay-aware Opportunistic Transmission Scheduling
MR-AMC	Multi Receiver MAC
HSR-MAC	Hybrid Sender and Receiver Initiated MAC
H-MAC	Hand shaking MAC
P-MAC	Preamble MAC
UW-MAC	Underwater MAC
PLAN	(Protocol for Long latency Access Networks
LDN	Linearly Deployed Nodes
CGW	Conventional Gateway
SS	Surface-Station
VCN	Vertical communication sensor Node
SPCL-MAC	Scheduled Process Cross Layer- MAC Protocol
SNC	Stochastic Network Calculus
RTS	Request To Send
CTS	Clear To Send
DPC	Duty Process cycle
CC	Clock Cycle
OFDMA	Orthogonal FDMA
UW-OFDMAC	UnderWater Orthogonal FDMA Control
ACMENet	Acoustic Communication network for Monitoring of Environment
DSS	Dynamic Slot Scheduling Strategy
UW-FLASHR	Underwater FLASHR

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PROF.M. SARAVANAN is serving as a Research Professor in Directorate of Learning and Development at SRM Institute of Science and Technology. He has completed Ph.D in Computer Science and Engineering. He is an active researcher in the field of Underwater wireless communication. He is Cambridge certified fellow in Education Leadership Professional Development Qualifications. His research interests are Underwater Wireless Communication, Wireless Sensor Networks, Data Mining, Natural Language Processing, Engineering Education, Curricula Design and Implementations. He completed many projects in the field of wireless networks and Underwater wireless communication.

PROF. RAJEEV SUKUMARAN Director, Learning and Development is an Engineering Epistemological and a Learning Researcher. With a field Experience of more than 30 years in both academia and industry, he has been instrumental in consulting several large-scale innovative educational and technology projects. In Education; he contributes to: Curricula Development, Instructional Design Systems and Technologies, Scientific Teaching-Learning, Technology-Enabled Learning, Educational Leadership. Area of Interest are Underwater Wireless Networks, Networks, Data Mining, Network Security.

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