

Stochastic Network Calculus Model for Delay Distribution of Time Division Multiple Access and Carrier Sense Multiple Access in Underwater Acoustic Wireless Communication

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Abstract

Underwater Acoustic wireless communication becomes a popular research area for transmitting and receiving data between the communicators in the ocean environment. High accuracy in data communication can be succeeded by proficient modeling of carrier sense multiple access and time division access. For such innovations, the system has to proceed with an appropriate framework to make constant data traffic and limitations on start to finish data traffic delays. There are two major wireless communication multiple access methods that can be utilized in real-time underwater networks. One of the multiple access schemes is TDMA and another one is CSMA/CA. This paper concentrated on the modeling of TDMA and CSMA/CA also proposes the comparison of delay (end-end) of both multiple access protocols. The results using SNC to obtain delay bounds and are associated with simulation. The results show TDMA has a lesser efficiency than CSMA/CA in the acoustic environment.

Key-words: Stochastic Network Calculus (SNC), Time Division Multiple Access (TDMA), Underwater Sensor Wireless Communication Networks (USWCN), Multi-hop Networks, Carrier_Sense_Multiple_Access - Collision Avoidance (CSMA/CA).

1. Introduction

Underwater Sensor Wireless Communication Networks (USWCN) contributes a substantial part in the advancement of hydroponics, marine scrutiny, contamination activities observing, military security concern applications, seaward exploration/investigation, and catastrophic events similar to storms, huge waves (Tsunami). Underwater acoustics embroil the reflected events and work of acoustical techniques to highlight the submerged occasions. It brings facts over the oceanic waveguide. Modeling is a strategy for arranging information amassed through the insights or articulate from fundamental standards. UWSN shows a couple of definitive and structural troubles concerning the sensor activities given its transmission medium characteristics and acoustics signals used to impart data. Wireless multi-hop systems are being seriously researched for continuous applications due to the simplicity of deployment work and ease of adaptability (Example: Ad-hoc wireless sensor Network, Mesh topology concerning wireless sensor networks). In an underwater environment, every application needs to satisfy the minimum bound of delay at data exchange. The packet transmission [5] should be reached at the destination within the margin value of the delay bound. Assuring real-time data exchange in an oceanic wireless channel is very hard due to the uncertainty and unreliability.

The Acoustic models of channels contain both the vertical depth model and the shallow-water multi-channel model. The dedicated stack [18] protocols can make a guaranteed for soft multi-hop communication with a small delay (∂m) between sources and destination. The following methods have been considered for multiple accesses: the first one is TDMA second one is CSMA/CA. TDMA works based on the Time slot initiation and CSMA / CA works based on event initiation for carrier reservation or identifying the channel busy status. TDMA mechanism working based on the deterministic time slot allocation property. CSMA / CA allows the node to communicate with other nodes dynamically when the carrier is free. It is one of the times based scalable multiple access mechanisms and bandwidth can manage according to the demand. Most of the research work on underwater MAC protocols are evaluated over simulation tools. Mathematical models for MAC protocols are required to be developed for better performance evaluation in ocean water environments. There is a big research opening for the mathematical model's intellectual developments and analytical results comparisons for upper/worst-case bound delays carried on an underwater wireless network. This paper introduces SNC based delay distribution of TDMA and CSMA/CA among the hops, it will be validated with simulations delay distributions. The propagation speed in the acoustic medium varies in the middle of 1493 m/s to 1501 m/s depends on the path and temp. The Mackenzie equation is used for fixing the speed for various trials.

The remaining sections of the article are structured as follows, Section II covers related work concerning TDMA and CSMA, Section III describes the system models and protocols, Section IV dealing with Delay Distribution and delays values -Worst-Case and conclusions.

2. Relates Works

There are various TDMA-based MAC shows that together using other MAC parts, for instance, arranging and reservation independently. The essential objective of these conventions is to address the setting and segment of timestamp adaptability in powerful lowered circumstances. For the time slot, the TDMA [1] starts partition from the central center to outward center points in a kind of wave-like duplication to abridge the network starting time. To ensure different centers to use unmistakable time allocations, centers are allowed to change existing conveyances during the modification cycle. That is, a center nearer to the central center has a more serious need to modify the existing schedule opening assignment for center points from the central center point. Zone-based TDMA [2] for a fixed corresponded UWAN, each center point streams the transmission approval as demonstrated by a pre-concluded progression to the time. The time slot task depends upon the spots of related centers. Space length is picked continuously as demonstrated by traffic stores close by a center point and its neighbors. A huge convention is created to spread data depends on position and traffic loads. It is improved to help AUVs, called LTM-MAC, by detecting hub to be utilized AUV's transmission [3]. It is improved to help AUVs, called LTM-MAC, by distinguishing the center to be used AUV's transmission [5]. To cover enormous zones, the channel reuse approach of flexible cell networks is gotten by the C-MAC (Cellular MAC) [4] for the schedule opening segment. It forms seven-plan openings into the packaging to cover a gathering including seven hexagonal cells. One cell is assigned a time slot to avoid a between cell sway. The scheduled opening apportioned to a cell is shared by the center points in that under the coordination of the sink according to the centers' circumstances to it.

Message exchanging to share position information is required. Such a fixed time table opening assignment per cell wastes information transmission if traffic loads are different in each cell. To modify MAC to long inducing delay for high throughput, it [6] uses a yield time instead of a fixed time slot so much that the sink can get data plots independently without gaps between them. This time is a period length between when a center point gets a super packaging and when it begins to send an edge. It moreover uses a lightweight SYN plan to reduce essentialness usage through choosing an ideal length of the guard time as a component of packaging lengths and the covariance of lowered causing delay. Its introduction relies upon the specific information on the detachments between the sink and various

center points. Association unfaltering quality and show capability are furthermore considered to improve adaptability by the spatially-shared TDMA MAC [7]. It intends to allow centers to share time assignments for simultaneous transmissions according to their requirements for high throughput, using a quality measure (e.g., the typical message spread time). Transmission and retransmission game plans as demonstrated by condition elements to diminish the number of transmissions. The ALOHA carrier sense (ALOHA-CS) [8] is a variation of CSMA utilizing another backoff window to adjust the convention to variable proliferation delays. The window size reaches among twice and multiple times the greatest spread postponement (D_m). Information is communicated once the channel is detected inertly, and out an irregular time for another endeavor for fruitless transmission. If sequential transmission happens, the most extreme back off time is set up to $5 D_m$. Essentially, CSMAALOHA [9] embraces an arbitrary detecting length shorter than the time required for the sign to spread over the reach to improve medium access opportunity, however may likewise cause more impacts at the receiver. That is, the point at which the channel is detected occupied, the hub continues detecting until the continuous transmission is finished. At that point, it detects the channel again for a short arbitrary time and starts a transmission if the channel is detected inactively.

The exhibition of the two conventions generally relies upon spread postponements between hubs. To handle the concealed terminal issue, the CS-MAC (Channel_Stealing_MAC) [10] adjusts IEEE 802.11 by requiring the beneficiary of an RTS to defer the transmission of the CTS for a span equivalent to double the contrast among D_m and the sender-collector engendering delay. Additionally, the sender likewise concedes a similar measure of time for information transmission. To diminish crash, the time between when an RTS is sent and when the normal CTS is gotten is opened. Such deferred transmission builds medium access delays. The abovementioned TDMA and CSMA [19] are simulated for underwater environments and stochastically derived models are not implemented for analyzing the delay. In this work, we have concentrated on the stochastic network calculus for deriving delay distributions for both TDMA and CSMA Protocols.

3. Underwater System Models and Protocols

In an underwater scenario, there are two major topologies are playing an important role in the deployment process. For simulation purposes, first, we concentrated on the horizontal deployment, in that the coverage area has to be extended in a particular direction based on the demand, as shown in Fig.1. Second, two relay/two flow topology for observing the contention effects of all nodes transmit various flows. Horizontal topology is one of the linear ways deployed nodes, where data can be

transmitted from Src. (S) to Dest. (D) The transmission happens from S to D through intermediate relay nodes. In case, the system chooses the α relay nodes from S to D. The real-time data transmission in relay nodes is difficult in an underwater environment. The second topology is shown in Fig.2. Here the intermediate relay node has to forward the data from two different nodes simultaneously. The difficulty for the intermediate relay node is to receive the acoustic signals from two different nodes and differentiate the signal data. Then it has to forward the signals to the next-hop node concurrently for two different signals.

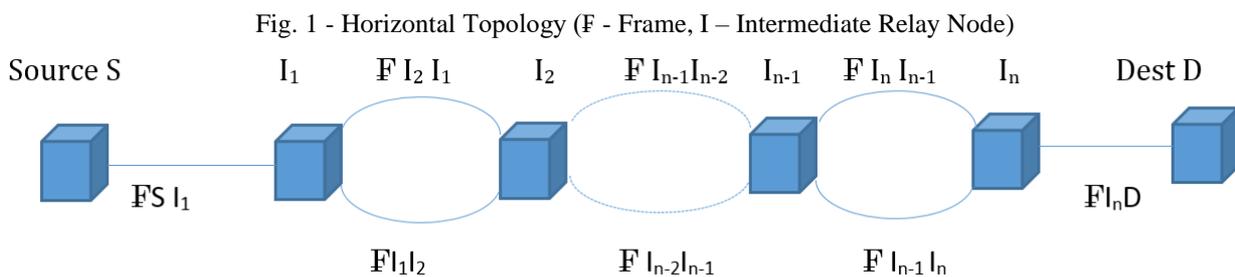
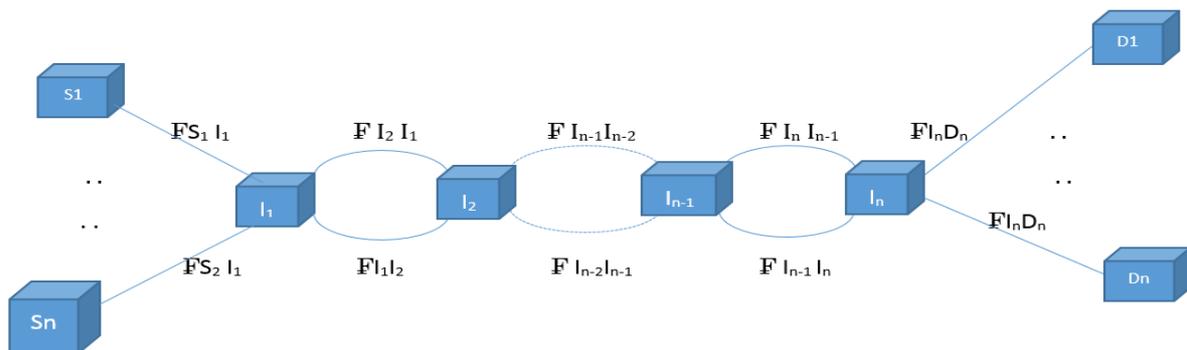


Fig. 2 - Cross Flow Topology



The node setup has the following constraints, the Source node has to generate frames periodically, and the Source node generates one frame at a time. The delay value only computing from the simulation and SNC for MAC. The queuing delay is not fixed in the intermediate node. It is working based on the constant flow time.

Sequential Procedure for Scheduling Time of Node in Slot

```
IF Time Slot is empty and the buffer queue slot ( $q \neq \phi$ ) THEN
  Transmit data sizes as a frame ;
ELSE_IF
  intermediate device (node) k gets a data F from intermediate node g with buffer Queue Slot q THEN
  Generate the random waiting time of a queue  $N \in [0,1]$  ;
  FOR Time slots  $y \in T, y \neq q$  do
  IF  $y=1$  and  $N \leq N_{nm}, q=1$  THEN
  Frame f allocated into slot 1 for the next transmission;
  ELSE
  Insert the frame f into buffer slot of y (waiting)
  END_IF
  END_FOR
  END_IF
END_IF
```

3.1 Underwater Network Model and Protocol

The underwater CSMA /CA model follows the procedure for Distributed coordinated function in the MAC layer. The hidden terminal a problem can be avoided by RTS/CTS messages. The RTS messages are sent by source nodes before starting the transmission process. Same time the receiver node will verify the RTS message, then sent CTS messages to the source node. Now the node can start the transmission process to avoid the hidden terminal problem. The CSMA/CA can useful for sensing the medium for sending RTS/CTS messages. It can be deployed in a distributed environment. TDMA modeling has considered a synchronized TDMA. The time slots will be infinite until the buffer is free for processing. For the cross-flow scenario underwater, the time slots (T) are fixed for constant values 4. First-time slot t1 fixed for sending the frame from S1, slot t2 fixed for the sending frame from S2, slot t3 fixed for relay I1, slot t4 for relay I2 denoted in Fig.3. There is relay communication that may occur in bi-directional (S to I or D to S over I). Each relay working based on the uniform forwarding probs. Let node k receives the frame from another node g in the 4 slots superframe. The superframe follows the time slot q. the next forwarding transmission of the node will follow the sequential procedure (slot y). The forwarding data fit in the slot q+1 of the intermediate node. One frame will be

received and forward the frame one at a time. The lost data probability calculation is 1- (total number of successful transmission between nodes). The forwarding capability of a node is directly proportional to the time slot y availability in each node. The maximum forwarding probability of a node is 1 in slot y . if the probability value is 0.5 for one arrival, then the 0.5 for departure. This rate is common for both horizontal relay and two flow and two relay topology. The forwarding operation completely depends on the amount of frame received from the other nodes. The probability is denoted as $Prob_{kg}^y$, the frame transmitted between node k and j in the slot y . The acoustic signal flow between nodes can be described as the sum of the outgoing acoustic signal entering into the node k from node g in the slot q incorporate with prob. of frames transmitted by the k in the slot q and prob. received by the g in the slot y . The acoustic signal flow is ensured in the following equation (1) is written as,

$$\sum_{(k,g) \in \eta} \sum_{q \in T} = \tau_k^q P_{kg}^q \chi_{kg}^{qy} = \tau_g^y \quad (1)$$

Where k, g denotes nodes, η denotes the number of incoming edges for a node in slot q , q belongs to the total allocated time for slot (For Ex. Slot= 4). P_{kg}^q Indicates the probability of frames sent from node k to node g in the slot q . χ_{kg}^{qy} denotes forward probability. τ_g^y is the node frame emission ratio to the neighbor node. The average delay is denoted as $\delta_D^c = \delta D / \delta c$. Where D is a delay, c is capacity for energy consumption.

Fig. 3(a) - Horizontal Flow

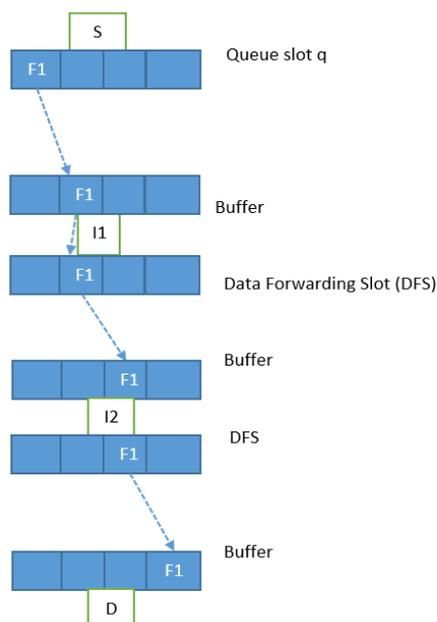


Fig. 3(b) - Horizontal Flow with Loss

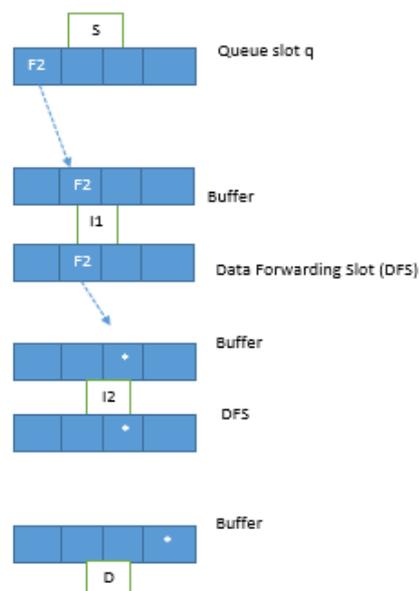


Table 1 - Data Transmission and Forward Ability of one Flow three Relays (Min, Avg, Max)

<i>Communication between S and D, I flow 3 relay scenario</i>	$\delta_{min} (x 10^4 \text{ sec})$	$\delta_{avg} (x 10^4 \text{ sec})$	$\delta_{max} (x 10^4 \text{ sec})$
$\chi_{S I1}^{12}$	0.58	0.65	0.97
$\chi_{S I2}^{13}$	0	0	0
$\chi_{S I3}^{14}$	0	0	0
$\chi_{I1 I2}^{23}$	0.87	0.89	0.95
$\chi_{I1 I3}^{23}$	0	0	0
$\chi_{I2 I1}^{32}$	0	0	0
$\chi_{I2 I3}^{34}$	0.79	0.84	0.96
$\chi_{I3 I1}^{42}$	0	0	0
$\chi_{I3 D}^{45}$	0.85	0.87	0.96

The minimum, average, and maximum delay from node to node is illustrated in Table 1 and it is derived from the fig 1 operation. Propagation speed or speed is seen as the fundamental limit in the acoustic bond illustration. As referred to previously, the spread speed of acoustic waves contrasts from the ocean to the ocean and it is essential to set the best possible appropriate value in the acoustic channel to gain powerful results. Acoustic Propagation speed can be resolved using the Mackenzie equation. Let us consider the transmission occurs between the node I1 and I2 in horizontal topology. The frame timing slots ($t=4$) are allowing one frame at a time. So the first slot occupied by frame 1, the remaining slots are allocated for F2, F3, F4. But F1 is only allowed to transmit at slot 1 in q. Frame 1 is arrived at intermediate node 1 and reside at buffer slot 1 and forwarded at slot 2 in q. The intermediate node will receive the information at slot 3 and forward it to destination node D. the lost signal flow have shown in Fig.3b. The signal lost from the intermediate node will maintain the rollback operation.

4. SNC for Delay Distribution and Delay Values -Worst-Case Analysis

4.1 Delay Distribution for CSMA/CA

This section deals with the analytical model for CSMA / CA. The delay value distribution for CSMA at Dj can be derived from prob. mass Function (PMF) is denoted as $P[D_j=del]$ with d belongs to the arbitrary positive E-E (end to end) delay values. Stochastic delay (worst case) for the node Dj can be donated as del^w . It can be derived from the stochastic equation (1). If concurrent flows occur, the worst-case delay value can be generated from the del^w .

$$del^w = \max(del) \text{ w.r.t } P[Dj \geq del] \leq \delta \quad (2)$$

$$\text{where } \delta = 10^{-9}$$

The standard delay distribution equation for underwater environment CSMA/CA can be written as

$$Diff.\chi(ti) = \left(\int_{-\tau}^0 \chi(ti + \theta)\rho(d\theta) \right) dt + \sigma(ti)dU^h(ti) \quad ti > 0 \quad (3)$$

Where $\chi(ti)$ is Hurst index, $\rho(\cdot)$ is Gaussian process with finite calculation (ti) belongs to $[-\tau, 0]$, the initial value of $\chi(ti)$ is equal to $\xi(ti)$. $U^h(t)$ is an acoustic motion based on Brownian for the signal as follows,

$$U^h(t) = \left(\int_{-\tau}^0 (ti + s)^h - 1/2 dU(s) \right) \quad (4)$$

Brownian motion Hurst parameter for acoustic signals in underwater $h > 1/2$ between the interval $[-\tau$ to $0]$.

The explicit form will be derived from the deterministic differential equation $\gamma(ti)$ with beginning value $\gamma(ti) = \xi(ti)$, ti lies between $[-\tau, 0]$

$$Diff.\gamma(ti) = \left(\int_{-\tau}^0 \gamma(ti + \theta)\rho(d\theta) \right) dt \quad (5)$$

The characteristic equation for (5) is,

$$C(\lambda) := \lambda - \int_{-\tau}^0 e^{\lambda\theta} \rho(d\theta) = 0$$

The fundamental solution denoted as $Zf(t)$, the initial value for $Zf(0)=1$ and $Zf(\theta)=0$, where θ lies between $[-\tau, 0]$. The explicit derived unique form is

$$Y(ti) := Zf(ti) \xi(0) + \int_{-\tau}^0 \int_{\theta}^0 Zf(ti + \theta - s) \xi(s) ds \rho(d\theta), \quad ti \geq 0. \quad (6)$$

The unique strong solution $Diff.\chi(ti)$ is written as

$$Diff.\chi(ti) := Zf(t) \xi(0) + \int_{-\tau}^0 \int_{\theta}^0 Zf(t + \theta - s) \xi(s) ds \rho(d\theta),$$

$$+ \int_{-\tau}^0 Z(t - s) \sigma(s) dW^H(s), \quad t \geq 0, \quad (7)$$

w.r.t Eqn (3). The standard distribution function of CSMA/CA can be expanded as follows

$$diff.\chi'(ti) := \left(\int_{-\tau}^0 \chi'(ti + \theta)\rho(d\theta) \right) dxt + \sigma(t)dWH(ti), \quad ti > 0 \quad (8)$$

The starting values are belongs to $\chi'(ti) = \xi(ti)$, $ti \in [-\tau, 0]$. The decomposed equation can be written as

$$diff.\chi'(ti) := \left(\int_{-\tau}^0 \chi'(ti + \theta)\rho(d\theta) + \sigma(ti)\phi(ti) \right) dxt + \sigma(ti)dWH(ti), \quad ti > 0 \quad (9)$$

multiply by $e^{-\lambda ti}$, where $\lambda' > c$ large, lies between 0 to ∞ , denoted as $L(\chi')(\lambda')$ the Laplace equation for the transformation of χ' (ti), then

$$h_{-}(\lambda)\text{Lap}(\chi')(\lambda') := \xi'(0) + \int_{-\tau}^0 \int_{\theta}^0 e^{\lambda(\theta-ti)} \xi'(ti) dti \rho(d\theta) + \int_0^{-\infty} e^{-\lambda ti} \sigma(ti) \varphi(t) dti + \int_0^{\infty} e^{-\lambda ti} \sigma(ti) dW(ti) \quad (10)$$

An application of the Laplace inversion theorem yields

$$\chi'(ti) := \int_{-\tau}^0 e^{\lambda ti} h^{-1}(\lambda) [\xi'(0) + \int_{-\tau}^0 \int_{\theta}^0 e^{\lambda(\theta-ti)} \xi'(t) dti \rho(d\theta) + \int_0^{-\infty} e^{-\lambda ti} \sigma(t) \varphi(ti) dti + \int_0^{\infty} e^{-\lambda ti} \sigma(ti) dW(ti)] d\lambda$$

Where $\text{Lap}(Z')(\lambda') = h^{-1}(\lambda')$,

The variable delay distribution bound equation of CSMA/CA from the above Laplace is as follows,

$$\chi(ti) := Z(ti)\xi(0) + \int_{-\tau}^0 Z(ti + \theta - s) \xi(s) ds \rho(d\theta) + \int_0^t Z'(ti - s) \sigma(s) dW^H(s), ti \geq 0 \quad (11)$$

Where the fundamental solution denoted as $Zf(t)$, the initial value for $Zf(0) = 1$ and $Zf(\theta) = 0$, where θ lies between $[-\tau, 0]$. The multi-hop total delay d multi-hop (χ), calculated for any complex number $\chi \in \mathbb{C}$, can be derived as the product of the probability generating function of MAC delays calculated for each hop, where \mathbb{C} is the set of complex numbers: $d_{\text{multi-hop}}(Z) = d_1(\chi) * d_2(\chi) * \dots * d_h(\chi)$, where $d_h(\chi)$ is the multi-hop delay (δ) for prob. generating function from Eqn.11.

4.2. Delay Distribution for TDMA

The results are derived from our previous work [21] An information packet may encounter a couple of ways, every one of different lengths in the number of bounces. It takes everything considered one s-frame range for the pack to travel one hop further. So all estimations of deferral are imparted in hops and can be viably changed over in time units by expanding them by $M \times \partial\text{slot}$, where M is the amount of time slot and ∂ the slot is the space length. One hop delay is approximately one unit time. Similarly G hop transmission will take $G \times$ unit times. The delay prob. $[\text{dest.} = G]$ is towards the destination node includes G hops. A frame can travel up to $G = \text{slot } q + (1)$ hops. The stochastic delay bound function is,

$$\text{Prob.}[\text{Dest} = G] \Rightarrow \text{prob}(\text{Dest} = G) = \begin{cases} \frac{\text{Arr}(s).\text{Dest}(a)}{\text{fun}(\text{Dest } j)}, G = 1 \text{ (no intermediate node)} \\ \frac{\text{Prob.fwd}(S).\text{hops}^{G-2}.\text{Arr}(s).I(\text{dep}).\text{Dest}(j)}{\text{fun}(\text{Dest } j)}, \text{for all } G \geq 2 \end{cases} \quad (12)$$

Where Arr(s) → arrival rate at source node, Dest(a) → arrival rate of destination, Fun(Dest j) → sum of normalized rate from src to dest, Prob.fwd(s) → probability of forward capability of source, hops(g-2) → more than one-hops except source and destination, I(dep) → departure rate of intermediate node, Dest(j) → destination node j. The variations in the analytical results and simulated results are computed by evaluating RMSE in Eqn. (13) (Root_Mean_Squar_Error).

$$RMSE(\psi) = \frac{1}{total\ points(k)} \sqrt{\sum_1^k \frac{(Analytical\ delay - Simualtion\ delay)^2}{f(i)^2}}$$

$$RMSE(\psi) = \frac{1}{k} \sqrt{\sum_1^k \frac{(D(an) - D(Sn))^2}{f(i)^2}} \quad (13)$$

The RMSE evaluation is shown in Fig.5 and Fig.6 for TDMA and CSMA/CA. Fig. 4 and Fig. 5 are showing the results of SNC and simulation for the CSMA/CA and TDMA respectively for one flow three relays acoustic communication in the horizontal topology. The minimum, average, and maximum delay values are showed in (a), (b), and (c) respectively. The delay bound values are the main key factors for worst-case delay occurrences in underwater environments. The comparative analysis shows TDMA has a lesser efficiency than CSMA/CA in acoustic environments.

5. Results and Discussion

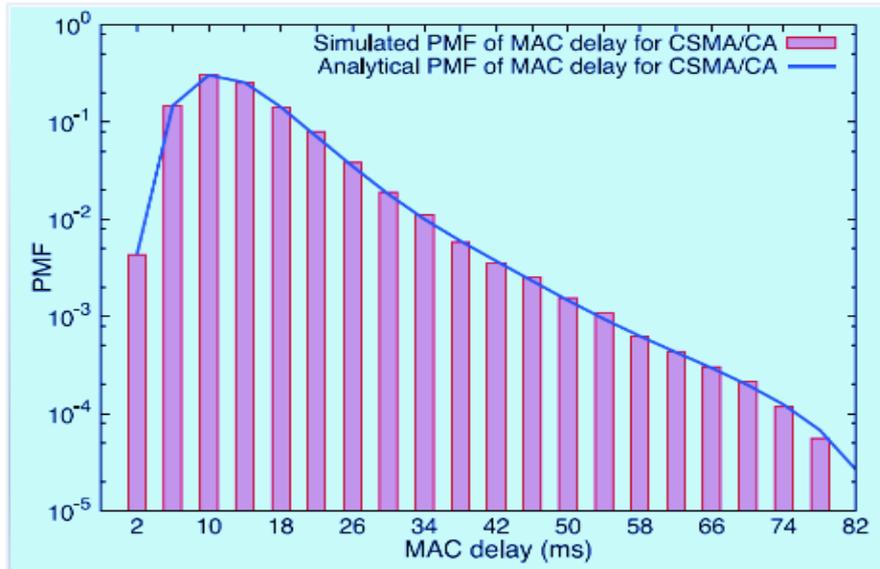
To begin with, this part affirms the precision of the delay distribution models determined for TDMA and CSMA/CA underwater acoustic wireless multi-hop network protocols simulation. The simulation setup has been shown in table 2. Next, the delay distribution and most pessimistic scenario delay bounds for TDMA and CSMA/CA are analyzed for the 1-stream and 2-stream showed in Fig. 1. Underwater wireless networks and conventions are simulated by utilizing the riverbed simulator. The start to finish delay is the span between the appearance of the frame in the source and the appearance of the frame in the destination.

Table 2 - Simulation Setup Parameters

A common setup for TDMA and CSMA/CA	
Simulated frame size	120 bytes/payload
Speed	1.5 Mbps
Frames per cycle	10000 frames
Temperature	1 – 30 Celsius
Salinity	(22 to 40) ppm
Depth	(0-850) m

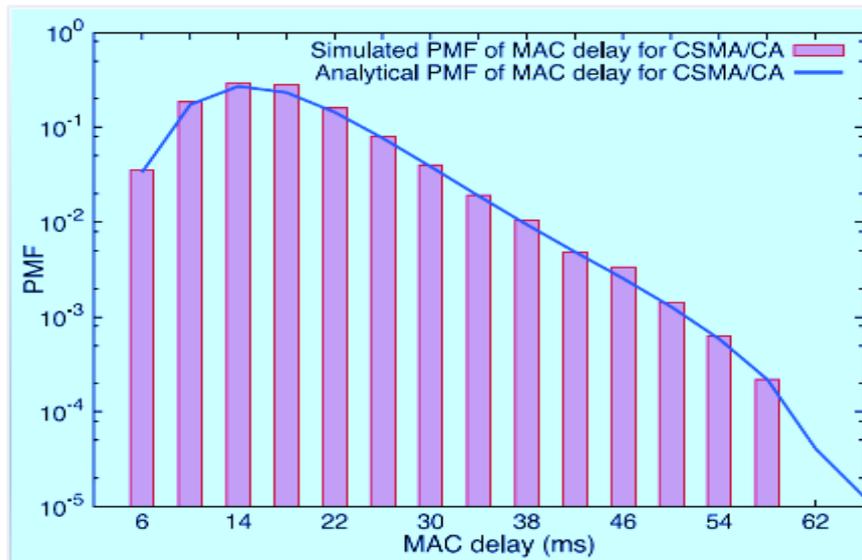
TDMA simulation Settings	
bit error rate	$Q(\sqrt{2\gamma})$ where γ =signal noise per bit
Minimum Slot duration	1.29ms @ 1.49 Mbps
Regular slot duration	20 ms @150 kbps
Topology	Horizontal Flow topology, cross-flow topology
Time Slot	4
Data –payload	120 bytes
IEEE reference standard	IEEE 802.15.4
Delay distribution	SNC
CSMA/CA Simulation Settings	
MAC delay includes	RTS, CTS
Physical Layer	DSSS
Analytical Model	Markov chain model
Data –payload	120 bytes
Buffer slot	$ \text{Total ti} - 1$
Delay distribution	SNC

Figure 4(a) - Minimum Delay of CSMA/CA:1 Flow 3 Relays Analytical (SNC) vs Simulation



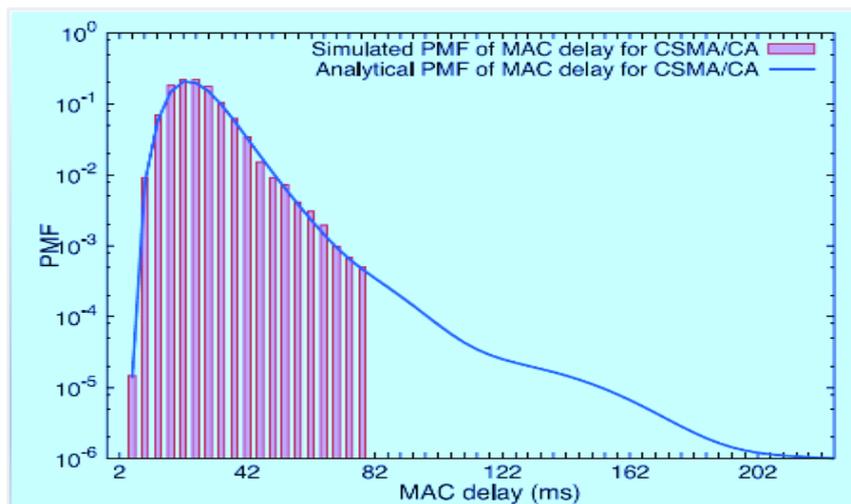
The above figure 4. (a) shows the minimum boundary level of delay variation between S to D. the comparisons have been done between the PMF and MAC delay in milliseconds. Analytical results of PMF vs CSMA/CA and simulation results have compared and shows the deviation in the results. It shows the results of 1 flow 3 relay communication results.

Figure 4(b) - Average Delay of CSMA/CA: 1 Flow 3 Relays Analytical (SNC) vs Simulation



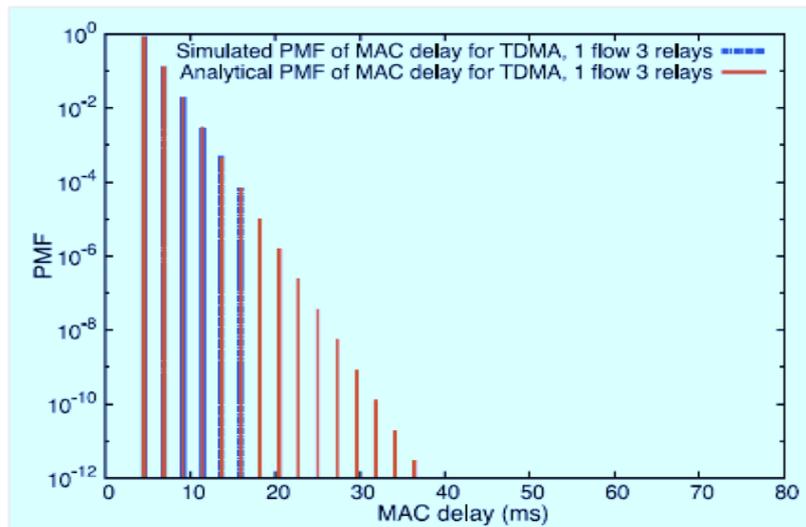
The above figure 4. (b) Constitutes the average boundary level of delay variation between S to D. the comparisons have been done between the PMF and MAC delay for CSMA/CA in milliseconds. It shows the results of 1 flow 3 relay communication results. Analytical results of PMF vs CSMA/CA and simulation results have compared and shows the deviation in the results.

Figure 4(c) - Worst Case Delay of CSMA/CA: 1 Flow 3 Relays Analytical (SNC) vs Simulation



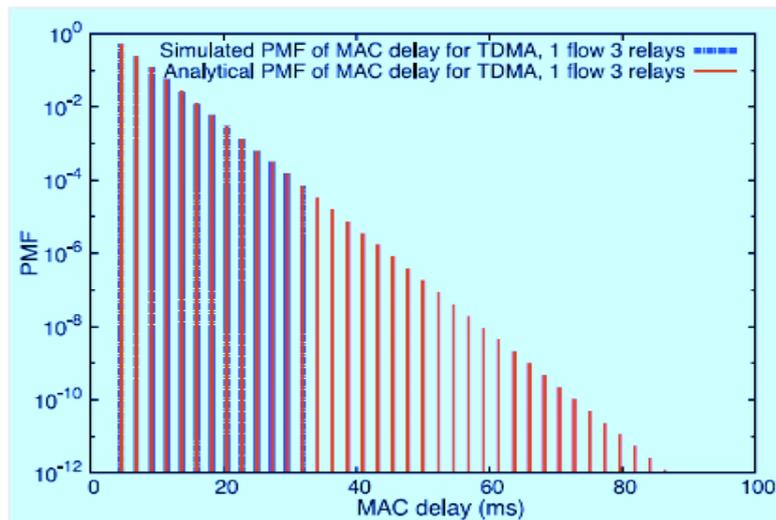
The above figure 4. (c) shows It shows the results of 1 flow 3 relay communication results and the upper boundary level of delay variation between S to D. the comparisons have been done between the PMF and MAC delay for CSMA/CA in milliseconds. Analytical results of PMF vs CSMA/CA and simulation results have compared and shows the minimum five percentage deviation in the results.

Figure. 5(a) - Minimum Delay of TDMA:1 Flow 3 Relays Analytical (SNC) vs Simulation



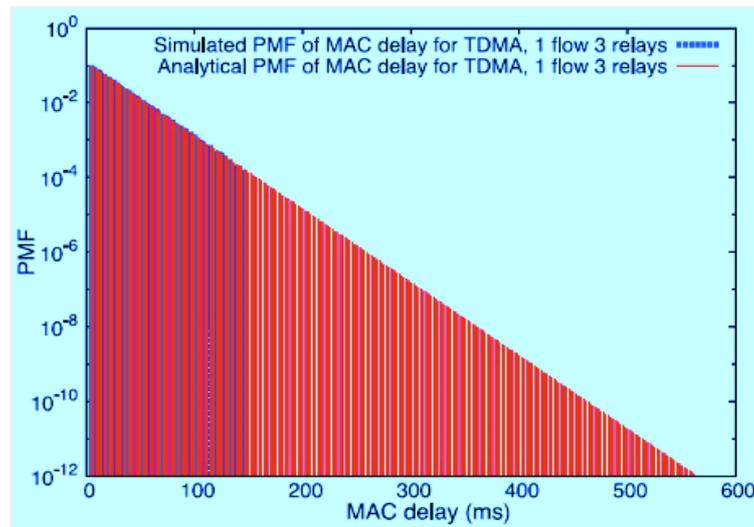
The above figure 5. (a) shows the minimum boundary level of delay variation between S to D. the comparisons have been done between the PMF and MAC delay for TDMA in milliseconds. Analytical results of PMF vs TDMA and simulation results have compared and shows a deviation in the results. It shows the results of 1 flow 3 relay communication results.

Figure 5(b) - Average Delay of TDMA: 1 Flow 3 Relays Analytical (SNC) vs Simulation



The above figure 5. (b) shows the average boundary level of delay variation between S to D. the comparisons have been done between the PMF and MAC delay for TDMA in milliseconds. It shows the results of 1 flow 3 relay communication results. Analytical results of PMF vs TDMA and simulation results have compared and shows the deviation in the results.

Figure 5(c) - Worst Case Delay of TDMA: 1 Flow 3 Relays Analytical (SNC) vs Simulation



The above figure 5. (c) shows It shows the results of 1 flow 3 relay communication results and the upper boundary level of delay variation between S to D. the comparisons have been done between the PMF and MAC delay for TDMA in milliseconds. Analytical results of PMF vs TDMA and simulation results have compared and shows the minimum five percentage deviation in the results.

6. Conclusions

This paper provides a Stochastic Network Calculus model for TDMA and CSMA/CA in underwater wireless communication networks. An original contribution of this work is the model of the analytical delay distribution. A scheme for the numerical model utilizing SNC is intended like submerged correspondence and Quality of Service dependent on input, defer variation probability of single-channel events of submerged correspondence channels with moderate blurring effect. Delay distribution is derived for both TDMA and CSMA/CA concerning different flows. Slow blurring disorder was presented during correspondence and distinguished delay are inducing eight to ten percentage variation has been an experienced between simulation and SNC. The comparative analysis shows TDMA has a lesser efficiency than CSMA/CA in acoustic environments depending on the node settings. Our future work would be demonstrating submerged remote organizations with various kinds of fading misfortunes.

References

- W. Lin, D. Li, J. Chen, T. Sun, and T. Wang, A wave-like amendment based time-division medium access slot allocation mechanism for underwater acoustic sensor networks, *In Proc. Cyber C, Zhangijajie, China.*2009; 369–374.
- J. Mao, S. Chen, Y. Liu, J. Yu, and Y. Xu, LT-MAC: A location-based TDMA MAC protocol for small-scale underwater sensor networks, *In Proc. Annu. IEEE Int. Conf. Cyber Technol. Autom. Control Intell. Syst.*, 2015; 1275–1280
- J. Mao et al., LTM-MAC: A location-based TDMA MAC protocol for mobile underwater networks, *In Proc. MTS/IEEE OCEANS*; 2016; 1–5.
- Y. Ma, Z. Guo, Y. Feng, M. Jiang, and G. Feng, C-MAC: A TDMAbased MAC protocol for underwater acoustic sensor networks, *In Proc. Int. Conf. Netw. Security Wireless Commun. Trusted Comput. (NSWCTC)*. 2009; 728–731.
- Saravanan M., Rajeev Sukumaran., Christhuraj M. R., Manikandan T. T., “SNC for Modeling Delay Dissimilarity in Acoustic Mode Communication for Underwater Wireless Multichannel Communication”, *IJAST*, vol. 29, no. 3, pp. 13625 - 13634, Mar. 2020
- L. Hong, F. Hong, Z.-W. Guo, and X. H. Yang, A TDMA-based MAC protocol in underwater sensor networks, *In Proc. Int. Conf. Wireless Comm. Netw. Mobile Comput. (WiCOM)*. 2008;1–4.
- R. Diamant, M. Pinkhasevich, and I. Achrak, A novel spatially shared TDMA protocol and quality measure for ad hoc underwater acoustic network, *In Proc. Int. Conf. Adv. Inf. Netw. Al. Workshop (WAINA)*, 2009; 1160–1165.
- F. Guerra, P. Casari, and M. Zorzi, World ocean simulation system (WOSS): A simulation tool for underwater networks with realistic propagation modeling, *In Proc. ACM Int. Workshop Underwater Netw. (WUWNet)*. 2009; 4.
- F. Favaro, S. Azad, P. Casari, and M. Zorzi, Extended abstract: On the performance of unsynchronized distributed MAC protocols in deep water acoustic networks, *In Proc. ACM Int. Workshop Underwater Netw. (WUWNet)*, 2011; 17.
- Y.-D. Chen, S.-S. Liu, C. M. Chang, and K.-P. Shih, CS-MAC: A channel stealing MAC protocol for improving bandwidth utilization in underwater wireless acoustic networks, *In Proc. MTS/IEEE OCEANS*. 2011; 1–5.
- S. Y. Shin, J. I. Namgung, and S. H. Park, SBMAC: Smart blocking MAC mechanism for variable UW-ASN (underwater acoustic sensor network) environment, *Sensors*. 2010; 501–525.
- S. Zhuo, Z. Wang, Y. Q. Song, Z. Wang, and L. Almeida, iQueue-MAC: A traffic adaptive duty-cycled MAC protocol with dynamic slot allocation, *In Proc. 10th Annu. IEEE Commun. Soc. Conf. Sensor, Mesh Ad Hoc Commun. Netw.*, 2013; 95–103.
- S. Petersen and S. Carlsen, WirelessHART versus ISA100.11a: The for-mat war hits the factory floor, *IEEE Ind. Electron. Mag.*, vol. 5, no. 4, 23–34, Dec. 2011.
- P. Suriyachai, U. Roedig, and A. Scott, A survey of MAC protocols for mission-critical applications in wireless sensor networks, *IEEE Commun. Surveys Tuts.*, vol. 14, no. 2, 240–264, Second Quarter 2012.
- Q. Wang, K. Jaffrès-Runser, C. Goursaud, J. Li, Y. Sun, and J.-M. Gorce, Deriving Pareto-optimal performance bounds for 1 and 2-relay wireless networks, *In Proc. IEEE Int. Conf. Comput. Commun. Netw.*, Nassau, Bahamas, Aug. 2013, 1–7.

Q. Wang et al. A thorough analysis of the performance of delay distribution models for IEEE 802.11 DCF, *Ad Hoc Netw. J.*, vol. 24, 21–33, 2015.

L. Pinto, A. Moreira, L. Almeida, and A. Rowe, Aerial multi-hop network characterization using cots multi-rotors, *In Proc. IEEE World Conf. Factory Commun. Syst.*, May 2016, 1–4.

Christhuraj, Rajeev Sukumaran. “Stochastic Network Calculus for various Fading techniques in Underwater Wireless Communication”, *Int. Jour. of Applied Math. and Stat.*, 2016; 0973-7545.

M. Schwartz, *Telecommunication Networks*, Adison Wesley, 2018.

Shengming Jiang, State-of-the-Art MAC Protocols for Underwater Acoustic Networks: A Survey Based on a MAC Reference Model, *IEEE Comm. Sur & Tut.*, 2018, vol. 20.

Saravanan M, Rajeev Sukumaran, MAC Layer Communication Protocol Design for Underwater Fish Farming Technology: Stochastic Network Calculus, *International Journal of Aquatic Science*, Vol 12, Issue 02, 2021.

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