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A Model of Multichannel Design in Underwater Wireless Acoustic Communication: SNC

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Abstract*: The structure of UWAN is problematic as the endeavors of underwater are totally disparate compared to terrestrial networks. A lot of factors which, includes the behavior of the wireless activities in underwater at the time of designing and modeling the original activities of wireless communication in underwater. Additionally, the data or signal transmission and fading losses are exceptionally high in UWAN than air. Thus, separation of communication channels is curiously inflexible to model for all purposes. The acoustic waves are the best disclosures for UWCN contrasted with other wave communication (Electromagnetic or Optical wave). The acoustics communication is demonstrated to be the best of UW in spite of the fact that they are restricted to channel allocation and bandwidth because of thermal_noise. Simultaneously acoustics_sound waves afford the sturdy communication everywhere, territory concerning separation and channel detachment appearing differently in relation to other communication techniques, because of its exceptional property has low attenuation in sound communication in underwater. In this proposal, the various parameters along with the mathematical model for multichannel communication of the acoustic_channel, attributes of acoustics, and various parameters investigated. Additionally, we investigate regulation techniques for acoustic systems that can be utilized in the transmitter and recipient.

Keywords*: Underwater Wireless Acoustic Communication (UWAN), Medium Access Control (MAC), Radio wireless Networks (RWN), Stochastic Network Calculus (SNC), Signal Noise Ratio, Underwater(UW).

I. INTRODUCTION

Human Research and commercial development progress in the oceans are increasing in the last four decades. For research and communication purposes, there are many advanced circuits, sensors, transceivers, other transmitters, and receivers have deployed in underwater. RWN utilized in earthbound remote correspondence since radio sign doesn't engender well in the submerged of the sea. Currently, acoustic [2] communication used in military security regions, surveillance, marine communications. These all RWN protocols are not directly used in underwater wireless communication due to the structure and flow of properties RWN protocols.

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MAC- channel allocation for UWAN needs to be satisfied with many challenges, especially propagation of the sound in water is getting slow (approximately 1.5-kilometer/second in seawater), very small communication acoustic channel capacity, low channel quality and etc. High propagation (transmission/receiver) is the key factor that denies the usage of RWN in underwater areas. Medium sharing by multiple users in underwater communication can be done through MAC protocols. These can be achieved only when the information successfully received by the receiver. Sometimes receiver can face the major difficulty at a receiver such that collision at receiver, hence there is a demand to create sender and receiver-centric MAC for UWC. There are following major properties encountered for acoustic-channels

(1) Long_propagation_delay [4]: Acoustic-wave speed is determined roughly 5 sets of size slower than the light-speed in submerged.
(2) Limited Bandwidth support and small channel: Underwater acoustic communication supports only limited bandwidth of maximal kHz.
(3) Changing Chanel [5]: Due to multipath propagation, the arrival of the signal from source to destination has different phase shit key values. These variations in phase shift key-value caused signal reflected from the surface of seawater (this reflection disturbed by floating objects)

Table 1. Data_Transmission distance with ratios

Range	Distance	Bits/Sec (Approx.)
Short Range	1 km	More than 100 kbit/s
Mid-Range	10 km	50 kbit/s
Long Range	20 km	10 kbit/s

(4) Inter-Symbol Interference (ISI): One symbolic representation may meddle with other symbolic representations and ISI occurs at various interims. So the demodulation in the receiver end is a difficult one in underwater communication. ISI may occur due to the creation of plentiful noises for other reasons.

Table 2. Noise Ranges in underwater

Noise	The ranges in Hz (Approx.)
Turbulence noise	10 Hz
Shipping noise	10 Hz -100 Hz
Wind	100 Hz–100 kHz
Rain	100 Hz–100 kHz
Thermal noise	More than 100 kHz

(5) UWN channel-quality [6]: The quality of channels always changes in a very short period.
A measurement of 100m deep water with a 3000m long link that has been recorded. Bit Error Rate (BER) increased periodically in a short span of time.

A. Challenges and issues in UWAN Design

Underwater contains different properties, due to the characteristics of underwater, UWAN – MAC protocols deal with different types of following design issues.

1) Utilization of Communication Medium
2) Energy Efficiency
3) Fairness in MAC protocol Sensing
4) Quality of Service
5) Mobility support
6) Protocol Validation support.

The applications of UWCN are given in terms of the environmental, marine, scientific and military systems such as,

- Marine Application – Finding natural resources, pollution control, oil and gas sources
- Scientific Application – Study of Oceanography, Geosciences, marine biology and seismic study
- Military Application – Bottom imaging, detection of underwater objects, threat detection and AUV controlling, etc.,

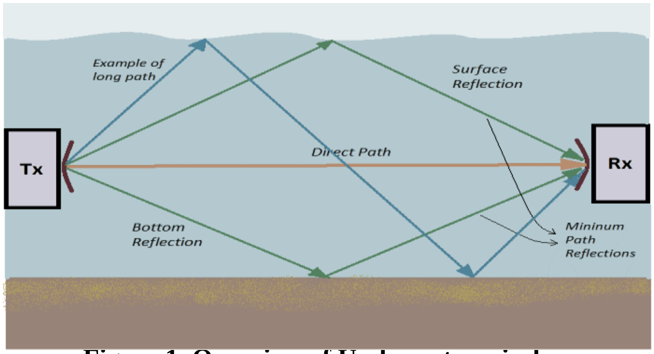

Figure 1. Overview of Underwater wireless communication

Fig. 1 shows the communication between the transmitter and receiver through different channels with sample paths. The communication channels are varying based on the reflections. The underwater wireless acoustic data transmission is a bidirectional or duplex communication system, where information is converted into acoustic sound signals [1]. these signals are received by another transceiver and then demodulated into original data through multipath acoustic signals. As illustrated in fig. 1.1, underwater wireless communication consists of a transceiver with antennas and sensors attached to them. The transmitter sends the data in multipath like direct path, bottom reflection, surface reflection to the receiver. There will be a loss due to fading, water density, temperature, and salinity.

II. RELATED WORK

Generally packet switching networks, network calculus gives a way to deterministically reason about planning, properties, and asset necessities. Systematic records of network-calculus are available in books [21]. DNC is as of late expanded and applied for execution investigation and asset dimensioning of WSNs by a few specialists [22]. In [23], Schmitt et al. Applied network calculus used to create the framework for sensor networks and proposed a conventional structure for execution investigation with different data flow designs.

Anis et al. [23], discussed a procedure for the demonstrating and most pessimistic scenario dimensioning of group tree-structured sensor-networks. It determined to fit articulations for start to finish defer limits, band_width prerequisites as an element of the WSN bunch tree-structured and traffic attributes. In [10], the creators exhibited a technique for processing the most pessimistic scenario delays, buffering and bandwidth necessities while accepting that the sink hub can be portable. Research on SNC has the capability of giving bits of knowledge into stochastic help certifications of packet networks.

The idea of measurable help curvature mentioned a probabilistic limitation in boundary values [24] on the administration got by a collection of streams or a solitary stream. The SNC by giving a network administration curve definition that is fit for ascertaining stochastic start to finish postpone and excess limits for various appearance and administration circulations. In Jiang and Emstad proposed a server model to encourage stochastic help to ensure investigation and address the difficulties of postponing ensure, build-up ensure, yield portrayal and link property. There is a lot of works giving theoretic essentials of stochastic network calculus, however, not many of them study the issue of mapping the hypothesis to a particular application.

III. MODELING OF MULTIPATH DATA TRANSMISSION WITH FADING

A. Channel Model for UWACN

Underwater multichannel communication in an acoustic medium is possible for long-distance compared to other methodologies. Here the following fig 2. represents the model of multichannel communication. This model shows the traffic flow from the transmitter to the receiver end in the multi-channel acoustic medium. Same data transmitted from the source, traffic flow occurs in multi-dimension based on the reflections. Finally, the transmitter receives the data from the different channels with different timestamp values. At the receiver side, it removes the duplication and reschedules the data frames. It's a little hard compared to terrestrial networks but the success rate of data transmission provides improved accuracy in asynchronous communication.

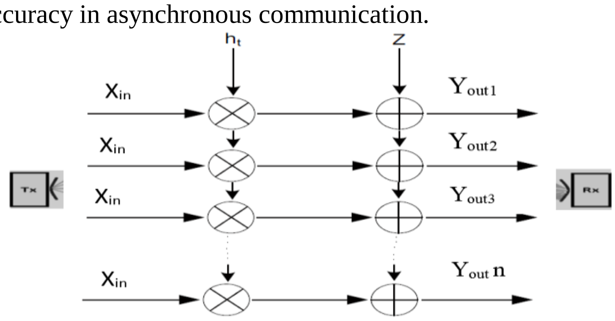

Fig 2: System model of multichannel with fading

Fig. 2 shows the system model of a flat multi-channel discrete flow with fading, which can be expressed in Eqn. (1) & (2) by,

$$Y_{out} = [R_t]\, e^{j\varrho}\, X_{in} + Z \tag{1}$$

Where Y_{out} includes,

$$Y_{out} = \{Y_{out1} \cup Y_{out2} \cup Y_{out3} \cup \ldots.. Y_{outn}\}$$

$$Y_{out1} = [R_{t1}]\, e^{j\varrho}\, X_{in} + Z$$

$$Y_{out2} = [R_{t2}]\, e^{j\varrho}\, X_{in} + Z$$

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$$Y_{outn} = [R_{tn}]\, e^{j\varrho}\, X_{in} + Z \tag{2}$$

Where X is the input given by Transmitter Tx, Y is the output received by Receiver Rx. Z is the uniformly distributed Gaussian noise. $[Rt]e^{j\varrho}$ is a multi-channel gain and amplitude [Rt] which is a dynamic one and phase ϱ is distributed uniform flow of data in an interval of 0 to 2π

Assumptions for this model:

1. CDI –channel distribution information available in both transmitter and receiver
2. CSI-channel- receiver only can view state information
3. Its multi-channel with slow fading
4. Same data transmitted in multi-channel

For this model implementation purpose, let us assume, P_{tx} is avg. transmission power, W is denoted bandwidth of multichannel and N_0 is expressing the power spectral noise density respectively. The channel capacity for a channel is expressed in eqn. (3).

$$C = W \log_2(1 + 10^{\gamma t/10}) \tag{3}$$

The channel capacity for multichannel with slow Rayleigh Fading is expressed in eqn. (4)

$$C = Wn \log 2\left(1 + \frac{P_{tx}|Rtn|^2}{WN_0}\right) \tag{4}$$

The signal-noise ratio ϒt is not declared at the initial transmission. SNR can be adjusted during the transmission according to the channel property and characteristics. The multi-channel with Fading_Rayleigh would be expressed in eqn. (5) as,

Prob. O/P =Prob.{Channel Capacity < Traffic Flow Data Rate(R)}

$$= \text{Prob.}\{W \log_2 (1+\frac{\{Ptx|Rtn|\text{^}2\}}{No}*W) < \text{Traffic Flow Data Rate(R)}\} \tag{5}$$

where the gain of the channel$|R_{tn}|$ has probability (eqn. (6)) density function with Rayleigh distribution

$$F(x) = x * \text{exponential } (-x^2/2) \tag{6}$$

from the data transformation derivation eqn. (7), $|R_{tn}|^2$ has an Exp. dist. of density function

$$\text{Density fun } G(x) = (1/2) \text{ exponential } (-x/2) \tag{7}$$

Therefore, the probability eqn. (8) can be derived as follows,

$$\text{Prob.O/P}=1\text{-exp}\left(\frac{1-2\text{^}(\frac{\text{datarate}}{\text{Bandwidth}})}{2*10\text{^}(\frac{\text{signalnoiseratio}}{10})}\right) \tag{8}$$

where signal Noise Ratio = 10 $\log_{10}[P_{tx}/(NoW)]$. which is calculated in dB.

B. Stochastic random service curvature calculation

the multi-channel capability C ={C1 U C2 U ….Cn} is random, Deterministic Service Curve (DSC) is producing results for well-defined input and outputs. We use the Stochastic curve to categorize the serviceability of the multi-channel, there are two parameters has used for the calculation. One of the parameters is data_rate R and the error_function €. The multi-channel can be mathematically modeled by the SSC (δ(t), €) with respect to Rayleigh characteristics, Where

$$\boldsymbol{\delta}\ (\mathbf{t}) = \textbf{data Rate}\ (\mathbf{R}) \cdot \mathbf{t}$$

$$\text{€}(\mathbf{R}) = \mathbf{1} - \mathbf{exp}\left(\mathbf{1} - \frac{\mathbf{2}^{\frac{\mathbf{R}}{\mathbf{W}}}}{(\mathbf{2} * \boldsymbol{Singal\ Noise\ Ratio})}\right) \tag{9}$$

The error probability function € expresses the maximum bound limitation probability of the multi-channel. It also means that the probability which does not provide the data rate lesser than the determined value of €(R). R determined by the scheme of transmission and modulation technique which have used by the transmitter.

IV. STOCHASTIC NETWORK CALCULUS FOR MIN AND MAX BOUNDS OF COMMUNICATION CHANNEL

This segment represents the outcome limits with data resources transmits on multi-channel with Rayleigh channel. The source machine transmits the data periodically properly exhibited by a DAC (deterministic arrival curve); Let Arr(t) is the arrival of a process and Det(t) is the departure of a process at the time t (basically input and output are referred like arrival and departure).

A. The arrival of a deterministic process

Arrival process Arr (t) bounded by a DAC to evaluate the inter-arrival time at α (t), and Arr(t) receives Stochastic_Service_curve based on the receiving rate at different intervals{δ (t), €} the performance values depends on the min and max with the help of infimum and supremum can be calculated as follows.

1) Backlog boundary value estimation:

The stochastic_service _curve used to analyze the backlog bound B (t) is expressed as:

$$\text{Prob}\ \{B(t) \geq\ \alpha\ \Theta\, \beta\ (0)\} \leq \text{€}, \tag{10}$$

where

$$\alpha\, \Theta\, \beta\ (0) = \text{super}_{\,t\, \geq\, 0}\{\ \alpha\ (t) - \ \beta\ (t)\} \tag{11}$$

2) Delay variation boundary value calculation:

The derivation of maximum delay value can be premeditated by using upper bound for delay del (t) in stochastic nature is denoted as,

$$\text{Prob}\ \{\text{del}\ (t) \geq \text{hi}\ (\alpha i,\ \beta i)\} \leq \text{€} \tag{12}$$

where

$$\text{hi}(\alpha i,\ \beta i) = \text{sup\_mum t \_time}{\geq}0\ \{\ \text{in\_mum}\ [\tau\text{\_time} \geq 0 : \alpha i(t) \leq \beta i(t\text{\_time} + \tau\text{\_time}\ )]\ \} \tag{13}$$

eqn. 13 express the deviation of the arrival_rate curve and the service_rate curve.

B. Arrival process calculated by stochastic network calculus

An arrival_rate can be estimated as the boundary values in stochastic randomnesses EBB (exponentially_bounded_bustiness) math_model [19]. We considered a stochastic_arrival rate service curve mathematical model with parameters (ρi, a1, a2) as following [13]:

Prob {sup_mum $0 \leq si \leq$ t_time [A (t) – A (si) − α (t_time – si)] ≥ 0 } $\leq a_1 e - a_2 \sigma$,

Where

$0 \leq si \leq$ t_time, $\sigma > 0$, and α (t) = ρi · t_time + σ. (14)

V. RESULTS AND PERFORMANCE EVALUATION

This part expresses the arrival rate of data, delay variation, receiver end data success rate as simulated_results. We followed the analytical of both numerical and simulated approach. Which provides the basement of designing transmission strategies of multichannel with respect to multi-dimension of traffic in underwater wireless_networks.

A. Simulation results and SNC modeled calculation.

We used simulations and associate with the results are taken by SNC calculation along with the simulation. The factors for this calculation and simulation is the bandwidth for all channels equally BW = 35 kHz, Signal_Noise_Ratio= 0.1 dB, frame-size is given as 1 kbit. This range is fixed for 40 runs 900 with different seeds in different Chanel. For every complete run, it takes 10000 cycles to complete the simulation and the sender side, the machine produces the packet per cycle time, the same payload has traveled in various paths. The jitter value and backlog values are recorded. For the above factors, there is no error probability is found in simulation. The results have compared with delay/backlog boundary values based on the simulation with respect to defilement probability. Perhaps, tot_m = 40 denote the cumulated value of runs, and tot_n = 10000 designates packets/cycles in single take simulation. Let delay_pack (i, j) (i = 1, 2, · ·; j = 1, 2, · ·) where i is number of transmission runs and j is delay-packet between two ends. We calculated and iterated in descending order d (i, j). Let *vio_prob_*$€_0$ (l) = (l − 1) × κ (l = 1, 2, · · ·, 1/κ) denote the set of violation probabilities, where κ is a scaler value (κ = 0.05). If the violation probability is € 0(l), the corresponding delay-boundary value is computed by d0 (l) = max1≤i≤m [d (i, ceiling (n ×€0 (l))]. The traffic source sends a packet periodically with data rate (r) = 10 kbps over the Rayleigh multi-channel. The arrival process curve is α (t) = data_rate + b, with b = 1 kbit.

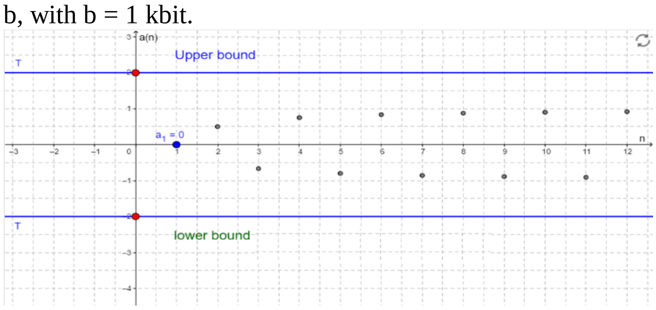

Fig. 3: Min and Max value for Upper and Lower Bounds

The above fig.3. shows the minimum and maximum bound value for effective communication in the UW communication channel.

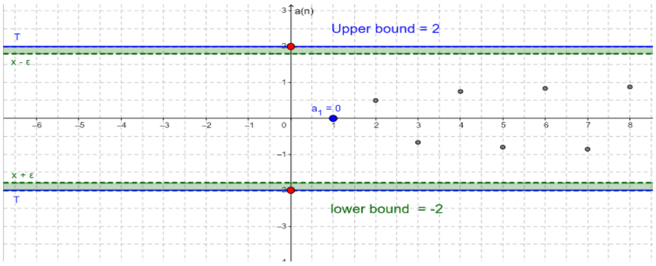

Fig. 4: Upper and Lower Bounds with delay violation probability

The above fig.4 shows the upper bound and lower bound region identification with error probability **€**.

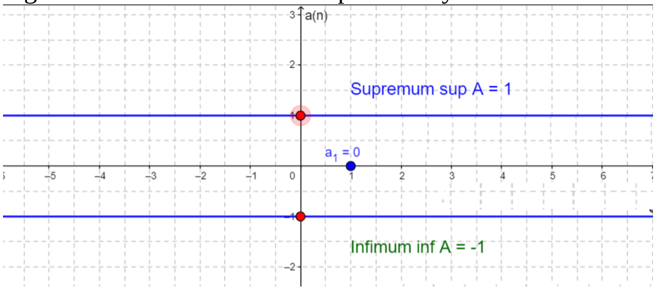

Fig. 5: Least Upper Bound and Greatest Lower Bounds(meters)

The above fig.5. shows Least upper bound and greatest lower bound value for maximum and minimum boundary values.

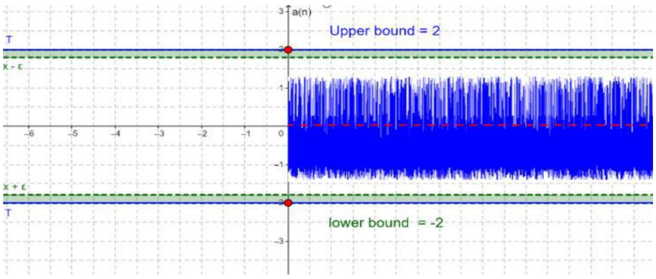

Fig. 6. Simulation Results: Packet Transmission with delay The fig.6 shows the packet transmission in the infimum and supremum boundary values with propagation delay. Parallaly it is simulated with 10000 packets with delay violation probability

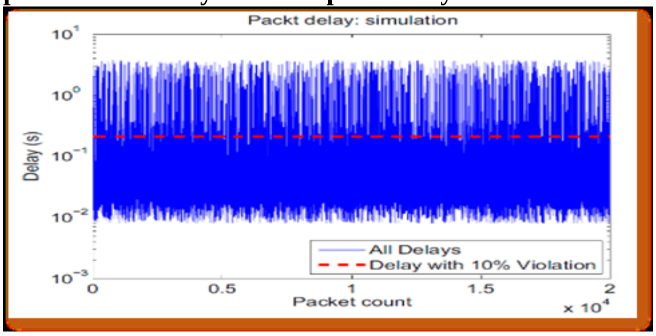

Fig. 7. Simulation Results: Packet delay This figure shows a delay for 10000 packets transmission in UW communication Channel with average delay violation probability.

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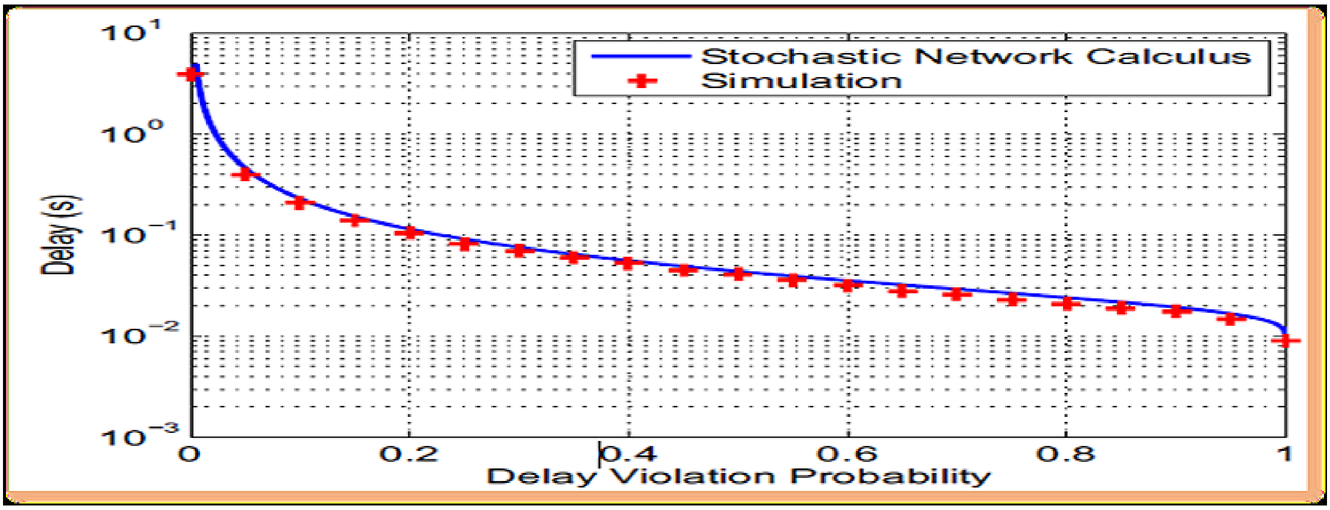

Fig. 8. Comparative analysis of the simulation model and SNC analytical results only for 1000 packets per cycle

This fig.8. shows the comparative analysis diagram between delay variation in the arrival packets in simulation and delay variation calculated by using the stochastic network calculus. The difference between the simulated results and stochastic network calculus delay variation is less. The comparative analysis of delay variation is discussed in the following table 3 and table 4 for both simulation results in multichannel communication

Packet counts / cycle		Delay with violation Probability (0 -1)																				
	Delay (Sec)	0.0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	0.1
1000		3.01	0.015	0.13	0.011	0.010	0.0095	0.026	0.024	0.022	0.020	0.018	0.011	0.0091	0.0090	0.0085	0.0079	0.0076	0.0075	0.0071	0.0069	0.0051
2000		3.12	0.131	0.27	0.022	0.017	0.016	0.030	0.028	0.026	0.022	0.020	0.013	0.0097	0.0091	0.0088	0.0080	0.0079	0.0076	0.075	0.0071	0.0060
3000		3.17	0.273	0.38	0.031	0.020	0.031	0.037	0.035	0.032	0.026	0.025	0.016	0.010	0.0097	0.0090	0.0082	0.0080	0.0079	0.0076	0.075	0.0069
4000		4.11	0.380	0.43	0.040	0.031	0.030	0.041	0.040	0.039	0.032	0.030	0.018	0.012	0.010	0.0091	0.0085	0.0082	0.0080	0.0079	0.0076	0.0071
5000		4.13	0.412	0.52	0.051	0.042	0.041	0.048	0.046	0.043	0.039	0.037	0.021	0.015	0.012	0.0097	0.0088	0.0085	0.0082	0.0080	0.0079	0.075
6000		4.15	0.504	0.65	0.063	0.052	0.052	0.052	0.050	0.045	0.043	0.038	0.025	0.018	0.015	0.010	0.0090	0.0088	0.0085	0.0082	0.0080	0.0076
7000		4.75	0.585	0.72	0.078	0.065	0.064	0.057	0.055	0.047	0.045	0.040	0.027	0.021	0.018	0.012	0.0091	0.0090	0.0088	0.0085	0.0082	0.0079
8000		4.81	0.610	0.83	0.087	0.071	0.070	0.061	0.059	0.049	0.047	0.042	0.029	0.023	0.021	0.015	0.0097	0.0091	0.0090	0.0088	0.0085	0.0080
9000		4.92	0.702	0.90	0.098	0.083	0.082	0.069	0.063	0.050	0.049	0.046	0.031	0.025	0.023	0.018	0.016	0.015	0.0091	0.0090	0.0088	0.0082
10000		5.101	0.712	0.921	0.101	0.091	0.101	0.072	0.065	0.051	0.046	0.041	0.033	0.027	0.024	0.021	0.018	0.016	0.014	0.012	0.011	0.009

Table 3: Result analysis table for delay and delay with violation probability

Packet counts / cycle		Stochastic Network Calculus - Delay with violation Probability (0 -1)																				
	Delay (Sec)	0.0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	0.1
1000		3.00	0.0147	0.129	0.0101	0.0100	0.00925	0.0236	0.0244	0.0242	0.0205	0.0186	0.0116	0.00911	0.00904	0.00859	0.00791	0.00760	0.00750	0.00710	0.00619	0.00511
2000		3.109	0.129	0.269	0.0202	0.0117	0.0126	0.0330	0.0248	0.0246	0.0225	0.0206	0.0135	0.00971	0.00914	0.00888	0.00801	0.00791	0.00762	0.0750	0.00711	0.00610
3000		3.169	0.2693	0.378	0.0301	0.0210	0.0321	0.0337	0.0345	0.0342	0.0265	0.0256	0.0162	0.0102	0.00971	0.00908	0.00821	0.00802	0.00793	0.00762	0.0752	0.00619
4000		4.199	0.379	0.423	0.0400	0.0311	0.0320	0.0431	0.0440	0.0349	0.0325	0.0306	0.0181	0.0124	0.0101	0.00917	0.00851	0.00825	0.00801	0.00791	0.00762	0.00711
5000		4.129	0.411	0.592	0.0501	0.0412	0.0421	0.0438	0.0446	0.0443	0.0395	0.0376	0.0218	0.0155	0.0125	0.00977	0.00881	0.00853	0.00821	0.00801	0.00792	0.0715
6000		4.143	0.500	0.695	0.0603	0.0512	0.0522	0.0532	0.0540	0.0445	0.0435	0.0386	0.0257	0.0186	0.0154	0.0105	0.00901	0.00880	0.00854	0.00821	0.00802	0.00716
7000		4.747	0.579	0.7192	0.0708	0.0615	0.0624	0.0537	0.0545	0.0447	0.0455	0.0406	0.0277	0.0211	0.0181	0.0125	0.00911	0.00904	0.00885	0.00851	0.00822	0.00719
8000		4.801	0.609	0.8293	0.0807	0.0711	0.0720	0.0631	0.0549	0.0449	0.0475	0.0426	0.0297	0.0232	0.0214	0.0154	0.00971	0.00916	0.00906	0.00881	0.00852	0.00810
9000		4.915	0.700	0.899	0.0908	0.0813	0.0822	0.0639	0.0643	0.0540	0.0495	0.0466	0.0317	0.0253	0.0231	0.0184	0.0161	0.0157	0.00918	0.00901	0.00882	0.00812
10000		5.100	0.714	0.920	0.1001	0.0911	0.1021	0.0732	0.0645	0.0541	0.0465	0.0416	0.0337	0.0277	0.0240	0.0214	0.0181	0.0167	0.0141	0.012	0.011	0.0019

Table 4: Result analysis table for delay and delay with violation probability using stochastic network calculus.

VI. CONCLUSION

we intend a scheme for the mathematical model using SNC and Quality of Service based on input and delay variation probability of underwater communication channels with fading. The key challenge in analyzing underwater wireless systems is uncertainty with fading in multi-channels. SNC is used to mathematically derive the model of an underwater wireless network with multichannel including fading and identify delay by stochastic network calculus and backlog value for min bounds and max bounds. The analysis method is validated through simulations. Our future work would focus on modeling underwater wireless network with different types of fading.

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