Stochastic Network Calculus for Delay Variation in UWAN Multichannel Communication

Saravanan M, Rajeev Sukumaran, M.R. Christhuraj, Manikandan TT

Abstract: The behavior of underwater acoustic wireless communication is challenging one compared to terrestrial communication due to the unpredictable changes in underwater. The multichannel communication needs to consider a lot of parameters at the time of modeling and investigation such as losses and noise. Thus, communication channel separation is curiously inflexible to investigate all properties of underwater. Compared with other modes of communication, acoustics waves afford the sturdy data delivery and receiving capability in underwater. The channel allocation and detachment appearing quite difficult in acoustic with respect to techniques that induce the transmission of data digitally, which compared with the major properties of attenuation variation in underwater. In this proposal, we concentrate on the numerical results for the transmission and receiver end delay variation with the help of stochastic network calculus to measure the deviation between the simulation and numerical results (SNC) with respect to multichannel (MC).

Keywords: Stochastic Network Calculus (SNC), Underwater Wireless Acoustic Communication (UWAN), Medium Access Control (MAC), Delay Bound, SNR - Signal Noise Ratio.

I. INTRODUCTION

Research activities are increased in the discovery of new findings to improve the security, minerals finding in an acoustic environment due to security concerns. Many research organizations have deployed sensors, actuators and other communications devices in underwater for making the data transmission. RWN has utilized in earthbound wireless communication but radio signals are not adequate for submerged area ocean level communication. RWN rules and regulations for communication are unsuitable for UWAN due to the flow of data and processing the digital data is different in RWN protocols. The channel allocation in MAC is a complex task that has to satisfy real-time requirements to satisfy the pedagogy challenges, especially absorption, Doppler effects, propagation delays, speed of the signal, lower capacity of the channel, low channel quality and etc. High variation in delay (transmission/receiver) is an important factor that forcefully pulls down the performance of underwater areas.

Due to uncertainty in underwater, the characteristics always changeable. Characteristics of underwater such as the utilization of channel, medium, energy preservation and conservation for node efficiency, selection of protocol based on the situation to implement, QoS, mobility, and validation of protocol. The UWCN applications need to improve the quality and security such as environmental studies related to natural hazards, communication-related activities for marine, scientific research towards the mines, water content quality monitoring, finding oil resources and gas refinery resources availability, scientific applications, bottom image scanning and AUV communication for anomaly object identification.

Fig. 1 indicate the correspondence between the Tx and the recipient through various channels. The correspondence channels are differing dependent on the reflections. The underwater wireless acoustic correspondence framework is a two-way correspondence framework in which advanced information is changed over into a unique underwater sound signal [1]. At that point, these signals are gotten by another station and afterward changed over back to advanced information. This correspondence is done in the multipath proliferation of underwater wireless acoustic signals. As appeared in figure 1.1, underwater wireless correspondence comprises a transceiver with radio sensors appended to them. We can transmit EM or acoustic wave however acoustics is the principle decision as it gives better outcomes and better range. Because of attenuation, the transmitted signal transmits in a type of multipath.

Figure 1. View of multipath communication in Underwater
II. RELATED WORK

Generally, Network calculus gives an idea about the systematic way of the design of networks and its numerical calculations, planning, and asset necessities. SNC is an extended version of network calculus for execution and investigation of properties which helps to analyze the different aspects of WSNs by a few specialists [22]. The network calculus [23] helps to analyze different flow designs of the networks along with topology. The tree-structured sensor networks have demonstrated and its optimistic scenario illustrated with sensor_networks. It focused on the delivery of streams with different limits, BW, tree structure mapped properties. The creators exhibited techniques to process the pessimistic delay scenario, memory-related to general-purpose register for buffering necessities [10]. SNC illustrates the capability of processing and arriving bits experienced knowledge helps to analyze the results in randomness in stochastic for packet size based networks.

The idea of probabilistic boundary values with respect to the bound values are drawn through the curve values[24]. The graphical representation is used to show the variation of the processed streams. The DFC will give the static outcome related analysis results and SNC extended the features of DFC and included the randomness analyzed properties and bounds for the entire network outcome deviation occurred along with the bits and delayed activities which can reduce the current innovations. Christ [3] et al. proposed different fading techniques using SNC for packet loss over the acoustic medium. The server framework to encourage investigation and solicitation of the issues in the channel allocation, data faded with different terminologies measured in through SNC. There are many research articles give the idea about the theoretical needs of acoustic communication, however, not many of them discussed the simulation and mathematically derived results to map the issue with the rationale to all types of wireless communication.

III. MODELING MULTI-CHANNEL PROPAGATION

A. Multi-Channel design with SNC for UWN

UWN communication is possible with long-distance when the signal is transmitted as acoustic signals compared to other methodologies. Fig 2. Illustrate the propagation of acoustic signals in a different path and different channels. This model demonstrates the signal in the form of acoustic flow from one end to another communication device with multichannel support. The data is converted as a digital wave then it is given to a sound wave signal converter, then the data sent by the Tx to the multipath propagation or multi-channel communication from (Tx to Rx) from the source. The traffic flow may be generated with variable size of the datagrams originated to multipath traffic flow occurs in multi-dimension with respect to propagation, reflection, and fading. Finally, the Rx receiver gets the low powered signal after long propagation in a different path with different time duration or time to live values. Rx will deposit all received signals in-memory buffer for later analysis. The analysis includes the bits verification and duplication removal of data from a different path. Finally, it removes the duplication data by sequence values, if there is any data loss or sequence number is missing then it sends the negative ACK to resend the data’s in a fast retransmission manner. These activities in terrestrial activities are hard to compare but the analytical comparison will help the researchers to enrich the quality transmission in the underwater asynchronous communication.

The above fig 2. shows the multi-channel with the discrete flow with fading in Eqn. (1) & (2) by,

Output Y for single-channel is derived from the channel amplitude and uniform distributed input from Tx added with uniformly distributed Gaussian noise. That can be written as

\[ Y(\text{single channel output}) = |Amp| \times \text{uniformly distributed input* channel gain} + \text{Gaussian Noise} \]

\[ Y(\text{single channel output}) = |Amp| \times e^\sigma \times \text{Gaussian Noise} \]

For multi-channel design, the output can be written as

\[ Y(\text{multi channel output}) = \{ Y_{1(\text{co})}, Y_{2(\text{co})}, Y_{3(\text{co})}, \ldots, Y_{n(\text{co})} \} \]

\[ Y(\text{multi channel output}) = \{ |Amp| \times e^\sigma \times \text{Gaussian Noise} \} \]

Where TX_in is denoted as input generated by Transmitter Tx, Y_in is denoted as output received by receiver Rx. Gn is Gaussian noise with uniformly distributed. \(|Amp|e^\sigma\) is the gain value of the channel with amplitude \(|Amp|\) which is a dynamic generated g during running time and \(e\) is UD_phase interval of 0 to 2\(\pi\). Sometimes \(|Amp|\) denoted as \(|Rtn|\) Assumptions for this model:

1. data distribution as a sound wave is carried out by both Tx and Rx.
2. intermediate device can record the state of information and can view the state information.
3. data propagation in multi-channel faced slow fading.
4. The signal can be transmitted in different paths within the available bandwidth. For this demonstration in the simulation, we considered the model \(P_{tx}\) is the required power for successful transmission and reception. BW is used to mention the bandwidth and \(N_0\) is expressing density of the power variation noise. The cumulative capacity which derived for a channel can be calculated in Eqn. (3).

\[ C = W \log_2 (1 + 10^{\text{BW}/10}) \]

\[ C = W \log_2 (1 + P_{tx}/|Rtn|^2) \]

The SNR value is not introduced in the initial transmission. But it can be introduced in the number of trains and the analytical process completed, then it will be introduced during the number of cycle processed.
transmission. The multi-channel with FR fading can be derived in Eqn. (5) as,

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

\[ = \text{Prob.} \left( W \log_2 \left( 1 + \left( \frac{P_{\text{tran}}}{P_{\text{noise}}} \right) \right) \right) < \text{Traffic Flow Data Rate}(R) \]

Gain value for the different transmission in the multi-channel can be recorded F(x), it has pdf with FR fade denoted int (Eqn. 6)

\[ F(x) = x \times \text{exponential}(x^2/2) \]

the density function for the equation 6 is expressed in the eqn.7

\[ \text{Density fun DEF}(x) = (0.5) \times \text{exponential}(x^2/2) \]

The probability of output is derived and analyzed with the following Eqn. (8) as follows,

\[ \text{Prob. O/P} = 1 - \exp \left( \frac{1 - 2 \times \langle \delta(t) \rangle \times \exp(-t) \times \text{exp}(\text{delay bound DB}(t)) \rangle}{2 \times 10^{12}} \right) \]

V. SIMULATION AND SNC RESULTS

This segment expresses the outcomes of simulated and SNC results. We used simulations and associated numerical results for evaluating the tight bond between the simulated outcomes and SNC outcome. For this evaluation, we considered a few parameters like bandwidth, SNR, frame size and simulation Period. The bandwidth value is W=30, the communication channel noise value is 0 dB, the frame size for every cycle is 1 kilobit. This range fixed for simulation is 40 runs with respect to the distinguished inputs. The source system generates an input packet per cycle. Every simulation takes is 10000 cycles. The Delay value registered for future jitter value calculation. For the above factors, the system cant calculates the error/ violation probability directly. So it needs to calculate the violation probability by encountering the differences in delays of every packet received at the receiver end.

The contribution towards this research compares the outcomes derived from the simulation, then it has to be mapped with delay bound values. Delay-bound value calculation takes no.of cycles completed runs is R=40 and packets count is Ni=10000; every packet has to be sent as proceeding with one per cycle. The DEL(No, S) where Ns is the input packets count has to be sent per one cycle execution. That is No=1,2,…,n; S denotes the simulation count (S=1,2,…,m).

Let m = 40 is the no. of execution, and n = 10000 is the no. of packets can be transmitted in a single cycle with one sim_run. Let d(i,j) where (1<i<n; 1<j<n) where i denotes no. of runs and j denote the delay. The calculation part shoes the descending order results with violation probabilities \( \varepsilon(R) \), the delay_bound value can be derived from the Eqn. (10). Sample delay bound calculation is obtained from the Eqn. (9) and Eqn. (10). Let the sample \( \varepsilon(3) = 0.1 \), The delay bound value is, \( \text{DEL(3)} = \text{Maximum}_{\text{vioProb}} \text{DB}(N_i,10000 \times 0.1) \)

The arrival curve can be recorded through the curvature model equation arr_o(t) = data_rate*t + b, with b = constant (1 kb).

\[ \text{DB}(t) = \text{Maximum}_{\text{vioProb}} \text{DB}(N_i,10000 \times 0.1) \] (10)
The above Fig.3 shows the simulation results with the packet transmission including 1000 packets in one complete transmission.

**Fig. 4. Comparison of simulation and analytical results.**

The delay of the packet transmission bounded between 0.13 seconds to 5.5 seconds, which is expressed in Fig. 4. The equation-10 helps to derive the analytical results for the delay bound values of the arrival packets. The outcomes induce to compare with simulated results show the heterogeneous outcomes. We got the differences between the simulated and analytical is 6.01% as the minimum difference and 15.4% is the maximum difference for multichannel communication. This comparative analysis concludes the tight bound delay performance which derived by both simulation and analytical.

**Fig. 5. Comparison of simulation and analytical results for various packet counts**

The min & max delay variation can be encountered through the simulation and analytical outcomes with respect to underwater multi-channel communication have illustrated in Fig. 4 and Fig. 5. The different input packet count has taken for comparison results as 2000 packets, 5000 packets, and 10000 packets respectively. The avg. delay-variation between simulation and SNC analytical are encountered 8.75% & 15.9% respectively. The closely bounded value of delay bound in the arrival of packets is derived from the SNC. The SNC produces the best optimized tight bound values for both simulation and analytical results.

**VI. CONCLUSION**

In this model, we intend a scheme for modeling the delay bound variation in underwater wireless acoustic multi-channel communication. The uncertainty is a key challenge to analyze the characteristics of the underwater with fading in multi-channels. Mathematical model SNC is used to derive the model for delay bound variation calculation between simulation and mathematical model of an underwater wireless network with multichannel including FR fading. The comparison results of SNC and simulation gives the difference 8-12% variation and identify delay bound calculation. Future work, we would like to focus on modeling underwater wireless network with backlog value for multichannel for different types of data loss and data fading.

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**AUTHORS PROFILE**

**M.Saravanan** is a research scholar in SRMIST Chennai and received Bachelor’s and Master's degrees in CSE from Anna University, Tamilnadu. Currently working in SRM Center for Applied in Research and Education, SRMIST, Chennai, India.

**Rajeev Sukumaran** is an Engineering Epistemologist and a Learning Researcher. He received his Ph.D in Computer Engineering and is an active researcher in Modeling Wireless Communication Networks and is with the Teaching Learning Centre, Indian Institute of Technology Madras, Chennai, India.
Christhu Raj is an enthusiastic researcher in Stochastic Network Calculus Models for Underwater Wireless Communication. He received his Ph.D. in CSE and is an active researcher. Currently working in SRM Center for Applied in Research and Education, SRMIST, Chennai.

Manikandan T T received a B.Tech in Computer Science and Engineering from SASTRA University, ME in Computer Science and Engineering from College of Engineering, Anna University and he is currently perusing Ph.D. in Computer Science and Engineering at SRM Institute of Science and Technology.