Journal on Internet of Things
DOI:10.32604/jiot.2021.016747
Article

Routing Protocol in Underwater Wireless Acoustic Communication Using Non Orthogonal Multiple Access

J. V. Anand[1], R. Praveena[2,*] and T. R. Ganesh Babu[2]

[1]PACE Institute of Technology and Sciences, Ongole, Andhra Pradesh, 523272, India
[2]Muthayammal Engineering College, Namakkal, Tamilnadu, 637408, India
[*]Corresponding Author: R. Praveena. Email: praveenajuhi@gmail.com
Received: 01 August 2021; Accepted: 15 October 2021

Abstract: The underwater wireless communication with the complexity of attenuation and low propagation speed makes resource constraints in networking sensor nodes and sink. Underwater Sensor Transmission with Attenuation Calculation using Non Orthogonal Multiple Access (UWSTAC-NOMA) protocol has been proposed. This protocol calculates channel gain along with attenuation in underwater channels and provides internetworking sensor for rate allocation minimizing interference. Successive Interference Cancellation has been used at the receiving sensor to decode the information sent. The network level performance of sensors and increasing the data rate improves the overall throughput. Simultaneously, connecting several sensors to sink based on its depth region of deployment has been achieved using Underwater Sensor Transmission with Attenuation Calculation using Non Orthogonal Multiple Access (UWSTAC-NOMA). The analytical background of attenuation never confuted the simulation results of the proposed protocol in NS2 simulator. Simulation results shows that the throughput, average bit error rate and residual energy of sink performance.

Keywords: Underwater sensor and sink networking; absorption loss; transmission loss; channel gain; resource allocation; interference mitigation; Non Orthogonal Multiple Access

1 Introduction

The broadcast channel description of single source communicating to several receivers are challenging in wireless communication. The source section deploys superposition coding, which implies the process of super imposing high rate information over the low rate information. The receiver section uses Successive Interference Cancellation (SIC) where individual user signals are successively decoded. The process of subtracting the individual user signal from the combined signal happens successively when each user signal is being decoded [1].

Non Orthogonal Multiple Access with Equal transmission times and operating range of good and bad quality links has been discussed in underwater sensor networks. The limitation of wasteful resource allocation has been dealt for low traffic scenarios and two receiver nodes [2]. Improving the throughput via simultaneous transmissions at the receiver using SIC (Successive Interference Cancellation) incorporates spatial and temporal estimates. The temporal and spatial reuse MAC protocol priorly classifies nodes based on an interference model which support SIC or not [3]. The protocol developed in this work does not estimate the channel capacity but uses simultaneous transmission of underwater sensors increasing the data transfer rate. The main contribution to this work is that the Non Orthogonal Multiple Access (NOMA) has been incorporated in underwater sensor nodes. The limitation is the channel gain difference that occurs among communicating sensors should be subsequently high to provision simultaneous transmissions in NOMA. So estimating the channel gain and disseminating interference is the focus carried out and deployed the sensors to increasing the throughput. Numerical estimate of Attenuations has been calculated using Thorps [4], F&S [5], and A&M [6]. The numerical estimates provide appropriate transmit power to be assigned in simulation to increase transmission time from sensors to sink.

Section 2 deals with Literature survey of simulation works with underwater sensors and attenuation analysis. Section 3 discusses the proposed system with NOMA based data transfer in underwater environment. Section 4 deals with results of proposed protocols and comparison with existing works. Section 5 concludes the overall work.

2 Literature Survey

2.1 Underwater Channel Simulation Works

In shallow water communication OFDM with adaptive synchronization produces better performance with channel impulse response. The channel impulse response is obtained for one symbol duration as a function of number of subcarrier divided by bandwidth [7]. However, OFDM is sensitive to Doppler effects and requires equalization techniques.

Doppler effects consider the mobility of sensor nodes and surface of water have been modelled in point to point links using the static Bellhop method for virtual signal transmissions. The disadvantage of the signal transmission model is it fails of multi point to point link in multi hop communication [8]. The acoustic system mostly uses wide band signals where the total communication bandwidth is 5 kHz. Thus the nature of uncorrelated taps assumption cannot be used in frequency dependent underwater channel and requires ultra wide channel model [9]. Double spread channel occurs due to large multipath and Doppler spread. This leads to increase in inter symbol interference in single carrier system and inter carrier interference in multi carrier system [10]. The connection between throughput and offered load (generated data) has been discussed with regression fitting model considering the positive and negative coefficients using effective hydrocast data [11]. The protocol uses MAC based on orthogonal access which fails to allocate resources when compared with NOMA techniques.

2.2 Overview of Routing Protocols for Data Transfer in Underwater Sensors

Directional Antenna Dual Channel based Medium access control has been proposed for increasing the spatial reuse and reducing the interference. The protocol deploys directional network allocation vector to overcome hidden terminal problem and deafness issues [12]. The problem of using multiple isometric beams coverage and switching to beam direction for transmission might lead to increased latency. In [13], the combination of NOMA with Orthogonal Frequency Division Multiplexing, NOMA with Filter Bank for Multi Carrier has been discussed in two user scenarios for underwater acoustic communication. Both the approach uses remotely operated vehicles and turbo codes in the deployed scenario. The filter bank approach produces better results considering the metrics of bit error rate by discriminating good and bad channels compared to OFDM.

2.3 NOMA Assisted Communication

The NOMA concept has been coarsely divided into power domain and code domain. In the power domain different signals from different users are being superimposed on the transmission side with superposition coding. The receiver uses SIC for recovery of signal. The code domain version of NOMA uses special spreading sequence analogous to CDMA [14–15].

2.4 Attenuation Analysis and Noise Model

The Table 1, Table 3 and Table 5 give input parameters for calculating attenuation for short distance underwater environment. The flow level performance indicated in Table 2, Table 4 and Table 6 shows absorption loss as a function of frequency and transmission loss as a function of propagation ranges [16].

Table 1: Input parameters considered in modelling the environment for short distance

Parameter	Value
Frequency	5 kHz
Temperature	4 degrees centigrade
Salinity	35 ppt
Depth	70 m
pH	8
Propagation range	400 meters

Table 2: Calculation of Attenuations for absorption and transmission loss with short distance

Attenuation model	Absorption loss(dB/km)	Transmission loss(dB)
Thorp	0.37718	52.19207
Fisher & Simmons	0.26469	52.14708
Ainslie & McColm	0.36582	52.18752

Table 3: Input parameters considered in modelling the environment for short distance

Parameter	Value
Frequency	5 kHz
Temperature	4 degrees centigrade
Salinity	35 ppt
Depth	200 m
pH	8
Propagation range	800 meters

Table 4: Calculation of Attenuations for absorption and transmission loss with short distance

Attenuation model	Absorption loss(dB/km)	Transmission loss(dB)
Thorp	0.37718	58.36354
Fisher & Simmons	0.26224	58.27159
Ainslie & McColm	0.36013	58.3499

Table 5: Input parameters considered in modelling the environment for short distance

Parameter	Value
Frequency	5 kHz
Temperature	4 degrees centigrade
Salinity	35 ppt
Depth	250 m
pH	8
Propagation range	1 km

Table 6: Calculation attenuation as a function of absorption loss and transmission loss with short distance

Attenuation model	Absorption loss(dB/km)	Transmission loss(dB)
Thorp	0.37718	60.37718
Fisher & Simmons	0.26131	60.26131
Ainslie & McColm	0.35797	60.35797

The results of conventional attenuation model in Table 2, Table 4 and Table 6 state that the observed that transmission loss varies as a function of spherical spreading.

Noise model used as a function of frequency [17] has been given using the Eq. (1) below:

$$10\log N(f) = 50 - 18\log f \tag{1}$$

The N(f) denotes noise coefficient of frequency calculated as a frequency used for communication.

The assumption is made such that all sensors incur identical noise and is given by "n" in the proposed system.

2.5 Problem Description

The propagation speed difference in the hostile underwater environment alters the transmission times of sensors to sink causing interference. The flow level findings with attenuation model states transmission loss varies as a function of propagation range and depth. The scenario is thus complicated when networking wireless sensors with power level coefficients in NOMA as the underwater channel suffers from attenuation changing the channel gains.

3 Proposed System

3.1 Motivation

The Proposed UW-NOMA uses frequency dependant attenuation characteristics of absorption loss with transmission loss to calculate the channel gain and distinguish sensors transmission.

3.2 System Model

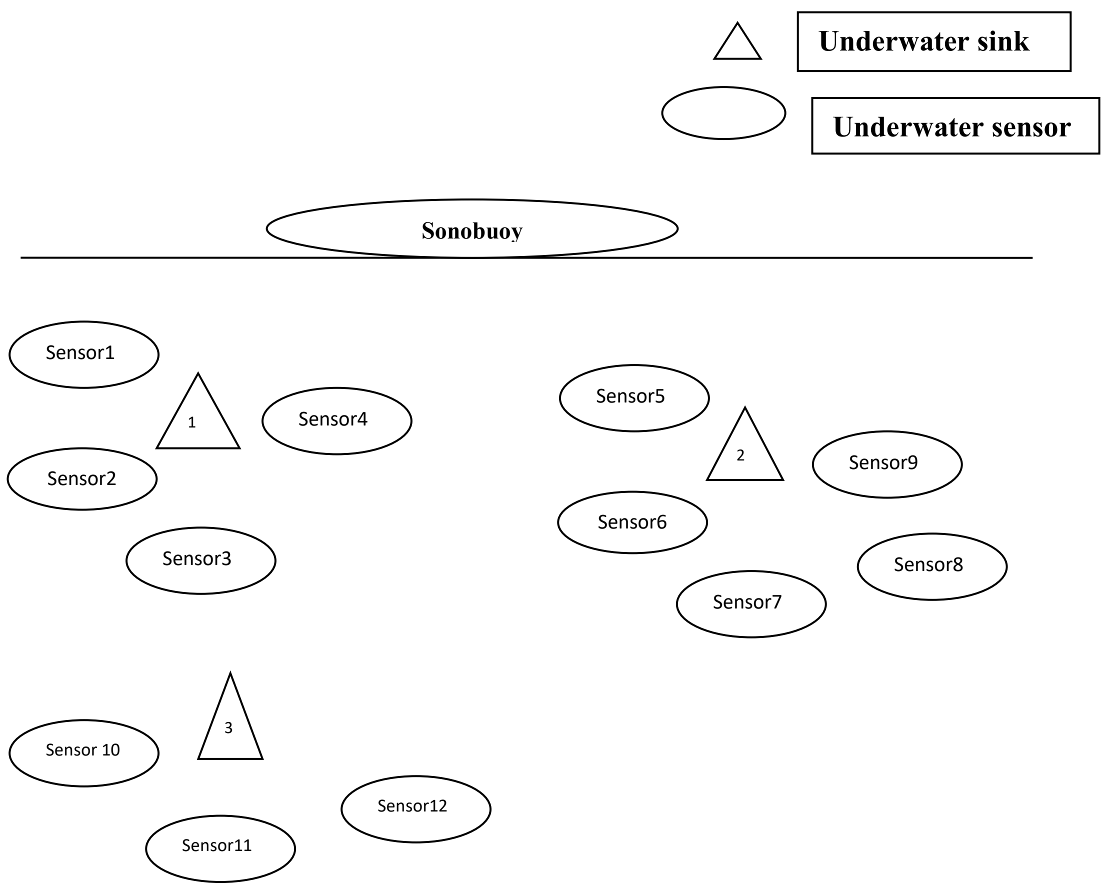

Figure 1: System model

As shown in Fig. 1, the sink is positioned beneath the underwater surface at different depth each user communication is assigned different power levels for interference cancellation. The interference cancellation at the receiver is achieved by using interfere model with propagation speed acoustic communication. Paired communication between sink and underwater sensor occurs at different depth via single hop communication. Impairments in Quality of Service (QoS) have been considered with attenuation and different depth of communication. Underwater sensors are being positioned beneath the surface of water at different depth and underwater sink placed within the location acquires data for communication to sonobuoy placed on the surface of water. The assumption used in this work is network state is stable and no mobility happens after sensors deployment. The uncertainty of underwater channel due to attenuation and distance is modelled. Thus individual sensor and its associated sink paired communication with power allocation have been estimated priorly using attenuation calculations.

3.3 Underwater Sensor Transmission with Attenuation Calculation Using Non Orthogonal Multiple Access (UWSTAC-NOMA)

Initialize the underwater sensors beneath the water surface with its associated sink. Calculate the distance of individual sensor with its associated sink. The depth distance is given by Eq. (2) below:

$$Depth\ Distance=\sqrt{\left(UW_{sxi}{}^{2}-UWS_{sx1}{}^{2}\right)+\left(UW_{syi}{}^{2}-UW_{sy1}{}^{2}\right)} \tag{2}$$

The UW_{sxi} and UW_{syi} denote the x and y coordinates of sensors. The UWS_{sx1} and UWS_{sy1} denote the x and y coordinates of sink.

Then, calculate the channel conditions of individual users and its associated sink based on the distance and depth difference to sink.

Prior to estimating channel state information the attenuation calculations provide the amount of transmission loss and absorption loss which helps in assigning power levels of sink to individual sensors. Channel gains of nearer nodes to sink are assigned less power and channel gains of further nodes to sink are assigned more power.

The scenario is explained with 4 users associated to underwater sink.

Transmitted signal:

$$X=\sum_{i=1}^{N}\sqrt{PB_{i}}\,.S_{i} \tag{3}$$

The composite signal to be transmitted by the source is given by Eq. (3). The total power is P and fraction of the power allocated based on channel condition is B_i and the original signal is S_i. A single input and single output is considered with a single antenna to reduce complexity.

$$y_1=h_1\left(P_1a_1+P_2a_2+P_3a_3+P_4a_4\right)+n \tag{4}$$

$$y_2=h_2\left(P_1a_1+P_2a_2+P_3a_3+P_4a_4\right)+n \tag{5}$$

$$y_3=h_3\left(P_1a_1+P_2a_2+P_3a_3+P_4a_4\right)+n \tag{6}$$

$$y_4=h_4\left(P_1a_1+P_2a_2+P_3a_3+P_4a_4\right)+n \tag{7}$$

The four user exhibits different channel conditions h_1, h_2, h_3 and h_4. The fraction of power allocated to four individual users has been represented as P_1, P_2, P_3 and P_4. The signal allocated to four individual users has been represented as a_1, a_2, a_3 and a_4. The noise is represented as "n".

Received signal:

The first sensor decodes the data using SIC which be obtained by rewriting Eq. (4) as below:

$$y_1-h_1P_2a_2+h_1P_3a_3+h_1P_4a_4=h_1P_1a_1+n \tag{8}$$

Thus the signal to noise ratio has been obtained from the first individual signal transmitted to first sensor. The received signal y_1 has been in Eq. (9).

$$y_1 = \frac{p_1 |h_1|^2}{n^2} \tag{9}$$

The received signal y_2 has been in Eq. (10) which is a weaker channel and it considers interference from the remaining users.

$$y_2 = \frac{p_2 |h_2|^2}{p_1 |h_2|^2 + p_3 |h_2|^2 + p_4 |h_2|^2 + n^2} \tag{10}$$

The received signal y_3 has been in Eq. (11) which is a weaker channel than sensor of first channel and sensor of second channel and it considers interference from the remaining users.

$$y_3 = \frac{p_3 |h_3|^2}{p_1 |h_3|^2 + p_2 |h_3|^2 + p_4 |h_3|^2 + n^2} \tag{11}$$

The received signal y_4 has been in Eq. (12) which is a weakest of all channels and received signal has been written using

$$y_4 = \frac{p_4 |h_4|^2}{p_1 |h_4|^2 + p_2 |h_4|^2 + p_3 |h_3|^2 + n^2} \tag{12}$$

The data rate of second individual users is given in Eq. (13).

$$R_i = \log_2 \left(1 + \frac{p_i p |h_i|^2}{p |h_i|^2 \sum_{k=i+1}^{N} p_k + n^2} \right) \tag{13}$$

4 Result and Discussion

Aquasim packet level simulator for underwater sensor has been used for simulating the desired topology of underwater sensors with Network Simulator 2 [18]. In built noise calculations is not present in aquasim but network entity class has been used for creating noise as a dependant of frequency to all sensors. The assumption is the number of sensors associated in sensing the information is less and all are perfectly synchronized transmission happens from sink to surface sink named as sonobuoy. Table 7 shows significant simulation parameter used in this work.

Table 7: Significant simulation parameter used in this work

Simulation Parameter	Corresponding values
Total number of sensors	20
Number of sinks	3
Initial energy of sink	8 J
Terrain	500 m^2
Minimum and Maximum communication range	70 m to 250 m
Channel capacity	10 Kbps
Frequency used	5 kHzs
Total simulation duration	1000 s

Increasing the data rate as a function of channel gain and attenuation in underwater with UWSTAC-NOMA has been noted across the conventional attenuation model shown in Fig. 2.

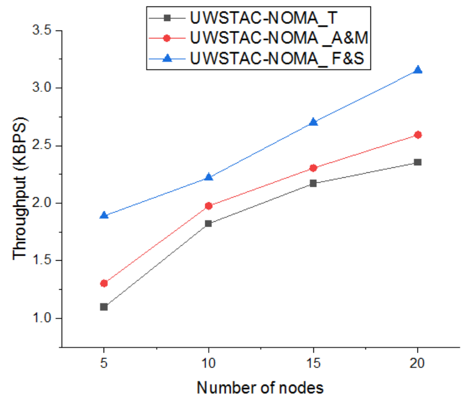

Figure 2: Throughput *vs.* Number of sensors

In Fig. 3, underwater sinks average energy consumption has been calculated with UWSTAC-NOMA where pair wise communication has been initiated simultaneously to underwater sensors. The Underwater sink has the responsibility of transferring data to the sonobuoy.

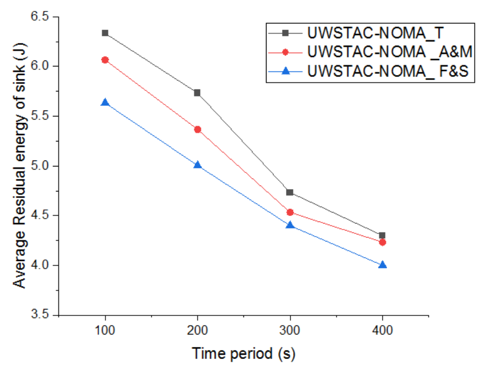

Figure 3: Residual energy of sink versus Time period

The interference of sensor with varying channel conditions and its impact of bit error rate have been shown in Fig. 4. Strong channel conditions produce low BER and weak channel conditions lead to high BER.

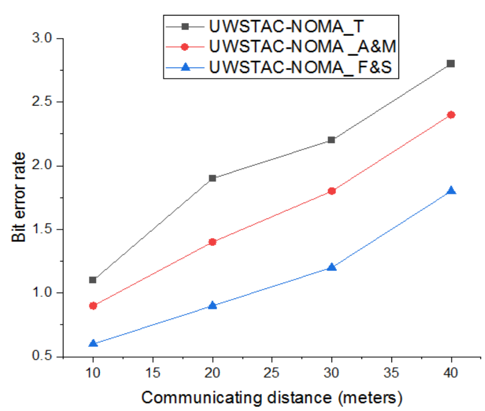

Figure 4: Bit error rate *vs.* Signal to noise ratio

Thus the non orthogonal multiple access and its deviation across three attenuation models in underwater with acoustic communication has been envisioned in this research work. Incorporating sensor network with channel gains has been different when underwater channels in the same protocol observed with throughput, bit error rate shown in the results section.

5 Conclusion

The theoretical calculations of attenuation provide individual channel gain of sensors in transmission from the sink. Thus prior to channel state information obtaining attenuation values provide the desired power allocated to sensors in transmission from the sink improving the transmission efficiency. Thus the conservative approach of increasing systematic transmissions is reduced and the simultaneous transmission has been initiated. Future work would emphasis on asynchronous NOMA in sensors with delay sensitive information transfer using multi-hop communication.

Funding Statement: The authors received no specific funding for this study.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

[1] T. Cover, "Broadcast channels," *IEEE Transactions on Information Theory*, vol. 18, no. 1, pp. 2–14, 1972.

[2] J. Cheon and H. S. Cho, "Power allocation scheme for non-orthogonal multiple access in underwater acoustic communications," *Sensors*, vol. 17, no. 11, pp. 1–13, 2017.

[3] R. Li, J. Tu and S. Yu, "Joint temporal and spatial reuse for underwater acoustic networks exploiting successive interference cancellation," *Adhoc & Sensor Wireless Networks*, vol. 44, no. 1, pp. 83–107, 2019.

[4] W. H. Thorp, "Analytic description of the low frequency attenuation coefficient," *The Journal of the Acoustical Society of America*, vol. 42, no. 1, pp. 270–270, 1967.

[5] F. H. Fisher and V. P. Simmons, "Sound absorption in sea water," *The Journal of the Acoustical Society of America*, vol. 62, no. 3, pp. 558–564, 1977.

[6] M. A. Ainslie and J. A. McColm, "A simplified formula for viscous and chemical absorption in sea water," *The Journal of the Acoustical Society of America*, vol. 103, no. 3, pp. 1671–1672, 1998.

[7] M. Stojanovic, "OFDM for underwater acoustic communications: Adaptive synchronization and sparse channel estimation," in *IEEE Int. Conf. on Acoustics, Speech and Signal Processin*g, pp. 5288–5291, 2008.

[8] M. Siderius and M. B. Porter, "Modelling broadband ocean acoustic transmissions with time-varying sea surfaces," *The Journal of the Acoustical Society of America*, vol. 124, no. 1, pp. 137–150, 2008.

[9] G. Tuna and V. C. Gungor, "A survey on deployment techniques, localization algorithms, and research challenges for underwater acoustic sensor networks," *International Journal of Communication Systems*, vol. 30, no. 17, pp. 1–21, 2017.

[10] M. R. Khan, B. Das and B. B. Pati, "Channel estimation strategies for Underwater Acoustic (UWA) communication, an overview," *Journal of the Franklin Institute*, vol. 357, no. 11, pp. 7229–7265, 2020.

[11] J. V. Anand and S. Titus, "Regression based analysis of effective hydrocast in underwater environment," in *IEEE Region 10 Conf.*, pp. 1–6, 2014.

[12] J. Yang, G. Qiao, Q. Hu, J. Zhang and G. Du, "A dual channel Medium Access Control (MAC) protocol for underwater acoustic sensor networks based on directional antenna," *Symmetry*, vol. 12, no. 6, pp. 878, 2020.

[13] M. J. Bocus, D. Agrafiotis and A. Doufexi, "Non-Orthogonal Multiple Access (NOMA) for underwater acoustic communication," in *IEEE 88th Vehicular Technology Conf. (VTC-Fall)*, pp. 1–5, 2018.

[14] L. Dai, B. Wang, Z. Ding, Z. Wang, S. Chen *et al,* "A survey of non-orthogonal multiple access for 5G," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 3, pp. 2294–2323, 2018.

[15] S. R. Islam, N. Avazov, O. A. Dobre and K. S. Kwak, "Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 721–742, 2016.

[16] 2020. [Online]. Available: http://www.tsuchiya2.org/.

[17] M. Stojanovic, “On the relationship between capacity and distance in an underwater acoustic communication channel,” *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 11, no. 4, pp. 34–43, 2007.

[18] P. Xie, Z. Zhou, Z. Peng, H. Yan, T. Hu *et al.,* “Aqua-Sim: An NS-2 based simulator for underwater sensor networks,” in *OCEANS*, Biloxi, MS, USA, pp. 1–7, 2009.