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Blue Laser Optical NOMA Communication Applied on Control Drone-to-Underwater Vehicle

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Abstract

Today deep ocean life has not been discovered by humans including many secret world things to be explored. The researcher has focused on underwater optical wireless communications using various kinds of complex digital Signal processing most of them used in air and starting applied in underwater communication. The Internet of Things (IoT) uses underwater called Internet of Underwater Things (IoUT) applications to explore the underwater world with other devices. However, the difference in concentration between air and water surfaces is not easy making wireless communication more complicated. Visible light passes the water's surface with scattering and distortion inside the water and each color of light has different attenuation the blue laser light has low distortions and scattering which means lower attenuation in water. The Non-Orthogonal Multiple Access (NOMA) is a promising next-generation underwater wireless optical communications technology. Moreover; this technology has many features such as low (power consumption, attenuation, noise, and BER (Bit Error Rate)) with a high bit rate. Therefore; our research proposes a blue laser optical communication system for drone-to-underwater vehicles by optical NOMA techniques that can support various important applications for marine exploration or inspection, This technology uses an underwater Remote Operating Vehicle (ROV) combined with a Drone to collect data information from deep oceans to study and discover the secret deep ocean underwater world with high-quality video and picture. In addition, studying the effect of different weather and water types on the proposed model.

Keywords- Blue laser, Non-Orthogonal Multiple Access, Underwater communication, Visible light communication, Kintex-7 FPAG.

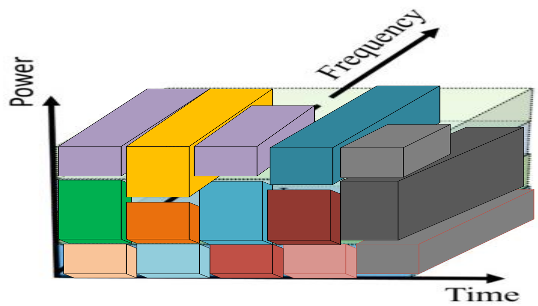
I. INTRODUCTION

The future of smart oceans and the Internet of Underwater Things (IoUT) will be the main enablers for exploring and monitoring the underwater world [1]. Visible light, particularly laser blue light, is one of the lowest attenuated signals in water compared to other color laser and electromagnetic signals such as RF acoustic waves, which makes practical underwater optical wireless communication feasible [2][3]. Recent advances in laser Under Optical Wireless Communication (UOWC) stimulate various applications of the (IoUT) in different fields such as smart oceans, environmental monitoring, and offshore engineering [3]. Underwater Communication is the key to achieving self-powered functionality when the ROV operates under the water’s surface. The main reason uses laser light is because radio frequency RF signals cannot penetrate the sea surface but the blue laser can break the water surface and work as a transport signal for the deep ocean and the RF signal has high attenuation in water when compared to laser light. The underwater drone-ROV communication using visible light has not been realized with low water attenuation and high bit rate. One of the candidate solutions is to get high-resolution video with low attenuation of the underwater signal and high bit rate by the combination of UWOC with another communication technology such as NOMA and blue laser. Therefore; use an integration between visible light communication technology and FPGA to design the model [4]. The underwater acoustic waves used in communication (UAC) are not electromagnetic waves but the Radio Frequency (RF) is an electromagnetic wave. However, both techniques are used for long-range but suffer from attenuation, scattering, high (time delay, power consumption, and transmission power). The transmission power of the RF techniques depends on the distance which increases with long distance and the latency is lower than acoustic techniques. These techniques above have a frequency of no more than 300 Hz. The bandwidth frequency in kHz for acoustic and MHz for RF. In data rate the RF techniques Mbit/s when compared with acoustic in Kbit/s. Therefore, the quality of communication is poor when using those techniques. Therefore, optical underwater wireless communication has many advantages over the two techniques above such as low (power consumption, latency, and transmission power). In addition, get high (data rates in Gb/s, bandwidth MHz-GHz, and frequency in THz). Furthermore, these techniques have features such as high-cost effectiveness, and lower power consumption when using laser diode, LED, and photodiode) [5]. In this work, we investigate and analyze the effect of different weather conditions such as (clear, rainy, cloudy, windy, and snowing) and different water types such as (clear tap water, and ocean turbid water) on the signal of control drone-to-underwater vehicle by using optical recursive (NOMA) techniques combined with blue laser systems. The recursive NOMA has lower complexity and power consumption when compared with conventional NOMA. Moreover, using a blue laser with NOMA because both techniques have low attenuation and high data rates when compared with other techniques and visible light types. The drone is equipped with visible high-power and energy-efficient blue laser light to serve the designed multiple optical

NOMA signals to support the intra-inter-node communication among underwater vehicle users. The drone ascends to hover about the sea surface to establish the line-of-sight communication link with the underwater control vehicle [6]. The access laser light in the downlink and backscattering signals among underwater vehicle users is optical NOMA with superposed signal beamforming, which can reach more than 100m in deep water[7]. The performance in terms of outage latency and bit error rate is analyzed and the impacts of multiple access channels of optical NOMA parameters and the positions of underwater vehicle users are considered. The proposed design idea provides a high data rate with low power consumption using blue laser light to transport data from the sky where the drone flies to ocean water so the blue laser can pass the water and have good transport for data to the ocean water where the vehicle dives through underwater. The design system uses MATLAB Simulink and AMD Xilinx system generator to design the NOMA transceiver using a Kintex-7 FPGA evaluation board. The proposed system design works towards UOWC smart oceans for underwater vehicle-to-drone laser optical wireless line of sight communication. This paper aims to present how the establishment of blue laser with recursive NOMA technology in optical communication for drone-to-underwater vehicles can lead to high data rate communication with low latency and attenuation.

II. IDENTIFY, RESEARCH AND COLLECT IDEA

Underwater optical wireless communication (UWOC) can dramatically increase data rates immune to electromagnetic interference and has attracted enormous attention as a core technology for underwater wireless systems [8]. However, owing to the properties of the underwater environment, there is a physical upper bound for the data rate. A practical UOWC technique should be developed so that it can be a system to which multiple high-data-rate systems can be concatenated [9]. Optical non-orthogonal multiple access (NOMA), a promising technique for visible light communications, also applies to UOWC [10]. We first demonstrate NOMA-based underwater optical communication technology because multi-users in the cell can send at the same time and not depend on frequency domain but on power location. This benefits NOMA over the other methods, such as OFDM which is a low water attenuation, depends on the power domain, not the frequency domain or time domain which achieves multi-users at the same time and with the same frequency resources to reduce the subcarrier interfaces, increased number of user on the same period, low latency, increase reliability, and flexible power control between weak and strong users, enhance the weak cell quality [11]. However, the results of early experiments show that the underwater environment's characteristics limit how much data can be transmitted [12]. Therefore, there is much diversity in underwater systems that are born from such various conditions: fixed or mobile modes, relatively high or low topological limitations, high or low data rates, and long or short connection distances [13]. Currently, no unique UOWC solution can satisfy all such constraints on the other hand, the physical layer throughput can be economically increased if multiple high-data-rate systems are properly combined [14]. Then, we make use of the fact that the pressure of the water is somewhat lower than the air pressure at sea level and consider the effects of sunlight on optical wireless communication [15]. Underwater communication is difficult because the radio frequency is usually not available for use over a long-range, and underwater sound waves have a long delay of several tens of milliseconds [16], while a large Doppler shift occurs due to the relative motion of the transmitter and the receiver [17]. In the traditional method, acoustic or radio waves are used under the sea but their communication distance is unfavorable as radio waves are difficult to propagate in the sea, and a wired communication system is sometimes constructed [18]. If there is a way to arbitrarily communicate over a long range with low latency and high speed, various circumstances such as disaster rescue and defense use cannot be solved that way. In recent years, with the advancement of technology, exploitation has been investigated, and many new methods have been proposed underwater [19]. Several mechanisms can attenuate and absorb visible light in water [20]. Although pure water has no absorption coefficient above UV, organic matter in water can low absorb blue light Laser light400-450 nm [21][22]. The organic matter in water is typically derived from decaying plant matter, decaying animal matter, or metabolic waste produced by marine species[23]. While it may still be used for very short-distance communication applications, for practical long-range communications, the communication channels in water can only be found in blue laser wavelength under 450nm [24]. These wavelengths correspond to the wavelengths that can penetrate seawater more deeply than others [25]. Light in water can be attenuated and absorbed by several mechanisms. Although pure water has no absorption coefficient above UV, organic matter in water can reabsorb light in UV down to 650 nm. The organic matter in water is typically derived from decaying plant matter, decaying animal matter, or metabolic waste produced by marine species. While it may still be used for very short-distance communication applications, for practical long-range communications, the communication channels in water can only be found in several infrared wavelengths: 780, 850, 1060, and 1550. These wavelengths correspond to the wavelengths that can penetrate seawater more deeply than others. The 850-nm wavelength was selected as the optical source wavelength since the 850-nm wavelength is also the commercially available laser optical cross-section. With an 850-nm wavelength as the downlink from the drone vehicle to the submarine, the communication system can be readily established. Compared with optical wireless communications, underwater acoustic communication has a longer application history due to its low attenuation level and long propagation distance. However, the slow data rate and severe delay are the drawbacks of underwater acoustic systems. Although RF communication can provide a much higher data rate than acoustic systems, the extremely limited propagation range due to the high attenuation of radio waves in the water limits its application. The attenuation of the RF signal is increased with increasing the frequency of underwater communication. The blue and green lights have low water attenuation coefficient which is preferable for clear and turbid underwater communication. The water attenuation is the total contribution of the signal absorption, fading, and scattering) as we know that optical intensity modulation and direct detection systems have large signal-to-noise ratios (SNRs) and large bit error rates (BERs) due to Short Noise and thermal noise [25]. To reduce the SNRs and BERs, we used multi-carriers for one subscriber. Multiple carriers can be generated by a digital signal processor and their phases and amplitudes can be controlled [30]. The newly developed non-orthogonal multiple access (NOMA) technique is a promising candidate for realizing massive connectivity of users [31]. In NOMA, users can share their resources, including frequency and time, so that the degree of freedom can be drastically increased. This approach is quite different from traditional orthogonal multiple access, which strictly maintains orthogonality for resource allocation of individual access devices [32]. This is a progressive change in the viewpoint of resource allocation for multiple access systems. Traditionally, most research on modulation and coding is conducted under the framework of orthogonal access, where users, including mobile terminals and other types of access devices, use the total available resources, such as frequency and time, in a strictly exclusive manner [33]. However, this new principle of non-orthogonal access liberates the restrictions imposed by orthogonality [34]. Figure (1) below shows NOMA techniques with subcarriers in power location. the multiple subcarriers can be sent at the same time with distributed in the power domain, not in the frequency or time domain. This technology increases the data rate for transmission [35].

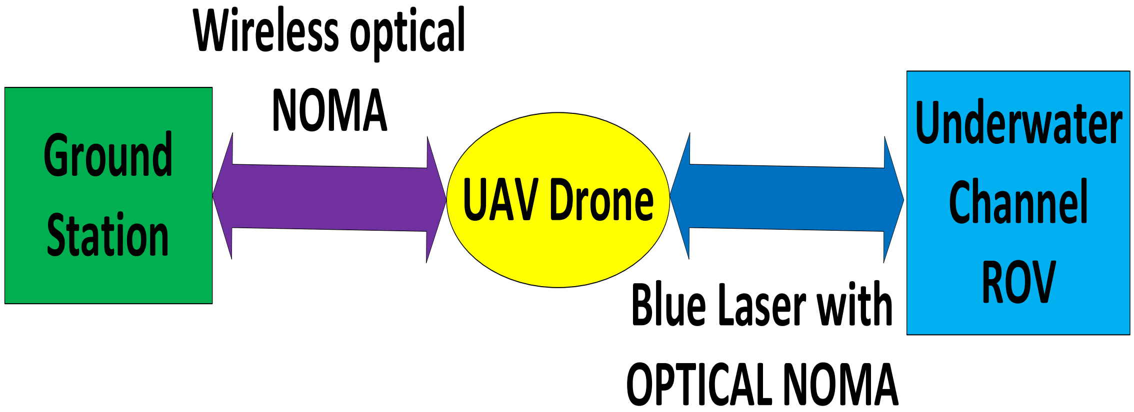


Figure, 1 Noma user's distributions

Non-orthogonal multiple access (NOMA) is an advanced technology for next-generation communication systems, aiming at extensive utilization of resources in a flexible manner [36]. Data communication between aerial and underwater vehicles is challenging. In many well-established communication systems, radio frequency (RF) waves are used as the medium of communication. However, RF waves do not function in underwater environments, particularly for long-distance communication [37]. By contrast, acoustic waves are the best means of communication underwater but have many disadvantages. Nevertheless, there are a few technologies like acoustic sound waves can be used to establish communication between aerial and underwater vehicles effectively. We proposed and developed a technology known as optical blue laser for underwater communication based on the non-orthogonal multiple access concept [38]. That technology is based on the use of lasers for both aerial and underwater transmission [39].

III. STUDIES AND FINDINGS

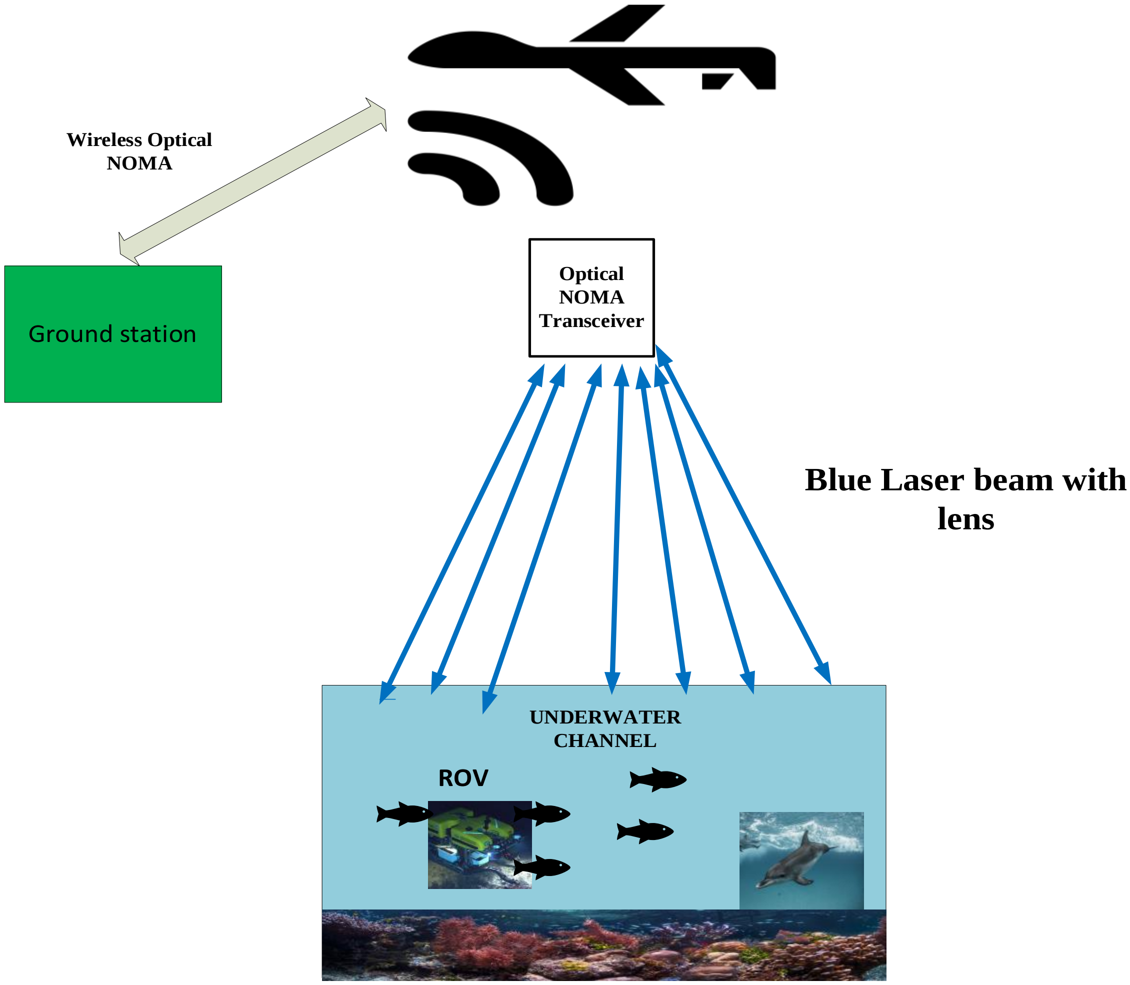
Underwater ROV motion control technology uses wireless communication with a range that involves harmonic motion and resonance rotating control operations, which are required alongside automatic docking and total laser automatic gain control in the optical communication system [40]. The underwater vehicle's autonomous operation in such an optical environment is an essential communication range adjustment technology that enables optical access [41]. In addition; Point-to-point optical communication methods have begun to mature, and methods have been developed to expand communication distance and bandwidth, such as NOMA figure 2 shows the main components structure of our experiment project



Figure, 2 Basic proposed model flowchart

The figure above shows that the drone has a high-power blue laser for data transmission with VLC using NOMA technology combined with OFDM. This technique uses a blue laser to communicate between drones in space and remotely operating vehicles ROVs dive in underwater also communicate with the drone through the blue laser technology. In addition, the optical amplification scheme is under development to realize division multiplexing or wavelength frequency division and stable communication. Although the communication area is significantly narrower compared to RF communication and the communication distance is generally short, the communication speed is much higher, and the distance-bandwidth product and the intercommunication interference characteristics are much better.

An experiment was done for a system model that combines recursive NOMA and uses a blue laser as a transport medium between air and water to control the drone from the ground station. In addition; the optical NOMA communication from drone to ROV using a blue laser. The description of the design model is shown in Figure. 3 which describes the type of communication of each stage in detail. the controller from the ground station uses optical wireless communication with NOMA to communicate with the UAV drone which hovers over the surface water to transmit and receive data from the underwater ROV, a blue laser is used for transmission using the same techniques as optical NOMA. The blue laser is used to transport from air to water with low distortions which can pass the water surface.

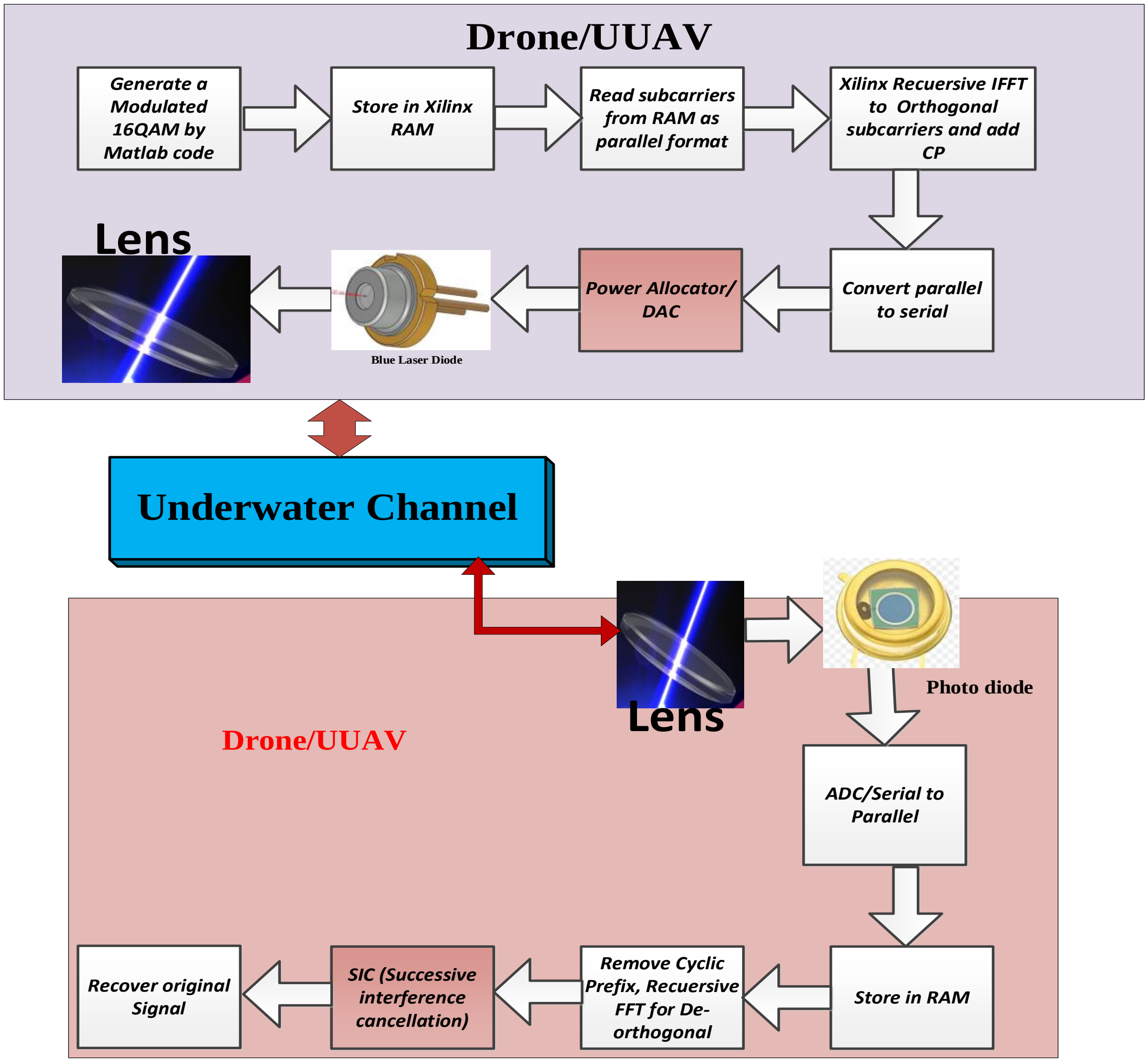


Figure, 3 Proposed model architecture

The figure above shows the laser beam in two directions send and receive from drone and ROV. In addition, they can control the drone from the ground stations.

The full path of the experimental description flow chart is in Figure 4 which describes the process from generating the signal to recovering it. The first stage uses MATLAB as a pattern generator to create a signal and encode it by 16 QAM. The encoded signal was transferred to AMD Xilinx evaluation board Kintex-7 with a high-speed daughter card using a USB cable through J-TAG connections. The signal generated is stored in the RAM of the evaluation board Kintex-7 in parallel format. The subcarriers transformed from AMD Xilinx RAM to the multiplexer to orthogonal the subcarriers using Recursive IFFT to generate recursive OFDM signal. The signal generated is a recursive OFDM signal the signal is converted to serial and then power is allocated to convert to NON orthogonal multiple access signal NOMA. The NOMA signal was generated and moved to a blue laser diode to transmit a signal to the underwater channel. The advantages of using recursive NOMA which is a lower complexity than traditional NOMA and consumes lower power. The transmitted signal is detected in the ocean water by a photodiode equipped with a lens fixed on the ROV.

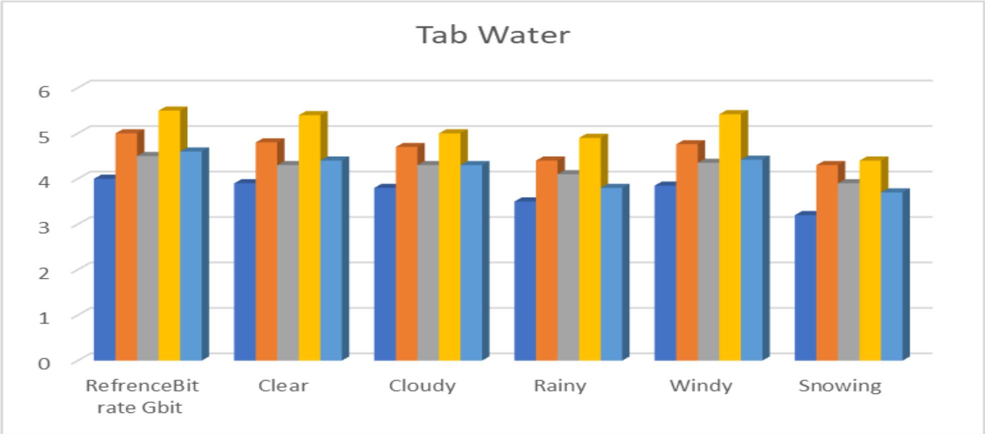
An experiment was conducted to evaluate BER under various weather conditions using recursive NOMA and blue laser for air-to-underwater optical wireless communication. Then the received signal is converted from the analog to the digital format using an analog-to-digital ADC convertor. The digital signal is stored in the RAM of the AMD XILINX evaluation board and then converted to parallel format. Next step; remove the CP and move to the recursive FFT to demultiplexed the signal which de-orthogonal the received signal.



Figure, 4 Proposed model description of hardware

Finally; before recovering the original signal goes to the SIC (successive interface cancellation) to reallocate the power of the received signal and recover the original signal. The MATLAB program is used in two stages encoding the signal and recovering the signal but the other stages use FPGA for the Xilinx evaluation board. The experimental testbed for the air-water used VLC adopts Non-Line Of Sight (NLOS) conditions. The emitter is placed above the water surface, and the receiver is lowered beneath the water surface. A device to request the position and probe the channel gain is equipped on an aerial vehicle that operates as a blue laser VLC transmitter. The depth information of the underwater vehicle is far away from the optical line-of-sight communication requested and searched using a depth sensor. A micro optical-electrical-mechanical system includes an electrowetting liquid lens micromirror and optical filtering components for elevation beam steering and stray light reduction. The optical lens is located alongside the device used for acquisition. A laser diode that is modulated by a visible light modulation signal is used as the laser transmitter. For reliability, a multi-type catadioptric lens was used in the air-water VLC to gain insight into laser diode-based communication from air to water. The electronic depth sensor can be concurrently utilized to act as an interface with vision-based technologies, such as controlling depth through the blue laser diode emission model based on depth information or making use of environmental information for routing.

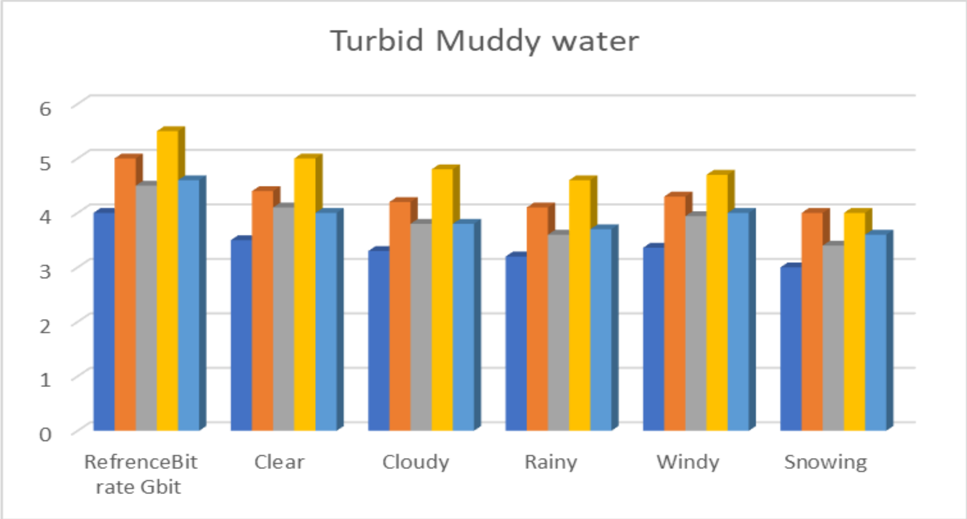
The experiment applied to different weather conditions and water types which collect user symbol bit rates. The five weather types used (clear, windy, snowing, rainy, and cloudy) for different water types (Tab, Muddy, or Turbid). In each experiment use five users' data symbols for the test. The NOMA users symbol reference data rate is (4,4.5,4.6,5, 5.5) Gb/s. The first experiment was done with tap water as in Figure 5.



Figure, 5 Bit rate affected by different weather conditions and tab water

The results show that the data rate of the proposed model decreases with snowing weather and clear water because the pieces of snow scatter the NOMA signal and blue laser beam. In addition, the blue laser beam can penetrate the water surface, carry the NOMA signal data, and affect the bit rate which affects the laser light attenuation. However, when the result is compared with the rainy weather there is a little increase in data rate and little effect on cloudy and windy weather. Finally, the clear weather low affected the data rate of the NOMA user signal using a blue laser. From the result above, it is discovered that the different weather conditions have a low effect on the bit rate change of the proposed model in clear and turbid water.

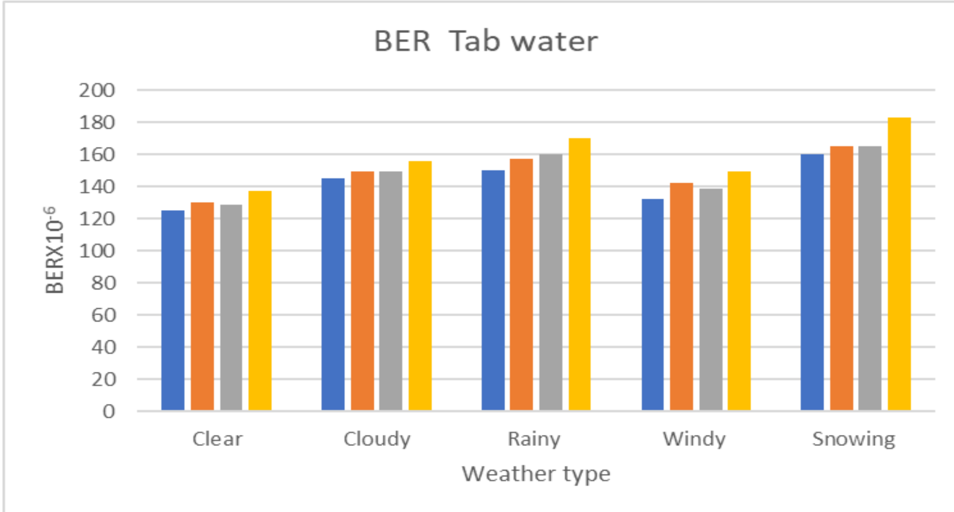
A second experiment was done with turbid water when the ocean waves were not stable with a high wave and muddy water type. This type of water increases the scattering of the blue laser beam and distortion of the signal the experimental result is shown in Figure 6.



Figure, 6 Bit rate affected by Turbid water with different weather conditions

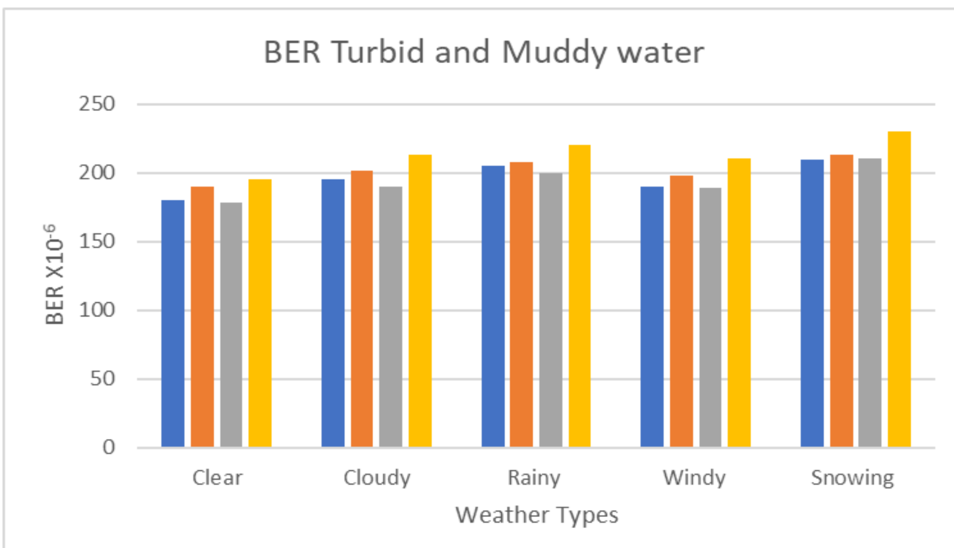
In this figure, the result shows the effect of data rate decrease for turbid water. In addition, the snowing weather and turbid muddy water have impacts on blue laser optical recursive NOMA communication between the drone hover on the water surface and ROV dives in ocean water which means lower data rate can be achieved by this type of water and weather when compared with other kind of weather conditions. However; when comparing windy and cloudy data rates there is a low difference in data rate but lower from tab clear water because of distortion blue laser due to obstacles in muddy water.

Another experiment to analyze the effect of BER for different weather conditions on the proposed model used recursive NOMA and blue laser for air-to-underwater optical communications. Figure 7 below describes the BER for tab water and other weather conditions. The BER increases with bad weather conditions such as snowing, which is a low increase in BER compared to clear weather with lower BER. However, when comparing BER for windy and cloudy we see a little difference of less than 2% but with rainy weather, the BER increases to 3%, and for snowing bad weather conditions the BER increases a little bit by about 6% from clear weather.



Figure, 7 The BER of the NOMA for different weather types with tab water

In another experiment with turbid water the result flow chart analyses as described in Figure 8 below. The result shows BER reduced in clear weather but it increases in muddy water when compared with tap water the difference is about 4%. In addition, the BER increases cloudy and windy weather because of the distortion of the laser beam with muddy water. Finally, the BER increased in rainy and snowing weather because the scattering of the blue laser beam breaks the water surface by an average of 7%.



Figure, 8 BER for Turbid muddy water with different weather conditions

The overall result shows in the proposed model that combines the NOMA with blue laser for data transmission between UAV and underwater ROV has a low effect on bit rate and BER by the different weather conditions for two types of water used in the experiments.

IV. CONCLUSION

The growth of underwater communication to discover the secret underwater world with high-resolution video and pictures pushes the researcher to find an easy way to explore different faraway ocean locations. Our research using a UAV drone controlled the underwater ROV with optical wireless communication using recursive NOMA which has lower power consumption than conventional NOMA and lowest complexity because of recursive FFT/IFFT. Moreover, adding this technique with blue laser light gets low attenuation and high bit rate data for transmission between air and water and also gets best control ROV from out of-water surface using drone. The research studies the effect of different weather types on the proposed model and how affect the bit rate and BER using different types of water. There is more one experiment used, first used tab water and applied different weather conditions to find how affected on blue laser data transmission with NOMA techniques. Second experiment, repeat experiment one with turbid muddy ocean water and analyze the result. The result shows a low effect of bit rate and BER on water type and different weather conditions when using the proposed model.

Future work uses satellite communication with GPS to control ROV of the underwater vehicles which can guide them to the correct place by a global positioning system and a satellite positioning system. Moreover, analyses the FPGA power consumption of each apart of the system using AMD Xilinx power analyzer tools .

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References

[1] G. Krishna, J. Mathew, and S. Gupta, "Blue-LED based electrical and optical PD-NOMA systems: Characterization in underwater environment," Optics Communications, vol. 555, p. 130248, Dec. 2023.

[2] S. Chaudhary, "Performance investigation of a VLC-PDM based UWOC system under adverse underwater conditions with varying chlorophyll levels," Optics Communications, vol. 573, p. 131025, Aug. 2024,

[3] S. A. Yosef and L. F. Abdul Ameer, "Performance Enhancement of VLC-NOMA Employing Beamforming Function based Vehicle-to-Multivehicle Communication System," IETE Journal of Research, vol. 70, no. 7, pp. 6069–6080, Dec. 2023

[4] D. Chen, F. Kang, J. Chen, S. Zhu, and H. Li, "Effect of light source wavelength on surface defect imaging in deep-water concrete dams," NDT & E International, vol. 147, p. 103198, Jul. 2024.

[5] X. Li et al., "NOMA Assisted Real-Time Downlink UWOC System Using a Software-Configurable Driver Under Different Channel Conditions," in Journal of Lightwave Technology, vol. 42, no. 14, pp. 4860-4873, 15 July15, 2024,

[6] A. M. Abdelhady, A. Celik, C. Diaz-Vilor, H. Jafarkhani and A. M. Eltawil, "Laser-Empowered UAVs for Aerial Data Aggregation in Passive IoT Networks," in IEEE Open Journal of the Communications Society, vol. 5, pp. 1609-1623, 2024

[7] C. Fang, S. Li, Y. Wang, and K. Wang, "High-Speed Underwater Optical Wireless Communication with Advanced Signal Processing Methods Survey," Photonics, vol. 10, no. 7, p. 811, Jul. 2023

[8] H. Zhou, M. Zhang, X. Wang and X. Ren, "Design and Implementation of More Than 50m Real-Time Underwater Wireless Optical Communication System," in Journal of Lightwave Technology, vol. 40, no. 12, pp. 3654-3668, 15 June15, 2022,

[9] L. Joseph and S. Anandan, "A Review on Feasible and Reliable Underwater Wireless Optical Communication System for Achieving High Data Rate and Longer Transmission Distance," International Journal of Electronics and Telecommunications, pp. 815–823, Nov. 2022

[10] X. Fang et al., "Overcoming laser phase noise for low-cost coherent optical communication," Nature Communications, vol. 15, no. 1, Jul. 2024,

[11] C.-Y. Peng et al., "Performance Analyses of Photonic-Crystal Surface-Emitting Laser: Toward High-Speed Optical Communication," Nanoscale Research Letters, vol. 17, no. 1, Sep. 2022.

[12] Q. Qin et al., "Demonstration of the First Outdoor 2-μm-Band Real-Time Video Transmission Free-Space Optical Communication System Using a Self-Designed Single-Frequency Fiber Laser," in Journal of Lightwave Technology, vol. 41, no. 16, pp. 5275-5283, 15 Aug.15, 2023,

[13] Y. Liang, H. Yin, A. Huang, X. Ji, and J. Wang, "Underwater wireless optical NOMA communication experiment system exploiting GaN-based micro-LED array grouping," Chinese Optics Letters, vol. 22, no. 3, pp. 030101-, Mar. 2024

[14] V. P. Aksenov, V. V. Dudorov, V. V. Kolosov, and Ch. E. Pogutsa, "Optical communication in a turbulent atmosphere via the orbital angular momentum of a laser beam. II. Symbol error rate in a data line," Appl. Opt. 63, 7485-7490 (2024)

[15] V. Arya, M. Kumari, M. Ridha, and Syed Alwee Aljunid, "Modeling of Satellite-to-Underwater Integrated FSO-PON System Using NOMA-VLC," Symmetry, vol. 15, no. 3, pp. 739–739, Mar. 2023

[16] Y. Liang, H. Yin, L. Jing, X. Ji, and J. Wang, "BER analysis for PAM-based UWOC-NOMA system in oceanic turbulence environment," vol. 545, pp. 129631–129631, Oct. 2023

[17] S.S Al-Obaidi, M. Ambroze, N. Outram, and B. Ghita, "Bit precision and Cyclic prefix effect on OFDM Power Consumption Estimation," Conference, ECDMO2017, ICCBN, Feb 20-22. 2017.

[18] E. T. Hope, "Using relays for utilizing and extending LoRaWAN networks with the use of Altibox LoRaWAN infrastructure for internet of things," Openarchive.usn.no, 2024.

[19] A. Jasim Mohammed, "Impact of Rain Weather Conditions over Hybrid FSO/58GHz Communication Link in Tropical Region ", IJSER, vol. 3, no. 3, pp. 117–134, Sep. 2024.

[20] S. Al-Obaidi, M. Ambroze, B. Ghita, E. Giakoumidis and A. Tsokanos, "A review on power consumption reduction techniques on OFDM", Proc. 11th Int. Netw. Conf. (INC), pp. 3-8, 2016.

[21] W. Aman, Saif Al-Kuwari, Muhammad Muzzammil, Muhammad, and A. Kumar, “Security of underwater and air–water wireless communication: State-of-the-art, challenges and outlook,” Ad hoc networks, vol. 142, pp. 103114–103114, Apr. 2023
[22] Naveed et al., “A Survey on Physical Layer Techniques and Challenges in Underwater Communication Systems,” Journal of marine science and engineering, vol. 11, no. 4, pp. 885–885, Apr. 2023
[23] S.S Al-Obaidi, “Green Networking: Analyses of Power Consumption of Real and Complex IFFT/FFT used in Next-Generation Networks and Optical Orthogonal Frequency Division Multiplexing,” Thesis, CSCAN DEP., University of Plymouth, UK., PEARL, 2018.
[24] W. Abd-Alaziz, B. A. Jebur, H. Fakhrey, Z. Mei and K. Rabie, "A Low-Complexity Coding Scheme for NOMA," in IEEE Systems Journal, vol. 17, no. 3, pp. 4464-4473, Sept. 2023
[25] H. Jafarkhani, H. Maleki and M. Vaezi, "Modulation and Coding for NOMA and RSMA," in Proceedings of the IEEE, vol. 112, no. 9, pp. 1179-1213, Sept. 2023
[26] Y. Wang, J. Wang, Vincent, and X. You, “Effective Throughput Maximization of NOMA With Practical Modulations,” IEEE Journal on Selected Areas in Communications, vol. 40, no. 4, pp. 1084–1100, Jan. 2022
[27] A. K. Ahmed and H. S. Al-Raweshidy, "Performance Evaluation of Serial and Parallel Concatenated Channel Coding Scheme With Non-Orthogonal Multiple Access for 6G Networks," in IEEE Access, vol. 10, pp. 39681-39690, 2022
[28] Shuaidong Chen, Jianxin Ren, Bo Liu, Yaya Mao, Xiangyu Wu, Rahat Ullah, Xiumin Song, Yu Bai, Jianye Zhao, Yibin Wan, Yiming Ma, Wenchao Xia, and Feng Wang, "Performance improvement of non-orthogonal multiple access with a 3D constellation and a 2D IFFT modulator," Opt. Express 31, 7425-7439 (2023)
[29] Y. Liu, W. Yi, Z. Ding, X. Liu, O. A. Dobre and N. Al-Dhahir, "Developing NOMA to Next Generation Multiple Access: Future Vision and Research Opportunities," in IEEE Wireless Communications, vol. 29, no. 6, pp. 120-127, December 2022
[30] X. Pei, Y. Chen, M. Wen, H. Yu, E. Panayirci and H. V. Poor, "Next-Generation Multiple Access Based on NOMA With Power Level Modulation," in IEEE Journal on Selected Areas in Communications, vol. 40, no. 4, pp. 1072-1083, April 2022
[31] M. Dai, Y. Wu, L. Qian, Z. Su, B. Lin and N. Chen, "UAV-Assisted Multi-Access Computation Offloading via Hybrid NOMA and FDMA in Marine Networks," in IEEE Transactions on Network Science and Engineering, vol. 10, no. 1, pp. 113-127, 1 Jan.-Feb. 2023
[32] Y. Li, Syed, X. Chen, Riffat Tehseen, S. Li, and J. Wang, “Research on Power Allocation in Multiple-Beam Space Division Access Based on NOMA for Underwater Optical Communication,” Sensors, vol. 23, no. 3, pp. 1746–1746, Feb. 2023
[33] N. Nomikos, A. Giannopoulos, P. Trakadas and G. K. Karagiannidis, "Uplink NOMA for UAV-Aided Maritime Internet-of-Things," 2023 19th International Conference on the Design of Reliable Communication Networks (DRCN), Vilanova i la Geltru, Spain, 2023, pp. 1-6
[34] D. Chen et al., “Experimental demonstration of a hybrid OFDMA/NOMA scheme for multi-user underwater wireless optical communication systems,” Optics Communications, vol. 548, p. 129823, Aug. 2023
[35] Sameer S. Al-Obaidi, M Ambrose, N Outram, B Ghita “Variant Parameters effect on OFDM Estimation Power Consumption,” International Journal of Computing, Communication and Instrumentation Engineering, vol. 4, no. 1, Oct. 2017.
[36] M. -T. Nguyen, T. -H. Vu and S. Kim, "Performance Analysis of Wireless Powered Cooperative NOMA-Based CDRT IoT Networks," in IEEE Systems Journal, vol. 16, no. 4, pp. 6501-6512, Dec. 2022
[37] R. Raj and A. Dixit, "An Energy-Efficient Power Allocation Scheme for NOMA-Based IoT Sensor Networks in 6G," in IEEE Sensors Journal, vol. 22, no. 7, pp. 7371-7384, 1 April1, 2022
[38] M. A. Arfaoui, A. Ghrayeb, C. Assi and M. Qaraqe, "CoMP-Assisted NOMA and Cooperative NOMA in Indoor VLC Cellular Systems," in IEEE Transactions on Communications, vol. 70, no. 9, pp. 6020-6034, Sept. 2022
[39] S. Ghosh, A. Al-Dweik and M. -S. Alouini, "On the Performance of End-to-End Cooperative NOMA-Based IoT Networks With Wireless Energy Harvesting," in IEEE Internet of Things Journal, vol. 10, no. 18, pp. 16253-16270, 15 Sept.15, 2023
[40] C. Wu, X. Mu, Y. Liu, X. Gu, and X. Wang, "Resource Allocation in STAR-RIS-Aided Networks: OMA and NOMA," in IEEE Transactions on Wireless Communications, vol. 21, no. 9, pp. 7653-7667, Sept. 2022
[41] Sameer.S.H. Al-Obaidi, B. Ghita, M. s al-timimi, and W. abd shukur, “Visible light communication system integrating road signs with the vehicle network grid,” Al-Iraqia Journal of Scientific Engineering Research, vol. 3, no. 4, Dec. 2024