# Performance Analysis of NOMA Assisted Underwater Visible Light Communication System

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***Abstract—*** *In this paper, we present the analytical investigation of the non-orthogonal multiple access (NOMA) assisted underwater visible light communication (UWVLC) system. The proposed system can cater to the needs such as low latency, high reliability and high data rate underwater multicasting to the sensor nodes. In particular, we derive the exact closed-form expressions of average bit error rate (BER) and ergodic capacity for underwater NOMA users. Further to understand the impact of the underwater scenario over the system performance, the analysis is carried out for parameters such as air bubble levels, gradient temperature and salinity level of the water. The obtained results validate the feasibility of the proposed system model. An experimental result shows the BER, SNR and Ergotic Capacity of the System.*

## I. INTRODUCTION

In the recent past there has been an increase in underwater exploration, deployment of underwater wireless sensor networks and unmanned underwater vehicles, this has lead to an increase in the research interest towards the underwater communication. The traditional underwater communication mostly banks on acoustic communication that suffers from low latency and low data rates. Underwater visible light communication (UWVLC) using green and blue lasers have attracted the interest of researchers as a probable communication link serving the underwater communication bodies. The performance of multi-user multiple-input multiple output (MIMO)-orthogonal frequency division multiplexing (OFDM) has been analyzed in for the underwater visible light communication system for the turbid water over the frequency selective channel. The authors in , considers the downlink of an underwater sensor network that builds upon the orthogonal frequency division multiple access (OFDMA)- based visible light communication system. There has been an exponential increase in the number of underwater communication devices hence multiple access techniques have to be amalgamated in the communication model. Non-orthogonal multiple access (NOMA) has evolved as a spectrally efficient, multiple access scheme that can cater to a large number of devices. NOMA has been extensively studied in terrestrial radio frequency (RF) communication but limited studies have been done in underwater applications. The authors in integrate the full duplex (FD) and NOMA with a relay based underwater acoustic network to improve the sum rate and reliability. A power allocation scheme for NOMA has been investigated in for underwater acoustic communications. The analytical expression for coverage probability and cell capacity is presented in for weak underwater turbulence for the NOMA systems. The proposed work in this paper builts upon the idea of NOMA aided UWVLC by deriving the closed form expressions of bit error rate (BER) and ergodic capacity at the near and far end users for different parameters like gradient temperature, bubble level (BL) and salinity of the water.

**Main Contribution**

- To design the NOMA System to show the parameters are SNR, BER and Ergotic Capacity of the system by using MATLAB Software.

### 1.1 Underwater Wireless Optical Communication

Two thirds of the earth's surface is covered with water. During the past thousands of years, humans have never stopped the exploration of the ocean. In recent years, with an increase of global climate change and resource depletion of land, there has been a growing interest in the research of ocean exploration system. Underwater wireless communication (UWC) technology enables the realization of ocean exploration systems, and thus attracts more and more attention. UWC refers to transmitting data in an unguided water environment through the use of wireless carriers, i.e. radio-frequency (RF) waves, acoustic waves, and optical waves. Considering the limited bandwidth of RF and acoustic methods and the increasing need for high-speed underwater data transmission, underwater wireless optical communication (UWOC) has become an attractive and viable alternative. In fact, light has been used as a method of wireless communication for thousands of years in various forms. For instance, the ancient Chinese used beacon towers in order to deliver military information around 1,000 BC, and the ancient Greek and Roman armies used polished shields to reflect sunlight for signaling around 800 BC. In 1880, Alexander Graham Bell developed a new wireless telephone system that used sunlight as the transmission medium. This system is regarded as the first optoelectronic communication system in the world. In the 1960s, the invention of laser as an optical source has changed the future of optical wireless communication (OWC). From that time on, a flurry of terrestrial OWC applications appeared. But due to the severe attenuation effects of seawater to visible light and the limited knowledge of aquatic optics, the early development of UWOC was far behind the terrestrial free-space optical (FSO) communications. In the remaining of this paper, we will provide a comprehensive survey of UWOC research during the period from early 1990s to now. The framework of our survey is based on nearly 20 years experimental and theoretical study of light propagation in the sea, in 1963, Duntley proposed that seawater shows a relatively low attenuation property to light with wavelengths from 450nm to 550nm which corresponds to the blue and green spectrum.

Over the decades, the interest of UWOC is still limited to military applications [8], [10]. The massive market promotion of UWOC has not been achieved so far. Only a few limited UWOC products were commercialized in the early 2010s, such as the BlueComm UWOC system which can achieve 20 Mbps underwater data transmission over 200m distance , and the Ambalux UWOC system which can provide 10 Mbps data transmission in a range of 40m. In order to satisfy the increasing demands for ocean exploration with efficient high bandwidth data transmission, researchers have proposed the concept of underwater wireless sensor networks (UWSNs). The proposal of UWSNs has greatly facilitated the development of UWOC. Thus the market of UWOC has begun to show a future promise. The basic UWSNs consist of many distributed nodes such as seabed sensors, relay buoys, autonomous underwater vehicles (AUVs) and remotely operated underwater vehicles. These nodes have capabilities to accomplish sensing, processing, and communication tasks that maintain the collaborative monitoring to the underwater environment sensors located at the bottom of the seabed collect data and transmit via acoustic or optical links to the AUVs and ROVs. Then, AUVs and ROVs relay signals to ships, submarines, communication buoys and other underwater vehicles. Above the sea surface, the onshore data center processes data and communicates with satellite and ships through RF or FSO links.

### 1.2 Categories of Underwater Optical Communications

- Point-to-point line-of-sight (LOS) configuration,
- Diffused LOS configuration
- Retro reflector-based LOS configuration
- Non-line-of-sight (NLOS) configuration.

**Point-to-point LOS configuration:**

It is the most commonly used link configuration in UWOC. In point-to-point LOS configuration, the receiver detects the light beam in the direction of the transmitter. Since the point-to-point LOS UWOC system commonly employs light sources with a narrow divergence angle, such as a laser, it requires precise pointing between transmitter and receiver. This requirement will limit the performance of UWOC systems in turbid or turbulent water environments and then becomes a severe problem when the transmitter and the receiver are non-stationary nodes, such as AUVs and ROV.

**Diffused LOS configuration:**

It employs diffused light sources with large divergence angle such as high-power light-emitting diodes (LEDs) to accomplish broadcasting UWOC from one node to multiple nodes Broadcasting method can relax the requirement of precise pointing. However, compared with the point-to-point LOS configuration, the diffused-light based link suffers from aquatic attenuation due to the large interaction area with water. Relatively short communication distances and lower data rates are the two major limitations of this configuration.

**Retroreflector-based LOS configuration**

It can be regarded as one special implementation of point-to-point LOS configuration. This configuration is suitable for duplex UWOC systems having limited power and weight budget, such as an underwater sensor node. In modulating retro-reflector link, the transmitted light is reflected back from a modulated retro-reflector. During this process, the information that the retroreflector responses to the transceiver will be encoded on the reflected light. Since there is no laser or other light sources in the retroreflector end, its power consumption, volume and weight will be tremendously reduced. One limitation of this configuration is that the backscatter of the transmitted optical signal may interfere the reflected signal, thus degrading the system signal to noise ratio (SNR) and bit-error rate (BER). Moreover, since the optical signals will go through the underwater channel twice, received signal will experience additional attenuation

**NLOS configuration**

It overcomes the alignment restriction of LOS UWOC. In this configuration, the transmitter projects the light beam to the sea surface with an angle of incidence greater than the critical angle, so that the light beam experiences a total internal reflection. The receiver should keep facing the sea surface in a direction that is approximately parallel with the reflected light to ensure proper signal receiving. The major challenge of NLOS links is the random sea surface slopes induced by wind or other turbulence sources. These undesirable phenomena will reflect light back to the transmitter and cause severe signal dispersion.

### 1.3 Advantages and Challenges of UWOC

- UWOC systems are used for high-speed underwater communications between multiple fixed or mobile nodes. They have great potential for applications in the UWSNs. Conventionally, there are three UWC choices for implementing UWSNs: acoustics, RF and optics. In order to emphasize the unique advantages and characterizations of UWOC, we will compare the UWOC with RF and acoustic methods in the following of this section.
- The acoustic method is the most widely used technology in UWC. It has a long application history that can be dated to late 1800s. After an extensive expansion of military applications during the two World Wars, underwater acoustic communication system has become a popular proven technology that has been applied to almost every aspect of UWSNs. Considering the extreme broadness of ocean and the strong attenuation effect of seawater to other transmission sources like optical wave and RF wave, the most attractive advantage of underwater acoustic communication is that it can achieve a long link range up to several tens of kilometers. Although acoustic method is the most popular method to achieve UWC, it also has certain intrinsic technical limitations. Firstly, since the typical frequencies associated with underwater acoustics are between 10 Hz and 1 MHz, the transmission data rate of acoustic link is relatively low (typically on the order of kbps) . Secondly, due to the slow propagation speed of sound wave in water (about 1500m/s for pure water at 20 Celsius), the acoustic link suffers from severe communication delay (typically in seconds). Thirdly, acoustic transceivers are usually bulky, costly and energy consuming. They are not economical for large scale UWSNs implementations. Furthermore, acoustic technology can also impact marine life which uses sound waves to accomplish communication and navigation.
- The underwater RF electromagnetic (EM) communication can be seen as an extension of the terrestrial RF-EM communication. The underwater RF communication has two major advantages. First, compared with acoustic wave and optical wave, the RF wave can perform a relatively smooth transition through air/water interface. This benefit can be used to achieve the cross-boundary communication which combines the terrestrial RF communication system and underwater RF-EM communication system together. Second, RF-EM method is more tolerant to water turbulence and turbidity than optical and acoustic methods. The fatal limitation that impedes the development of underwater RF-EM method is its short link range. Since seawater that contains lots of salt is a conductive transmission media, the RF waves can only propagate a few meters at extra-low frequencies (30-300Hz). Moreover, the underwater RF-EM systems also require huge transmission antenna and costly, energy-consuming transceivers.

**Main Challenges:**

- Optical signal suffers from severe absorption and scattering. Although the wavelength of transmission light has been carefully selected in the blue and green spectrum to minimize the transmission attenuation effect, due to the inevitable photon interactions with the water molecules and other particulate matters in water, absorption and scattering still severely attenuate the transmitted light signal and cause multi-path fading. Due to the impact of absorption and scattering, UWOC suffers from poor BER performance over a few hundred meters link distance in turbid water environment. In underwater environment, matters such as chlorophyll are capable of absorbing the blue and red lights. These matters and other colored dissolved organic material (CDOM) can increase the turbidity of the water, and thus shrink the propagation distance of the light. Moreover, the concentration of CDOM will also change with ocean depth variations, thus changing the corresponding light attenuation coefficients. These undesirable impacts will increase the complexity of UWOC systems.
- Underwater optical links will be temporarily disconnected due to misalignment of optical transceivers. In several UWOC systems, blue/green lasers or LEDs have been implemented as the light sources due to their narrow divergence

feature; however, a precise alignment condition is required. As the underwater environment is turbulent at relatively shallow depths, link misalignment will take place frequently, especially in the vertical buoy-based surface-to-bottom UWOC applications. Random movements of sea surface will cause serious connectivity loss problem.

- Implementation of UWOC systems requires reliable underwater devices. The underwater environment is complex. The flow, pressure, temperature and salinity of seawater will strongly impact the performance and lifetime of UWOC devices. Considering that no solar energy can be exploited undersea and the long undersea operation time of UWOC devices, the reliability of device batteries and efficiency of device power consumption are critical.

### 1.4 NOMA:

Non-orthogonal multiple access (NOMA) is one of the most promising radio access techniques in next-generation wireless communications. Compared to orthogonal frequency division multiple access (OFDMA), which is the current de facto standard orthogonal multiple access (OMA) technique, NOMA offers a set of desirable potential benefits, such as enhanced spectrum efficiency, reduced latency with high reliability, and massive connectivity. The baseline idea of NOMA is to serve multiple users using the same resource in terms of time, frequency, and space.

The available NOMA techniques can broadly be divided into two major categories, i.e., power-domain NOMA and code-domain NOMA. Code-domain NOMA can further be classified into several multiple access techniques that rely on low-density spreading and sparse code multiple access. Other closely related multiple access schemes in this context are lattice-partition multiple access, multi-user shared access, and pattern-division multiple access.

Recent studies demonstrate that NOMA has the potential to be applied in various fifth generation (5G) communication scenarios, including Machine-to-Machine (M2M) communications and the Internet-of-Things (IoT). Moreover, there are some existing evidence of performance improvement when NOMA is integrated with various effective wireless communications techniques, such as cooperative communications, multiple-input multiple-output (MIMO), beam forming, space–time coding, network coding, full-duplex, etc. Given all advancements and experimental outcomes, standardization of NOMA has been established for the next-generation American digital TV standard (ATSC 3.0) under the term layered-division multiplexing (LDM), and has been initiated for the third generation partnership project (3GPP) under the name multi-user superposition transmission (MUST).

Since the principle of NOMA allows multiple users to be superimposed on the same resource, this leads to interference for such systems. Consequently, existing resource management and interference mitigation techniques, especially for ultra-dense networks, need to be revisited due to the incorporation of additional interference this new technology brings. For the similar reason, beam forming and the resultant other problems (e.g., precoding) in massive-MIMO systems introduce additional challenges and need to be solved in order to achieve full utilization of these technologies. From the perspective of physical layer, existing channel coding, modulation and estimation related problems need to be revised as well. Cognitive, cooperative, and visible light communications all are conducive paradigms under NOMA systems compared to conventional systems. However, the resultant evolved problems due to the incorporation of this new technology need to be solved before acquiring benefits from these paradigms. Although NOMA technique offers numerous advantages, the enhanced information sensing ability of more users via this technique, leads to higher security and privacy threat. Therefore, a series of security problems from the physical to application layers need to be solved in order to build a robust, efficient and effective system via this technique.

## II. LITERATURE REVIEW

**[1] TITLE:** Hierarchical full-duplex underwater acoustic network: A NOMA approach. **AUTHOR NAME:** Makled, E. A., Yadav, A., Dobre, O. A.,

**DESCRIPTION:** This paper attempts to increase the sum rate of underwater channels without utilizing additional resources, through adding a relay and employing full duplex (FD) and non-orthogonal multiple access (NOMA) technologies. The adopted system model has two sensors and two robotic arms communicating with a buoy via a relay. Employing FD-NOMA allows multiple uplink and downlink transmissions to occur simultaneously, using the same time and frequency resources. The main challenge for this deployment is the interference between the transmissions. Interference cancellation techniques, successive interference cancellation and self-interference cancellation, are employed to mitigate the interference due to NOMA and FD, respectively. In order to maximize the sum rate, an optimization problem over the power is formulated and solved as a convex optimization problem. The performance of the system is benchmarked with the performance of the non-relay (NR) aided FD-

NOMA and relay-aided (R) half duplex orthogonal multiple access (HD-NOMA). It is shown that R-FD-NOMA always has higher sum rate than NR-FD-NOMA, irrespective of the efficiency of interference cancelation. In addition, it is shown that at efficient interference cancellation, the sum rate of FD-NOMA is higher than HD-OMA.

**[2] TITLE:** Power allocation scheme for non-orthogonal multiple access in underwater acoustic communications.

**AUTHOR NAME:** Cheon, J., & Cho, H. S.

**DESCRIPTION:** In this paper, we propose a power allocation scheme for non-orthogonal multiple access (NOMA) in underwater acoustic sensor networks (UWASNs). The existing terrestrial sum-rate maximization (SRM) power allocation scheme suffers from the degradation of the overall sum-rate in UWASNs due to wasteful resource created by unequal transmission times between each transmission path. To address this issue, we propose the equal transmission times (ETT) power allocation scheme, which can prevent wasteful resource generation by guaranteeing equal transmission times between each transmission path. ETT considers the number of packets waiting for transmission in the sender's buffer for creating equal transmission times. Numerical results show that the proposed ETT outperforms SRM in terms of the overall sum-rate, while having nearly identical maximum sum-rate to the SRMs.

**[3] TITLE**: Non-orthogonal multiple access (NOMA) for underwater acoustic communication.

**AUTHOR NAME:** Bocus, M. J., Agrafiotis, D., & Doufexi

**DESCRIPTION:** In this paper we investigate the application of the non-orthogonal multiple access (NOMA) technique for multiuser underwater acoustic (UWA) communication. The NOMA scheme can be implemented using either orthogonal frequency division multiplexing (OFDM) or filterbank multicarrier (FBMC) modulation for waveform shaping. In order to boost the throughput over a 1 km time-varying underwater acoustic channel (UAC), spatially multiplexed multiple-input multiple-output (MIMO) systems are considered. We evaluate the bit error rate (BER), packet error rate (PER) and maximum bit rate performances of Turbo-coded NOMA-OFDM and NOMA-FBMC systems for a 2-user scenario where both users utilize the same frequency bandwidth. It is shown that while both the NOMA-OFDM and NOMA-FBMC systems show comparable performance in terms of BER and PER, the MIMO NOMA-FBMC system however achieves higher bit rates than the OFDM-based system.

**[4] TITLE:** A study of non-orthogonal multiple access in underwater visible light communication systems. In 2018 IEEE 87th Vehicular Technology Conference (VTC Spring) (pp. 1-6). IEEE.

**AUTHOR NAME:** Geldard, C., Thompson, J., & Popoola

**DESCRIPTION:** This paper presents an analytical investigation into the performance of an underwater optical wireless cellular network based upon the non orthogonal multiple access (NOMA) scheme in the presence of weak underwater turbulence. The performance metrics used are the probability that all nodes in a network can achieve a connection and the total cell capacity. Coverage probability and cell capacity are solved numerically and the results presented. Further it is shown that the strength of turbulence affects the maximum data rate supported by a cell as well as the coverage probability. In a NOMA cell however the number of users is shown to be a bigger limiting factor than turbulence.

**[5] TITLE:** Improving Data Rate Performance of Non-Orthogonal Multiple Access Based Underwater Acoustic Sensor Networks.

**AUTHOR NAME:** Goutham, V., Reddy, G. K. K., Babu, Y. G., & Harigovindan, V.

**DESCRIPTION:** In this article, initially we propose an optimal packet size selection scheme for reduced channel time wastage for Non-Orthogonal Multiple Access (NOMA) in Underwater Acoustic Sensor Networks (UASNs). Existing conventional NOMA technique achieves the sum rate without considering the traffic generation in UASNs, which leads to wastage of resources due to unequal transmission times in paired transmission. In contrast, the proposed scheme overcomes this problem by making equal transmission time slots for both weak and strong users using optimal data packet sizes to avoid the wastage of resources. Further, we propose an optimal power allocation for weak and strong users with respect to the distance between transceiving nodes by using particle swarm optimization. The analytical results clearly show that the proposed scheme for NOMA in UASNs significantly improves the data rate performance in comparison with the existing conventional NOMA technique.

## III. EXISTING SYSTEM

- In our Existing method, the project demonstrated the performance of an orthogonal frequency division multiplexing (OFDM)-based MU-MIMO system for underwater visible light communication (VLC) is investigated.
- It is worth to note that MU-MIMO OFDM has been applied for indoor optical communication, however, to the best of our knowledge, it has not been studied for underwater environment yet.
- The system is considered to be 2×2 and the channel gain for each path is calculated with the closed-form expression for weighted double gamma function (WDGF).
- Zero-forcing precoding scheme is implemented to eliminate multiuser interference.

**Drawback:**

- Less accuracy.
- Inefficiency.
- Low Performance.
- Data Transmission not accurate.

## IV. DEVELOPMENT PROCESS

**Input Design**

The input design is the link between the information system and the user. It comprises the developing specification and procedures for data preparation and those steps are necessary to put transaction data in to a usable form for processing can be achieved by inspecting the computer to read data from a written or printed document or it can occur by having people keying the data directly into the system. The design of input focuses on controlling the amount of input required, controlling the errors, avoiding delay, avoiding extra steps and keeping the process simple. The input is designed in such a way so that it provides security and ease of use with retaining the privacy. Input Design considered the following things:

- What data should be given as input?
- How the data should be arranged or coded?
- The dialog to guide the operating personnel in providing input.
- Methods for preparing input validations and steps to follow when error occur.

**Objectives**

1. Input Design is the process of converting a user-oriented description of the input into a computer-based system. This design is important to avoid errors in the data input process and show the correct direction to the management for getting correct information from the computerized system.

2. It is achieved by creating user-friendly screens for the data entry to handle large volume of data. The goal of designing input is to make data entry easier and to be free from errors. The data entry screen is designed in such a way that all the data manipulates can be performed. It also provides record viewing facilities.

3. When the data is entered it will check for its validity. Data can be entered with the help of screens. Appropriate messages are provided as when needed so that the user will not be in maize of instant. Thus, the objective of input design is to create an input layout that is easy to follow.

4. For automatic detection of diabetic retinopathy in retinal images by using Machine Learning

**Output Design**

A quality output is one, which meets the requirements of the end user and presents the information clearly. In any system results of processing are communicated to the users and to other system through outputs. In output design it is determined how the information is to be displaced for immediate need and also the hard copy output. It is the most important and direct source information to the user. Efficient and intelligent output design improves the system's relationship to help user decision-making.

1. Designing computer output should proceed in an organized, well thought out manner; the right output must be developed while ensuring that each output element is designed so that people will find the system can use easily and effectively. When analysis design computer output, they should Identify the specific output that is needed to meet the requirements.

2. Select methods for presenting information.

3. Create document, report, or other formats that contain information produced by the system.

The output form of an information system should accomplish one or more of the following objectives.

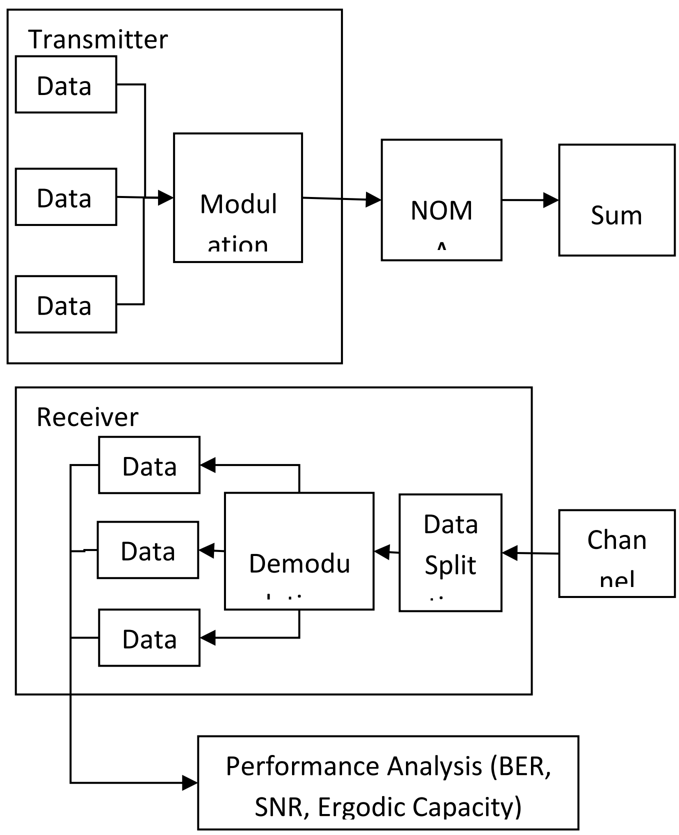
- Convey information about past activities, current status or projections of the
- Future.
- Signal important events, opportunities, problems, or warnings.
- Trigger an action.
- Confirm an action.

## V. PROPOSED METHOD

- In our proposed method, the project demonstrated the idea of NOMA aided UWVLC by deriving the closed- form expressions of bit error rate (BER) and ergodic capacity at the near and far end users for different parameters like gradient temperature, bubble level (BL) and salinity of the water.
- To statistically analyze the proposed system model, we consider model for the UWVLC system based on the NOVA Architecture of the system. We derive expressions for average BER and ergodic capacity in terms of a parameters of the system.
- It needs such as low latency, high reliability and high data rate underwater multicasting to the sensor nodes.
- The performance of the considered NOVA model on UWVLC system in terms of average BER and ergodic capacity is evaluated to show the results by using Matlab Software.

**Advantages:**

- Result shows effectively high.
- Performance is high when compare to the other technique.
- Better Accuracy.
- Efficient data Transfer.



**Explanation:**

- First, the randomly data can be generated to process the data.
- Data can be transmitted through the channel as well as the show the output in the receiver part of the system.
- Finally, the performance metrics can be calculated in the SNR, BER and Ergotic capacity.

## VI. CONCLUSION

In this Project, we derive the novel closed-form expressions of average BER and ergodic capacity in terms of NOMA users. The performance of the system is analyzed for different underwater scenarios such as BL, salinity of water, and gradient temperature. Thus, it is concluded that the results can assist system designers for selecting parameters to suit their water ecosystem. As a part of future work the analysis can be extended to 'N' number of NOMA users in UWVLC scenario.

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