# Improving the Hybrid FSO/LI-FI/UWOC Network's

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**Abstract:** Optical wireless communications are an alternative approach to address the challenges in completing the deployment of terrestrial networks to underwater optical wireless communication (UWOC) environments. This study aims to investigate the effectiveness of a free-space optical (FSO) channel system to feed light-fidelity Li-Fi-closed underwater platforms that, in turn, supply the non-line-of-sight (NLOS) link with the proper communications. The FSO link faces the challenge of attenuation due to the surrounding environment, which in turn negatively affects the communication link reaching the end user underwater via Li-Fi underwater platforms according to the proposed scenario. measurements show a strong signal at the receiver, it indicates that the reflection is effective and that the system can successfully transmit information using NLOS methods. Multipath with apt transmit power and NLOS transmission surface incident angle selection achieved ambitious results and sustainable connectivity even in rainy situations surrounding the FSO system.

**Keywords**: Free-Space Optical (FSO), underwater optical wireless communication (UWOC), light-fidelity Li-Fi, NLOS.

## I. Introduction

Owing to the dual aspects of NLOS-UWOC, FSO, optical fiber and the continuing emphasis on developing hybrid networks and LI-FI technology, the combination of the hybrid networks will represent an attractive solution for achieving connectivity in submerged platforms. Taking advantage of each technology's strengths, such networks offer high data rates and robustness and adaptability, thus being suitable for a wide range of services in marine research, underwater robotics, and telecommunications. Free-space optical (FSO) communications is a laser-based technology used to connect distant or difficult to access sites where traditional wired networks are not available. This is a line-of-sight technology that provides remarkably high-speed data transfer rates, while at the same time, maintaining hardened security features; an apt solution for organizations that prioritize data security as equally as data throughput. By being simple and cheap to implement compared to other options, FSO systems are an adaptable choice for businesses requiring an expandable means of connecting their expanding infrastructure in a cost-effective way wherever traditional cable laying is impractical.

Li-Fi (light fidelity) is the technology which uses visible light (580 nm) for data transfer at unmapped speeds exceeding 10 Gbps which is many times more than the traditional Wi-Fi. This technology is characterized by key attributes high bandwidth, low latency and increased security since it forms beams of light that do not penetrate walls, making it suitable for environments where radio frequency communication is banned or restricted like hospitals and airplane. A few recent studies acknowledge the potential it has to transform wireless communication by ensuring reliable connectivity in difficult environments.[1]

Li-Fi technology using the visible light of 580 THz (terahertz) is significantly faster data transmission than traditional Wi-Fi, with speed beyond 10 Gbps. Features: high bandwidth; low latency; also, excellent security thanks to light being both localized and physically limited. As a result, it is especially suitable for environments where radio frequency communications are restricted such as hospitals or airplanes. New research shows that its potential to revolutionize wireless communication is huge: creating secure, dependable links in difficult places. [2], [3] in Underwater communication, Reliable and high-speed data transfer has always been challenging for demanding environments. Obstacles, nature of water, etc. are believed to be influential factor in transmitting the signal.

Among these challenges, reliable and efficient transfer of data in underwater scenarios is difficult due to many hurdles, including the nature of water, attenuation, and signal distortion. The presence of turbidity, temperature gradients and underwater currents adds another level of complexity to this already demanding environment, as communication links cannot be kept constant. Overcoming these challenges requires novel approaches that can improve the robustness and efficacy of underwater information transmission. In NLOS channels, the multipath propagation can be used that is, where the signals reflect from surfaces like the sea floor or the sea bottom, or from under the water structure to reach the receiver.[4] Underwater scenarios are notoriously difficult to navigate, which can make this powerful signal reception possible with the propagation from our system using multiple paths for arrival, improving reliability and data rates. While multipath does provide benefits in terms of reflected signals, the effects are complex, providing some challenges to signal processing and equalization. Figure 1 shows the proposed scenario of signal transmission from terrestrial communications to underwater platforms.

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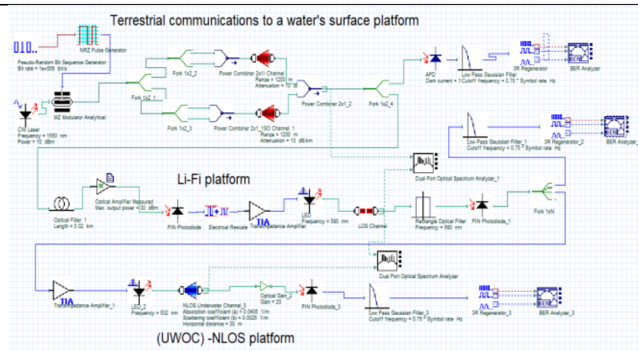


Figure 1. Terrestrial TO UWOC optical communications link

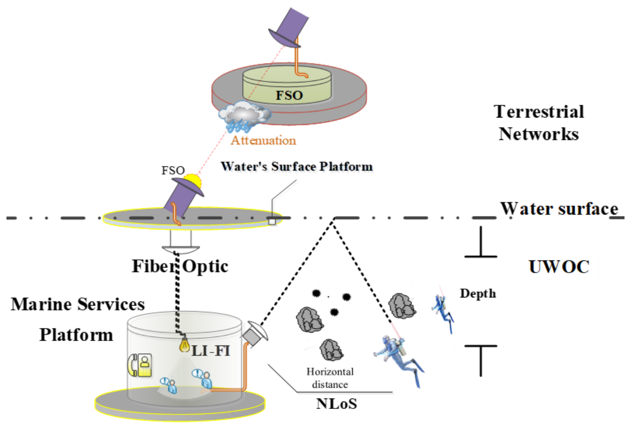


Figure 2. Shows a simulation of the proposed design for ground-to-underwater platforms

Simulation models were built to predict the performance of the hybrid FSO-Li-Fi-NLOS system under various configurations and environmental conditions. The system performance was evaluated in terms of Bit Error Rate (BER) and Quality of Service (QoS). The structure of the paper is as follows: Section 2 presents the components of the suggested system model design. Section 3 delineates the degradation processes of the primary channel of the proposed system. Section 4 addresses the findings and observations Section 5.

**System Design**

Using Free-Space Optical (FSO) communication to support Light Fidelity (Li-Fi) systems in underwater platforms is an intriguing approach to overcoming the challenges of network deployment. Here’s a structured overview of how to investigate the effectiveness of such a system, including key considerations, methodologies, and potential outcomes.

This work presents a new communication scheme that extends optical wireless networks from terrestrial to underwater environments, taking into account different channel degradation factors. This study specifically suggests designing a communication link terrestrial network, water's surface, and underwater platforms; they will be discussed, respectively.

Terrestrial communication to a water's surface platform.

Free space optics serves as a bridge between terrestrial networks and the above-water platform. Figure 2 shows the design of the proposed system. design of the proposed system.

FSO Atmospheric Model

The signal is transmitted to the platform installed above the water surface according to the proposed design; one end of the bidirectional is installed on the land side and the other is installed above the platform on the water surface. Attenuation in the environment surrounding the FSO link caused by changes in the surrounding environment is a negative factor when evaluating the signal strength. [5]

The following formula can be used to calculate the atmospheric attenuation coefficient.

$$\gamma\ (\lambda)=\frac{A}{\lambda^{b}}\cdot e^{-\lambda^{\alpha}} \qquad (1)$$

Where:

The attenuation coefficient γ(λ) at a certain wavelength λ is determined by several factors, with the fixed value A representing the particular environment experienced by the given path (fog, rain, air turbulence, etc.). Given the relation between exponential

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$\lambda^b$ which shows how the attenuation varies across wavelengths, and $\lambda^\alpha$ for the local atmospheric limitations. Moreover, the distance d that the signal navigates is meaningful.

This formulation is often applied in FSO systems to model how light is weakened as it moves through the atmosphere, considering both the impacts of wavelength and the bordering environmental determinants. The surrounding conditions can greatly modify the attenuation, as even on a clear day some wavelengths may experience greater weakening than others over long ranges. Meanwhile, short term fluctuations in the atmosphere introduce variability into the coefficient on fast timescales. [6], [7]

Rain attenuation affects the range and reliability of the FSO link, being 10 dBm in rainy weather and 0.2 dBm in clear weather, according to Kim's model. From the previous concepts, the attenuation coefficient was extracted. The main components of an FSO system can be described as follows: three main parts of an FSO system: transmitter, channel, and receiver.

Figure 2 shows the block diagrams of a hybrid FSO/fibre optic system. The transmitter includes an NRZ pulse generator, a pseudo-random bit sequence generator, and a Mach-Zehnder modulator. The frequency of 1550nm with a bit rate of 1Gb/s has been installed in the transmitter system [8]. In the transmitter channel, the most important parameters were fixed in Table No. 1, which shows the range that was based on the range of visibility and attenuation according to the climatic conditions surrounding the system, as well as the area of the transmitter and receiver lenses. The FSO receiver unit consists of a photodetector and a Bessel low-pass filter. A 3R generator is used to measure the bit error rate and Q factor of the signal.

Table I. Bidirectional Fso Parameter Configuration

| **Parameter** | **Measurement** |
|---|---|
| Range | 1000 m |
| Attenuation | 10dBm |
| Additional losses | 1 |
| Transmitter aperture diameter | 2.5cm |
| Beam divergence | 1 |
| Receiver aperture diameter | 35cm |

These parameters were adopted for the multipath FSO systems according to the scenario that was applied. was at a distance of 1 km at 10 dBm was adjusted in rainy weather, for the purpose of examining the effect on the signal that reaches the end user underwater.

Marine Services Platform

The method of installing the two Bidirectional FSO systems: the first with the ground network and the second one on the side with the network and the other is installed on a platform above the water surface that is connected with fiber optic up to 10 meters deep in the water to transmit the received signal to the closed platform under the water that was designed using Li-Fi technology inside it.

The marine services platform adopted in this scenario is 10 m deep .This platform is designed to provide marine services with the necessary requirements, namely communication between the depths and the outside. Figure 1 shows what was previously described.

Li-Fi is a wireless communications technology that uses visible light emitted from LEDs (light-emitting diodes) to transmit data. This technology highlights how quickly oscillating LEDs can transmit binary data. Compared to traditional Wi-Fi, which relies on radio waves, Li-Fi uses light signals to send and receive data, offering an ambitious approach to wireless communication. The basic parameters of visible light communication (VLC) technique are shown in Table 2.

Table 2. VLC parameter in marine services platform

| **Parameter** | **Measurement** |
|---|---|
| Distance | 2 m |
| Transmitter half-angle | 30m |
| Incidence half - angle | Adjustable deg. |
| Detection surface area | 5cm^2 |

Figure 3 show the Simulation parameters in visible light communication component that adopted in total design. Electrical Rescale to user-defined minimum and maximum values. For applications requiring high bandwidth and low noise, a transition impedance amplifier is a suitable choice. It is associated with the LED which is set to 580 nm frequency. Simulates a modulated LED connected with Filter for a rectangle frequency transfer function. The signal coming out of the system is copied to duplicate component output ports. The first is for measuring the error rate and the other is sent to (UWOC)- NLOS.

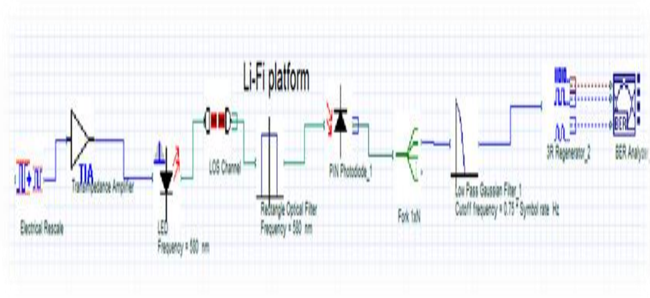


Figure 3. VLC system design in marine services platform.

Underwater Optical Communication (UOC)

UOC is a promising technology that takes advantage of the propagation mechanism of light to transmit data through water. It offers positive advantages when compared to radio frequency (RF) technology, through higher bandwidth and data transfer speed. However, the alignment between the transmitter and receiver is a critical factor for system performance. This study will explore the effect of changes in these angles and how they affect communication efficiency.

In this part, reference will be made to the basic principles of NLOS in underwater environments, and the design has incorporated these parameters to reach the desired results.

A NLOS underwater channel has been used to transfer optical signals between two telescopes that are not in direct line of sight. To illustrate the mechanism of light signal transmission in the underwater layer, the signal is transmitted from the source towards the water surface and once it touches the surface it is reflected back to the underwater environment. Here, the signal is weakened by the effect of the attenuation coefficient and also due to other elements such as biological interference, temperature gradients and water quality.

The attenuation coefficient in underwater optics, often referenced in studies of light propagation in water, is the following: [9]

$$c(\lambda)=a\ (\lambda)+\beta(\lambda) \qquad (2)$$

Where:

The attenuation coefficient in Pure Sea, which has been used in this study, is c(λ) at wavelength 532 nm, and a (λ) is up to 0.0405 1/m; absorption and scattering coefficients are indicated by β(λ) at 0.0025 1/m, respectively

This research investigates how different angles between the transmitter and receiver affect performance, with transceivers positioned vertically to project light beams defined by inner and outer angles (θmin and θmax). According to Fresnel's law, light that travels through various media undergoes partial refraction and reflection at their boundaries, causing some light to be reflected from the sea surface at a depth h. The power received in an Underwater Wireless Optical Communication (UWOC) system can be represented by the equation:

$$PR = PT \cdot \eta T \cdot \eta R \cdot ARec\ Aann \cdot \cos(\theta) \cdot \cos(\theta t) \qquad (3)$$

In this equation, PT indicates the average optical power from the transmitter, while ηT and ηR denote the optical efficiencies of the transmitter and receiver, respectively. The variable l represents the distance between the transmitter and receiver, θ is the angle of incidence of the transmitted ray concerning the water surface, and θt is the angle of the refracted ray. [10]

Figure 2's lower portion displays the UOC-NLOS design. The attenuation of light as it travels through water, taking into account the effects of wavelength on visibility, the effect of immersion in depth, transmission angles, horizontal transmitter-receiver distance and surface incident angle. The angle of incidence refers to the angle at which a ray of light strikes a surface, such as the air-water interface. This angle can be measured from the normal (line perpendicular to the surface) to the incident light ray. The angle affects how a light is reflected when it hits a surface. According to Snell's law, the angle of refraction depends on the refractive indices of the two media and the angle of incidence.

**II. Results and Discussion**

In this section, we will present the most important results related to the performance of the Q factor and BER of free space optical communication systems and fiber optic systems linked to the platform above the water surface to send the marine service room the signals, which utilize the Li-Fi technology through which the UWOC signal is provided, derived from the parameters described previously.

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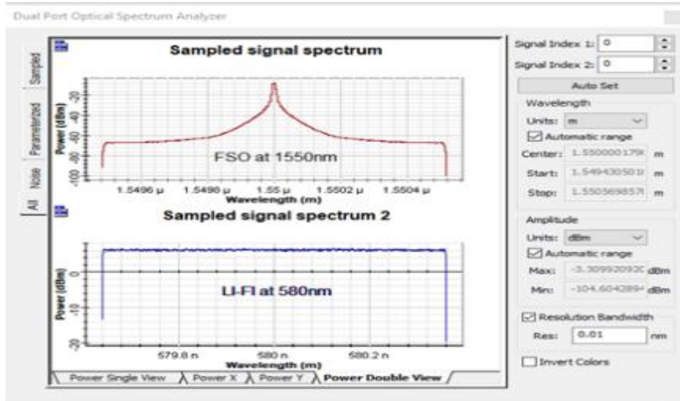
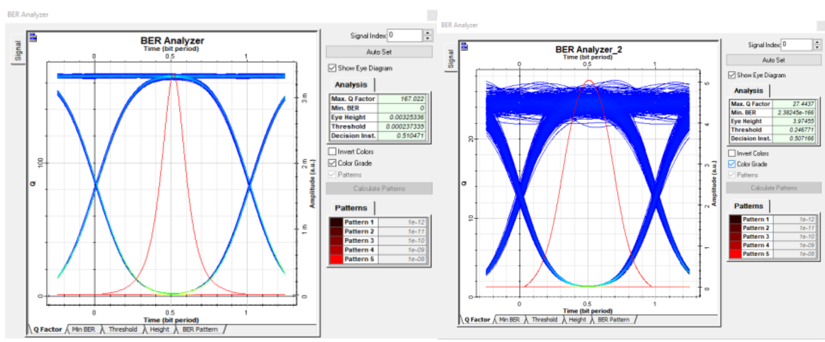



Fig.4 Optical Spectrum Analyzer for FSO and Li-Fi Signal.

The main metrics, including the Q factor, eye height and bit error rate, are used to comprehensively evaluate the system performance. Initially, the signal arriving at the water services platform will be displayed by the FSO. Two sampled signal spectra of the Dual Port Optical Spectrum Analyzer are shown in the figure 4.

The upper spectrum displays a clear peak corresponding to the FSO signal at 1550 nm, while the lower spectrum represents a constant output of the Li-Fi signal at 580 nm. This spectrum has a flat line shape, meaning the power becomes relatively stable, which means the intensity of Li-Fi signal does not fluctuate significantly at 580nm wavelength indicating an even and stable transmission.

figure 5(a) show FSO signal QoS coefficient of 167.022 after applying an attenuation of 10 dBm over a distance of 1 km.




(a) (b)

Figure 5. QoS coefficient (a) FSO, (b) LI-FI

While Figure 5(b) shows the LI-FI QoS coefficient of 27.4 inside the marine services platform at a distance of 2 meters between the transmission source on the ceiling of the room and the floor.

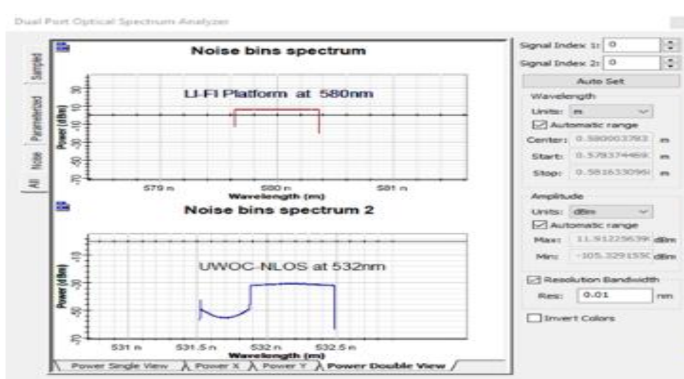



Figure 6. Optical Spectrum Analyzer for FSO and Li-Fi Signal

In figure 6 the upper spectrum indicates a stable LI-FI signal with minor noise, while the lower spectrum reflects a robust UWOC signal with a clear peak, demonstrating effective performance in the specified wavelength ranges. Lower Spectrum for UWOC -

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NLOS at 532 nm. indicating a constant output with some noise. The UWOC-NLOS transmission source is connected through the service room for the purpose of transmitting the signal to end user.

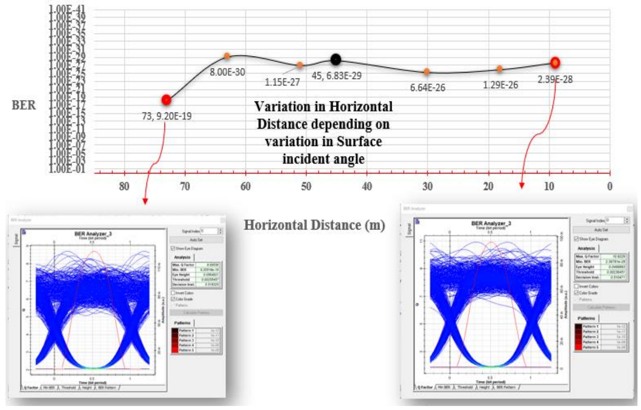


Figure 7. Horizontal distance variation with BER

Figure 7 shows the variation in the error rate due to the change in surface incident angle. Which leads to determining the horizontal distance between the sender and the receiver. It should be noted that the value of the critical angle is close to 46.7 degrees, which total internal reflection occurs. For this reason, it was exceeded in measurement, as the angle before it was measured at 45 degrees and continued after 56.3 degrees, reaching 67.65 degrees. The bottom left and right sides of the figure contain an eye diagram to show the bit error rate for the horizontal distance at 9 m and 73 m in the curve.

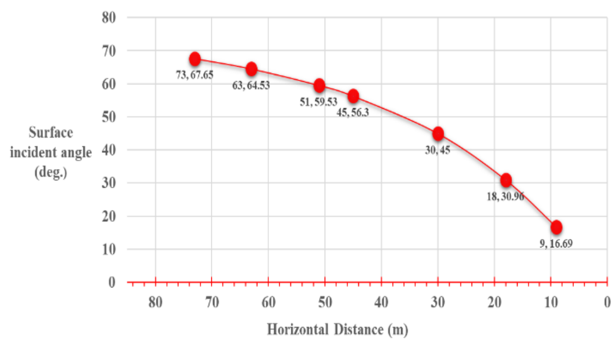


Figure 8. Variation between horizontal distance and surface incident angle

Figure 8 shows the variation in horizontal distance depending on the variation in surface incident angle. when the transmitter and receiver depth are set at 10, 20 meters deep respectively.

There is a clear behavior of the curvature in Figure 8, where the increase in the horizontal distance is directly proportional to the increase in the angle of incidence of light on the surface. Since the horizontal distance that light can travel underwater is affected by the angle of incidence at the surface, the angle must be chosen to ensure that the light reaches the receiver effectively while maintaining an acceptable error rate.

Table 3. Parameter Measurement for LI-FI and UWOC-NLOS

| | **Parameter** | **Measurement** |
|---|---|---|
| **LI-FI** | Transmitter Half-Angle | 15 deg. |
| | Irradiance Half-Angle | 0 deg. |
| | Incident Half-Angle | 0 deg. |
| **UWOC-NLOS** | Transmitter depth | 10 m |
| | Receiver depth | 20 m |
| | Horizontal distance | 30 m |
| | Surface incident angle | 45 deg. |

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It is worth noting that the LI-FI signal is coming from the marine services platform, which has its own conditions for controlling the signal strength received by the UWOC-NLOS system. The robustness of the system's performance will be tested if the conditions of the LI-FI signal between the sender and the recipient change. Table 3 Shows the Parameter Measurement that was adopted for the first test.

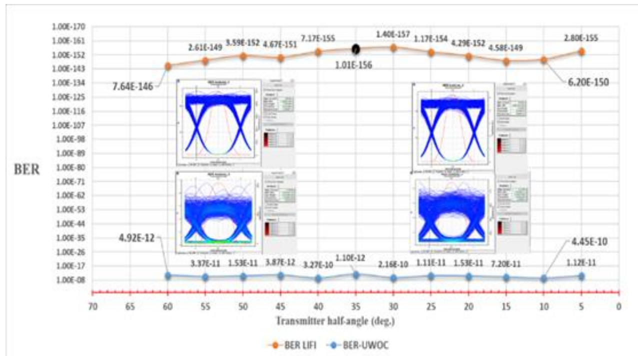
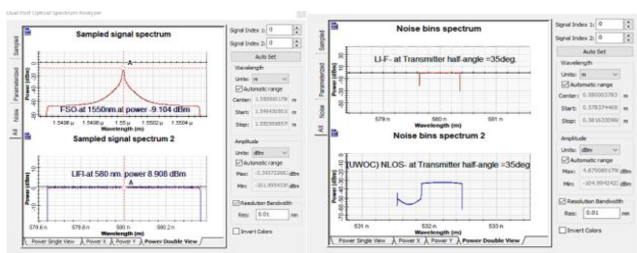



Figure 9. Variation Transmitter half-angle for Li-Fi and BER for both LI-FI and UWOC-NLOS

Figure 9 shows the variation in the half-angle of the transmitter for Li-Fi technology, despite the difference in signal strength between Li-Fi and NLOS, where the BER varies between 1.4E-157 at an angle of 30 degrees and 7.6E-146 at an angle of 60 degrees. The BER of the UWOC-NLOS system is shown to be stable in spite of the transmitter's half-angle change. The error rate is still within the permissible limits. The eye diagram included in the figure shows the BER for the points at the beginning and end of the curve for both cases. Note that the parameters listed in the Li-Fi portion of Table 3 have been adopted.




(a) (b)

Figure 10. Optical spectrum analyzer between FSO-LI-FI and LI-FI- UWOC-NLOS

Figure 10(a), (b) shows the power for utmost systems of the proposed design preliminary from FSO where we notice the power value at indicator A reaches -9.104dBm while at the bottom it reaches 8.908dBm which represents Li-Fi at Transmitter half-angle 35deg. While the lower part of Figure 10(b) indicates the UWOC-NLOS signal power in case it uses the identical parameters.

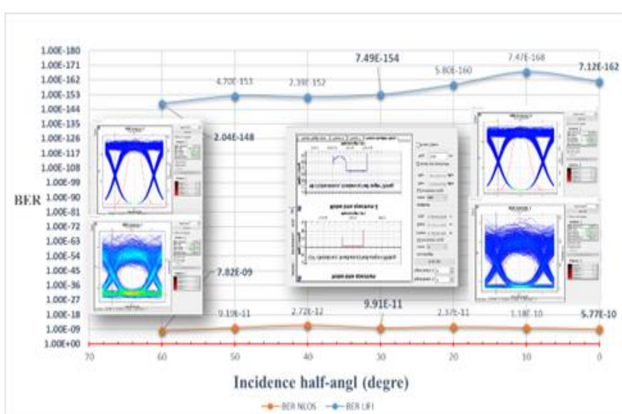



Figure 11. variation in Incidence half-angle for Li-Fi and BER for both LI-FI and UWOC-NLOS

Figure 11 shows the variation in the half angle of incidence after the transmitter is installed, a half angle of 35 degrees. We can see that the stability of the UWOC-NLOS system is maintained despite the change in angles in the Li-Fi system. It should be noted that the error rate remains within acceptable bounds.

Key metrics, including Q factor, eye height, and bit error rate, are used to comprehensively evaluate the system's performance.

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Finally, does the FSO system have an impact on the results of the system overall if the link strategy and parameters adopted in this research change? Let's change the multi-path transmission to a single-path transmission, reduce the transmission power for both to 5dBm, and examine the changes in the system's behavior. The impact of transmission methods on system performance is clear when the transmission method is changed from multipath to single-path, in addition to the effect of the power factor. Figure 12 highlights the above suggestion.

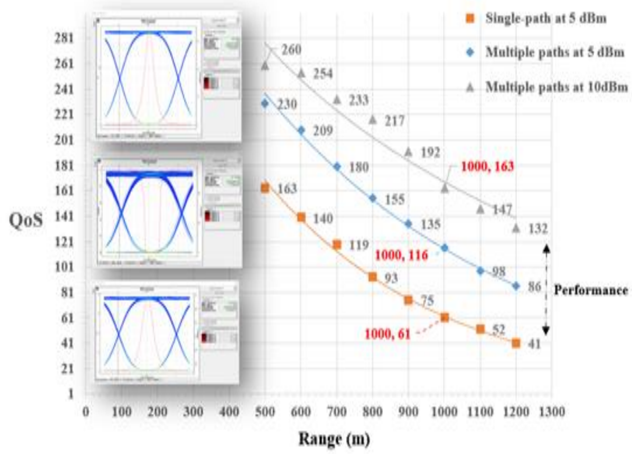


Figure 12. Variation in QoS with FSO Range in (Multi/Single) Path

when comparing approaches, alongside the influence of power levels. With a power setting of 5 dBm and a range of 1000 meters, the permissible limit in rainy conditions, as outlined by the Kim Model, results in performance metrics ranging from 61 to 116 dBm. However, in the case of multi-path adoption and the power reaches 10 dBm, it reaches 160 dBm. which will be positively reflected in the system performance.

From the previous results, the most important factors affecting performance are as follows:

The proposed system has been being tested from several aspects. From the previous results, the most important factors affecting performance. transmission methods and power levels for the FSO system. Transmitter half-angle, incident half-angle for Li-Fi in marine services platform. Furthermore, impact of surface incident angle on horizontal distance between transmitter and receiver depth in UWOC-NLOS. The results were promising and could be enhanced by examining additional factors in future studies.

## III. Conclusions

To overcome the difficulties of deploying terrestrial networks in UWOC environments, optical wireless communications are an alternative. This study investigates the effectiveness of the FSO channel system to cover enclosed underwater service, utilizing Li-Fi technology to support underwater NLOS links with suitable communications. The effectiveness of the proposed system has been tested. The effectiveness of the proposed system has been verified. The performance of the system significantly improves when using multi-path transmission power levels (10 dBm). To avoid rainy weather effects. And to transmit a sufficient signal to avoid changing the transmission angle in the Li-Fi system. Thus, being considered the signal provider for the UWOC-NLOS system. Several surface incident angle tests have been tested, where a horizontal distance of up to 70 meters was achieved with a depth of 20 meters between the transmission and receiving platform. The system has succeeded in achieving more reliable and efficient communications, even in less-than-ideal conditions.

## References

1. A. K. S. S. Kumar et al., "A Survey on Li-Fi Technology: Applications, Challenges, and Future Directions," IEEE Access, vol. 10, pp. 123456-123478, 2022.
2. H. Haas, "Li-Fi: A Paradigm Shift in Wireless Communication," IEEE Wireless Communications, vol. 29, no. 2, pp. 4-5, April 2022.
3. M. A. Khalid et al., "Recent Advances in Li-Fi Technology: A Comprehensive Review," IEEE Communications Surveys & Tutorials, vol. 24, no. 1, pp. 123-145, Firstquarter 2022.
4. Liu, Y., Wang, Y., Chen, C., & Liu, C. (2023). Underwater Wireless Sensor Network-Based Localization Method under Mixed Line-of-Sight/Non-Line-of-Sight Conditions. Journal of Marine Science and Engineering, 11(9), 1642. https://doi.org/10.3390/jmse11091642
5. Alnajjar, S. H., & Hameed, A. M. (2022). Light fidelity performance via hybrid free space optic/fiber optic communication under atmospheric disturbance. Indonesian Journal of Electrical Engineering and Computer Science, 27(1), 355-365.
6. H. Haas, "Li-Fi: A Paradigm Shift in Wireless Communication," IEEE Wireless Communications, vol. 29, no. 2, pp. 4-5, April 2022. doi: 10.1109/MWC.2022.9741234.

7. A. A. M. Al-Habash, M. A. Khalid, and A. A. M. Al-Hamadi, "Challenges and Solutions in Free Space Optical Communication: A Survey," IEEE Communications Surveys & Tutorials, vol. 24, no. 1, pp. 123-145, Firstquarter 2022. doi: 10.1109/COMST.2022.1234567
8. Alnajjar, S. H., Ali, M. H., Al-Obaidi, A., & Alsaedi, M. A. (2020). Hybrid of multiple (TX/RX) FSO/fiber optic communication system under environmental disturbances. Journal of Multidisciplinary Approaches in Science, 2(1), 7-16.
9. M. A. Khalid, A. A. M. Al-Hamadi, and K. A. M. Al-Habash, "Underwater Wireless Optical Communication: Challenges and Solutions," IEEE Communications Surveys & Tutorials, vol. 22, no. 3, pp. 1234-1256, 2020. doi: 10.1109/COMST.2020.2991234.
10. S. Arnon, "Underwater optical wireless communication network," *Opt. Eng.*, vol. 49, no. 1, Jan. 2010, Art. no. 015001.