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Performance evaluation of VLC based Li-Fi Channels under the influence of Ambient Light

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Abstract—**Visible light communication (VLC), also known as light fidelity (Li-Fi), is the most advanced type of wireless communications that uses free space and transmits data through Light Emitting Diode (LED) or Laser Diode (LD). The advent of light emitted diodes (LED) have significantly revolutionized modern communication systems. The LED serves as a transmitter and uses light to transmit data through a range of channel configurations. The high-speed optical detector decodes the transmitted data. VLC proves to be a practical, economical, and energy-efficient option, reducing radio interference. In this study, a Non-Return-to-Zero On-Off Keying (NRZ OOK) visible light communication system is designed and simulated using a 550 nm LED and a Pin photodetector. Simulations are performed on Opti System v.20.0 software under influence of ambient light. Three different channel configurations are considered for transmitting 3 Gbps of data including Line-of-Sight (LOS), Free Space Optics (FSO), and Optical Wireless Communication (OWC), while reaching a range of up to 10 meters. The system performs best in LOS channels without and with ambient light. Without ambient light, it achieves a maximum Q factor of 7.12 with a minimum BER of 3.1 × 10-13, while with ambient light, it achieves a maximum Q factor of 6.34 with a minimum BER of 6.5 × 10-11.**

Index Terms— **Li-Fi, NRZ-OOK Modulation, optical Channels, Range, Data Rate, Q-factor, Bit Error Rate (BER).**

I. Introduction

A Li-Fi communication system based on VLC uses light for transmitting data at speeds that are undetectable to the human eye. This technology improves security and safety in areas with radio frequency restrictions. The transmitter is an LED, and the receiver is either a photodiode or a phototransistor. The transmission occurs in the visible to humans 400-700 nm wavelength range [1], [2]. VLC operates without interference with RF signals, making it practical for applications like navigational services, vehicle communication, screen displays, hospitals, virtual reality, and underwater communications. The system's secure connection, implementation process, and absence of licensing requirements make it a promising replacement for traditional fiber optic connections in [3] .

Li-Fi technology has been extensively researched in both indoor and outdoor environments, using optical light sources, modulation methods, and channel connections for applications. First, present an overview of a few previous studies that are chosen in this area.

Li-Fi, another name for optical Wi-fi, is a special kind of OWC that utilizes the IR and VLC band (3-790THz) around 2600 times more than the RF band (0.3THz). Fig. 1 depicts the electromagnetic wave spectrum. Li-Fi is also more favorable in terms of very high bandwidth, ultra-speed transmission, higher spectrum efficiency and information security and may be utilized in locations where RF cannot, such as underwater and in mines.[4], [5] .

In hospital environments, Li-Fi technology provides an excellent and affordable way to continuously monitor a baby's heart rate, body temperature, and movements. Li-Fi is an emerging technology for healthcare monitoring because of its creative solution to the security issues with conventional wireless technologies, which provides reliable and safe patient monitoring in hospital environments.as shown by study [6].

Optical sources for electrical signal transformation include laser diodes and LEDs. While laser diodes use Free Space Optics (FSO) technology for increased efficiency and lower power consumption, LEDs are limited in terms of range and bandwidth. Because of this, laser diodes can transmit data over longer distances and with larger bandwidths, which makes them perfect for applications that need these features. In the end, laser diodes provide an optical signal transmission method that is more energy efficient [7].

In [8], [9] the authors reported the limitations of Vehicle-to-Vehicle Communication systems, focusing the longer the duration and higher power efficiency of LED lighting. A VLC system simulation is used to explain several aspects of VLC communication, such as potential simulation software, light-based LED approaches, video and audio transmission systems, impediments, and VLC-based vehicle communication in [10], [11]. Data rate, coverage area, Line-of-Sight and Non-Line-of-

Sight concerns, uplink connectivity, regulatory factors, and possible interference are all covered in the research.

The author of [12]created a hybrid Wi-Fi/Li-Fi network in a classroom by combining 8 Li-Fi Access Points (APs) known as Li-Fi Atto cells with already installed Wi-Fi APs. The bandwidth delivered by this system, which can support up to 8 users at a 43 Mbps speed in a classroom context, ranges from 43 Mbps to 344 Mbps. A circular area with a diameter of 2.5 to 3.5 meters is covered by the Li-Fi AP. In related research, the technology[13] combined WDM and OFDM across four channels that were each illuminated by various colors of LED. This method significantly increased data speed and effectiveness, with a bit error rate (BER) of about 28 × 10-4. However, the system had drawbacks because it depended on electrical OFDM, which limited its transmission range to about 1.6 meters.

In [14], the authors demonstrated the effectiveness of a Li-Fi system using laser light and a white light system. The system achieved data rates of 22.45 Gb/s over a 3-meter distance, 1.7 Gb/s over a 50-meter distance, and 11 Gb/s over a 5-meter distance. The system had a maximum processing speed of 22.45 Gbps and a transmission range of 5 meters, demonstrating significant developments in high-speed wireless data transfer.

In this paper, Opti System software is used to design, model, and evaluate a Li-Fi system based on VLC. The aim is to improve the system's performance when there is ambient light present, such as using fluorescent lamps that emit noise at a frequency of 50 Hz and 36 w.

Section II, discuss an evaluation of different configurations of Li-Fi system is provided in the presence of ambient light. All-optical non-return-to-zero on-off Keying (NRZ OOK) techniques are used to create detailed models. The Opti system's simulation software is used to evaluate these models in the presence of background noise. Section IIIV presents the simulated results of our proposed system, offering insights into its performance under various conditions. Lastly, in Section IV, offer some concluding remarks about the system's overall performance and implications.

II. USING VLC-BASED LI-FI SYSTEM WITH THE OPTI-SYSTEM SIMULATION SOFTWARE

Design and evaluate optical connections using Opti System simulations software, achieving data rate up to 3 Gbps. The use of the Opti System is primarily focused on determining and assessing the performance of Visible Light Communication (VLC) Li-Fi systems in environments that are affected by ambient noise while providing an effective communication range of up to 10 meters. In simulation, focus particularly on optical wireless communication, free space optics, and line-of-sight circumstances, examining their efficiency and dependability in actual situations.

In this paper, A transmitter, optical channel, and receiver make up the VLC based Li-Fi system. On the transmission end, an LED with a modulation bandwidth of 6 terahertz (THz), an NRZ pulse generator, and a pseudorandom binary sequence (PRBS) generator operating at data rate of 3 Gbps are used. A fluorescent lamp in the surrounding area is interfering with the sent signal's path across the channel. By removing undesirable frequency components, a low-pass Bessel filter is used to measure the optical signal-to-noise ratio (OSNR). A rectangular filter is used to filter the optical input before it is sent to a PIN photodiode. Using a transimpedance amplifier (TIA) configuration, a front-end amplifier (FEA) is added. A bit sequence regenerator is used on the receiver side to reconstruct the original bit sequence. To calculate the BER values of the received signal, the 3R-Regenerator is linked to the BER analyzer. The form of input and output signals is checked using an oscilloscope visualizer. Using simulation results, the VLC system's performance is examined. Show In Fig.1 .

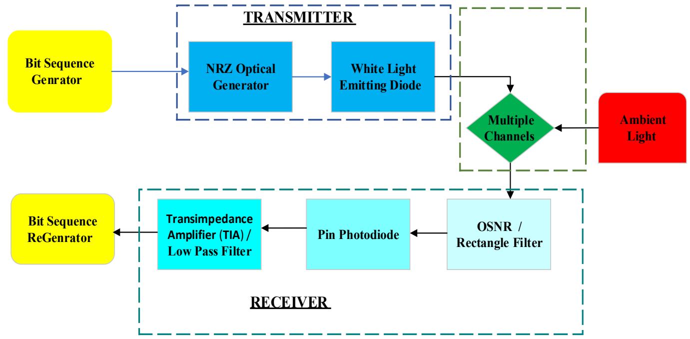

Fig. 1. Proposed Block diagram of the Opti system-based Visible Light Communication Li-FI system.

A. Channel Modeling

Include a noise model to the channel architecture to allow for different ambient light interferences, like sunlight, incandescent, and fluorescent lighting. Equation (1) is used to show how additive white Gaussian noise (AWGN) affects the transmission of visible light within a linear optical system.

$$I\,(t) = \eta p i(t) \otimes h(t) + N(t) \qquad (1)$$

I(t) in the VLC method stands for light detector currents, and η for the photodetector's photosensitivity. In conditions requiring direct line of sight (LOS), this form of detection uses lightning-fast power input to operate. The process of convolution ⊗ is a part of the technique, and h(t) stands for impulse response (IR) and N(t) for additive white Gaussian noise. LOS stands for the uninterrupted visible channel between both sent and received ends, implementing that there is clear line of sight for communication.

Line of Sight (LOS) propagation is a definition of propagation used to describe the direct and uninterrupted path through which signals travel between both the transmitter and the receiver. In that situation, the transmitter points the LED beam directly at the detector. Considering LOS situation, Equation (2) can be used to determine the received power. The received power is calculated using this equation, which also takes into account the channel DC gain, represented by the directed path and denoted as H LOS(0). In this particular situation, the power that is received equation is defined in accordance with the references [13].

$$Pr\,LOS = H\,LOS\,(0)pt \qquad (2)$$

Light reflects off of walls and other objects in non-line-of-sight (NLOS) conditions performing an important part in communication. The DC gain of the LOS channel usually impacts the brightness of this received light, and Equations (3,4) are used to determine the exact path of the reflected light, represented as H ref (0).

$$Pr\,LOS = H\,LOS\,(0)pt + H\,NLOS\,(0)pt \qquad (3)$$

$$= H\ LOS\ (0)pt + \sum ref\ Href\ (0)pt \qquad (4)$$

Evaluate the optical signal-to-noise ratio (OSNR), which is the use to measure the ratio of the signal power to the noise power when the signal in optical channel.

$$OSNR = 10dB\ log_{10}\left[\frac{Ps}{Pn}\right] \qquad (5)$$

The signal power, represented as Ps, is 99.9973W, whereas the noise power, represented as Pn, is 1.4057W. The Optical Signal-to-Noise Ratio (OSNR) is determined to be 18.5209 dB using the given Equation (5). OSNR evaluates the signal's quality and provides information about the accuracy and quality of the transmission system.

In this research, used a variety of channels, including OWC, FSO, and LOS, to send data at 3 gigabits per second. There was ambient noise that exist during the transmission between the sender and receiver. The aim was to increase data rate, range, Q factor, OSNR and etc. Then made a comparison between these channels to evaluate which one had the best performance.

B. OWC Channel Model

The study generated a high bitrate 3×10^9 bits/s pseudorandom data sequence using an Opti system for optical wireless communication (OWC) channels with the LED transmitter was modulated using these data, with a range of up to 10 meters. As shown in Fig. 2, the received signal was processed by parts, such as OSNR, a rectangular filter, the PIN photodiode, a transimpedance amplifier, a low-pass Bessel filter, and a 3R regenerator component. By evaluating signal quality, time domain behavior, and frequency domain optical signals, oscilloscope visualizers, optical time domain visualizers, and optical spectrum analyzers were used to evaluate system performance.

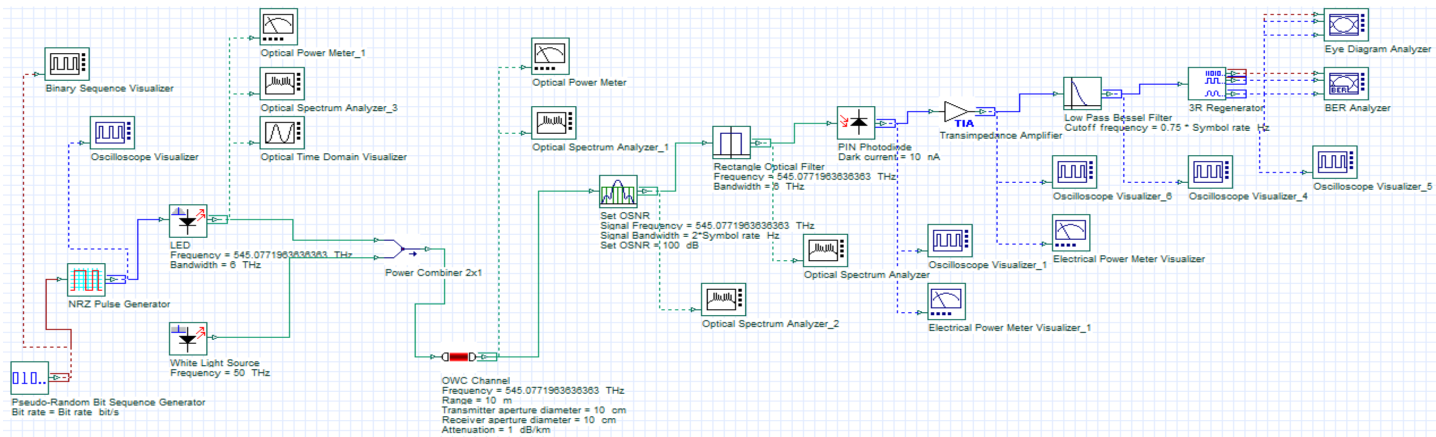

Fig. 2 Opti system simulations software for the OWC channel model with ambient light

C. FSO Channel Model

This study used the Opti system for Free Space Optics (FSO) channels simulation to create a high-bitrate 3×10^9 bits/s pseudorandom data sequence for an LED transmitter. The data was modified using NRZ electrical pulses, and up to a 10-meter continuous connection was achieved. Techniques like low-pass filters and transimpedance amplifiers were used to improve signal accuracy. Fig.3 shows the VLC based Li-Fi FSO channel in an Opti system simulation.

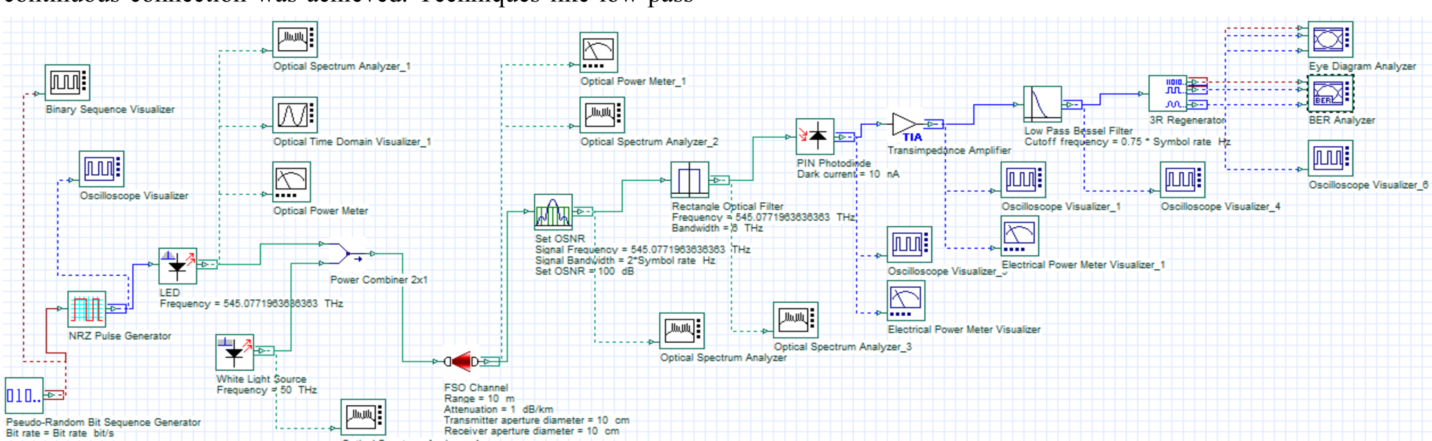

Fig. 3 Opti system simulations software for the FSO channel model with ambient light

D. LOS Channel Model

A high-bitrate pseudorandom data sequence of 3×10^9 bits/s was created in the study using the Opti system software through Line-of-Sight (LOS) channels. Non-Return-to-Zero (NRZ) electrical pulses were used to modulate the data and shape the stream for transmission via an LED transmitter. The LOS channels allowed for continuous connection up to 10-meter range, with half angles of incidence 25°and irradiance 22°under the influence of ambient noise. An efficient communication link was designed, and the Optical Signal-to-Noise Ratio (OSNR) was evaluated to assess signal accuracy. Signal enhancing methods included a low-pass Bessel filter, rectangular filter, PIN photodiode, and transimpedance amplifier. A 3R regenerator component was used to reduce data transmission errors and maintain signal integrity. Fig.4 displays the VLC-based Li-Fi LOS channel in an Opti system simulation, while Table I provides a detailed analysis of component specifications for a comprehensive evaluation of Line-of-Sight channels.

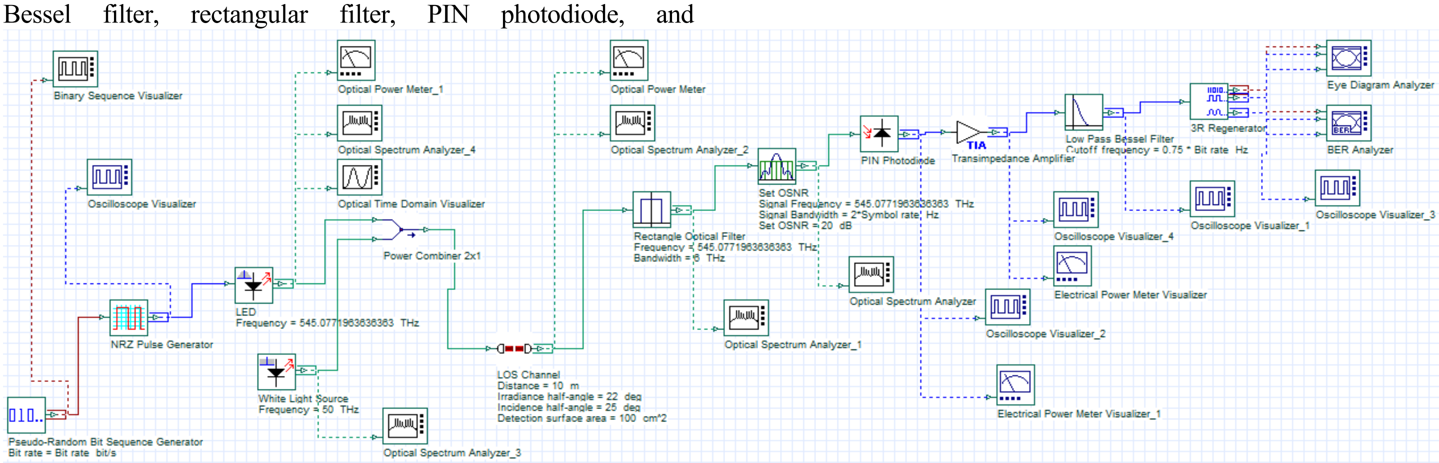

Fig. 4 Opti system simulations software for the LOS channel model with ambient light

TABLE I
THE COMPONENTS PARAMETERS OF VLC BASED LI-FI LOS CHANNEL UNDER THE EFFECT OF AMBIENT NOISE.

Component	Values
Bit rate	Bitrate = 3Gbp Operation Mode = Order
Modulation Technique	NRZ on-off Keying (OOK) Format for pulse range = Min/Max
LED Source	Frequency = 550 nm (545.077 THz) Electron lifetime = 100 × 10−12 s RC time constant = 100 × 10−12 s Slope efficiency = 0.5 W/A Quantum efficiency = 0.65 Bandwidth = 6 THz
Ambient noise Light Source	Frequency = 50 THz Average power = 36 W
LOS Channel	Distance = 10 m The half angle of incidence = 25° The half angle of irradiance = 22°
Rectangle Optical Filter	Frequency =550 nm (545.077 THz) Bandwidth: 6 TH
PIN Photodiode	Type of Responsivity = Silicon Responsivity = 1 A/W Dark Current = 10nA Short Noise Distribution = Gaussian
Transimpedance Amplifier (TIA)	Open loop Voltage gains = 90 Ω
Bessel Low Pass Filter	Cutoff frequency = 0.75 × symbol rate

III. RESULTS AND DISCUSSION

The propagation properties of the Line-of-Sight (LOS), Free Space Optics (FSO), and Optical Wireless Communication (OWC) channels were evaluated in the research using the Opti System simulation software , as shown in Fig. 2, 3, and 4.Results showed significant form changes under background noise, particularly in Line-of-Sight channels from Fig. 5,6,7. The study validated the efficacy of VLC systems under real-world conditions, indicating excellent signal quality and minimal data transmission errors in Fig. 8.

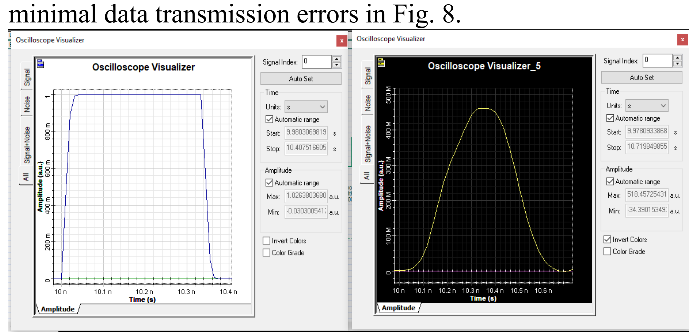

Fig. 5 VLC based LI-FI OWC channel simulation results. input signal is (Oscilloscope visualizer). output signal (Oscilloscope visualizer_4).

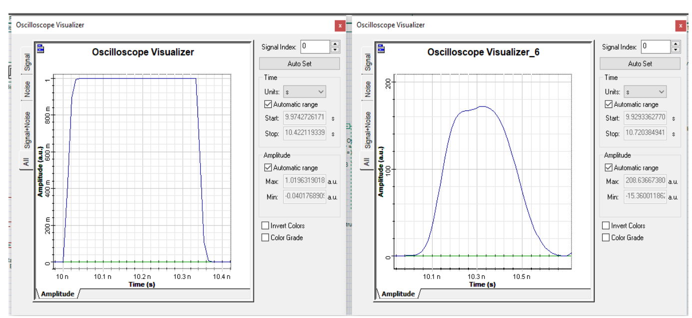

Fig. 6 VLC based LI-FI FSO channel simulation results. input signal is (Oscilloscope visualizer). output signal (Oscilloscope visualizer_6).

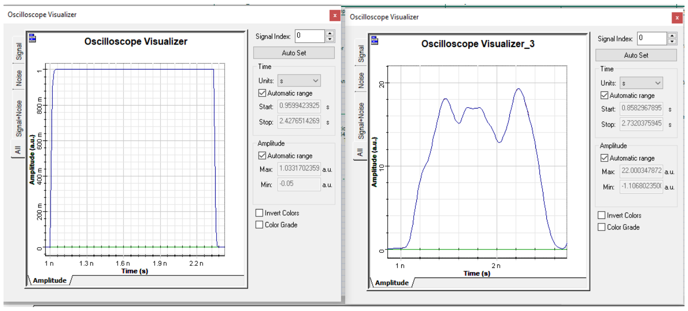

Fig. 7 VLC based LI-FI LOS channel simulation results. input signal is (Oscilloscope visualizer). output signal (Oscilloscope visualizer_3).

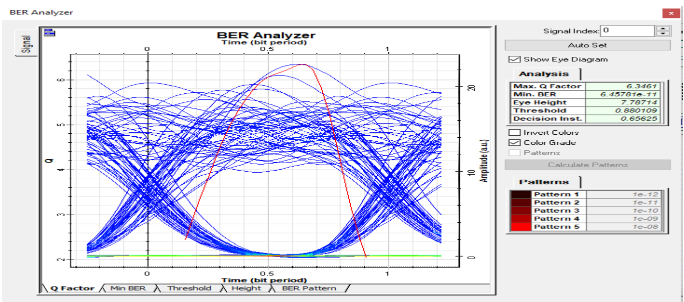

Fig. 8 VLC based LI-FI LOS channel BER Analyzer results.

The effect of ambient light on OWC channels is seen in Fig. 9. The maximum Q factor decreases to 5.84 in the presence of light and increases to 6.104 in the absence of light. With light, the minimal BER is 1.35e-09; in the absence of light, it is 2.76e-10. With light, the eye height is 2.04e+08, whereas in the absence of light, it is 5.07e+8. With light, the threshold is 1.13e+11, and in the absence of light, it is 3.54e+8. With light, the decision instance is 0.5; in the absence of light, it is 0.625. According to investigation, the presence of ambient light causes every parameter to decrease which reduces system performance.

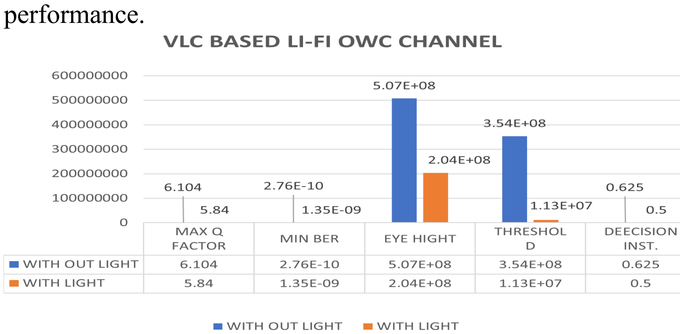

Fig. 9 LI-FI OWC channel based on VLC with and without the influence of ambient noise.

A comparison of the FSO channel performance in the presence and absence of ambient light is shown in Fig. 10. The maximum Q factor is 6.203 when ambient light is present, as compared to 6.548 when it is excluded. The minimal BER in ambient light is 1.45e-10; in the absence of light, it is 1.53e-11. Eye height is 217.75 without ambient light and 104.14 with it. Decision moment with light is 0.5, without is 0.53; threshold with light is 5.49, without is 10.85. Investigation shows that when ambient light is present, all parameters decrease, which suggests a reduction in system performance.

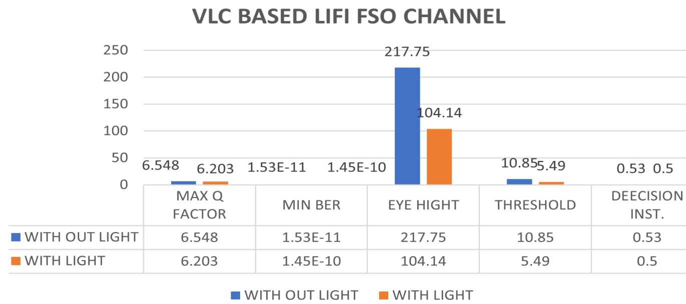

Fig. 10 LI-FI FSO channel based on VLC with and without the influence of ambient noise.

Fig. 11 compares the effect of ambient light using LOS channels with the absence of it. The system's performance is influenced by the maximum Q factor of 6.34 in the presence of ambient light and 7.1271 in the absence of it. The minimum BER is 6.45 e-11 in the presence of ambient light and 3.10e-13 in the absence of it. The eye height is 7.78 in the presence of ambient light and 17.12 in the absence of it. The threshold is 0.88 in the presence of light and 2.3 in the absence of light. The decision-intent is 0.65 in the presence of light and 0.68 in the absence of light. Results indicate that in the presence of ambient light, the minimum BER increases, all parameters decrease, and system performance decreases.

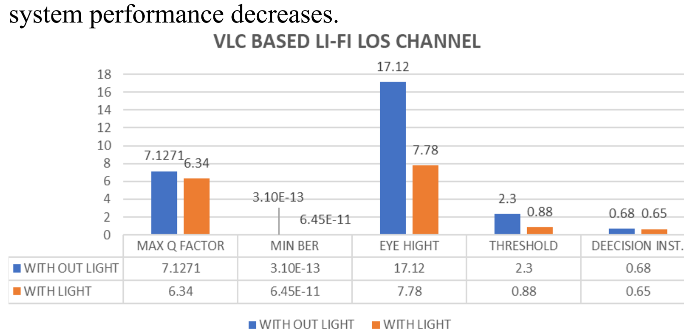

Fig. 11 LI-FI LOS channel based on VLC with and without the influence of ambient noise.

A comparison of the OWC, FSO, and LOS channels influenced by ambient light is shown in Fig. 12. The maximum Q factor, it should be observed, is 5.84 in OWC channels, 6.203 in FSO channels, and 6.34 in LOS channels. Analysis of the minimum Bit Error Rate (BER) with ambient light shows that LOS channels exhibit 6.45e-11, FSO channels display 1.45e-10, and OWC channels record 1.34e-09. Furthermore, when Eye Height is considered in ambient light, OWC channels display 2.04e+08, FSO channels show 104.14, and LOS channels display 7.78. For OWC channels, the threshold values are 1.13e+07, for FSO channels they are 5.49, and for LOS channels they are 0.88 in the presence of light. For OWC and FSO channels, the Decision Instant is 0.5 in the presence of light, whereas for LOS channels, it is 0.65. Analysis shows that in the presence of ambient light, all parameters should be increased and the minimum BER should be decreased, improving system performance. Further investigation confirms that, when ambient noise is present, LOS channels perform better than OWC and FSO channels.

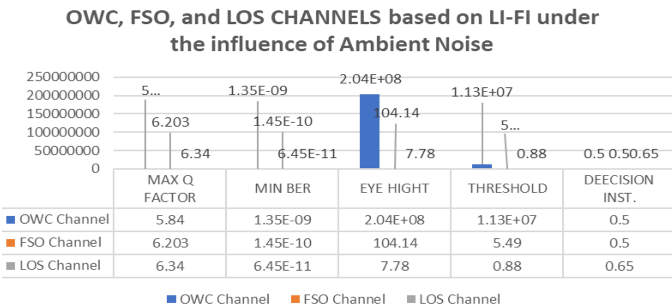

Fig. 12 LI-FI OWC, FSO and LOS channel based on VLC with the influence of ambient noise.

IV. Conclusion

This paper evaluates visible light communication (VLC) based Li-Fi channels under the influence of ambient noise systems, focusing on performance evaluation aimed at parameters like OSNR, Q-factor, bit error rate (BER), eye height, and threshold, and others. The research results reflect an improvement in indoor communication technology, with a reliable VLC Li-Fi system that can achieve 3Gb/s over 10 m and OSNR is 18.52 db. Line-of-Sight (LOS) channels perform better than Optical Wireless Communication (OWC) and Free Space Optics (FSO) channels under difficult noise conditions, showing better results with a bit error rate of 6.45e-11 and a Q-factor of 6.34. A rectangular optical filter is used in the study to solve the problem of interference from ambient light as a noise. This study expands the possibilities for wireless communication technology and helps the field of wireless communication in the future.

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