Light fidelity performance via hybrid free space optic/fiber optic communication under atmospheric disturbance

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Article Info

Article history:

Received Feb 22, 2022
Revised May 17, 2022
Accepted Jun 8, 2022

Keywords:

Fiber optic channel
Free space optic
Light emitting diodes
Light fidelity
Optical wireless communication
Visible light communication

ABSTRACT

Light fidelity (Li-Fi) considers technology in optical wireless communication (OWC) that utilize visible light for transmission in free space, visible light communication (VLC) technology was chosen to overcome the interference issues of radio frequency (RF) communication and it also has higher bandwidth and is more secure. This paper aims to analyse the influence of atmospheric attenuation on the end-users of VLC system that consisted of five light-emitting diodes (LEDs) distributed in a room, which in turn linked with the hybrid optical system includes a multi-channel of free space optic (FSO) connected with a fiber-optic channel (FOC). The hybrid system to the end-user was estimated in terms of bit error rate, quality factor, and signal power under dust-rain weather conditions. In the dust scenario, the suggested system achieved acceptable bit-error-rate (BER) to a distance of 1,100 m. In rainy conditions, the performance accomplished acceptable BER to a distance of 3000 m. The VLC system's end-user also was evaluated under the effectiveness of the variation of irradiance and incident angles. Despite the harsh environmental conditions imposed on the communication network, VLC has proven its ability to maintain acceptable performance in end-user.

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1. INTRODUCTION

The weather conditions play an important role in the free space optics (FSO) link implementation, attenuation of atmospheric on the FSO system has a huge effectiveness on optical power, causing it to drop significantly. These attenuations caused by the weather environment, such as rain, fog and dust [1]. Because of high data rate requirements and major network ability can be seen as a challenge newly in newfangled wireless communication due to high demand of network access and backing of users mobile [2]. Light is considered a carrier because it can be transmitted wirelessly using optical transmitters through a medium such as the air and the known FSO system. The technology of the FSO is a high-speed data rate and wide-band applications when the fiber-optic (FO) system is complex to establish [3], [4]. Moreover, part of the enormous modern requirements for high-capacity communication systems has been achieved by wired optical communication and wireless systems, thus, hybrid configurations have been introduced to fulfill these needs. The types of hybrid communication systems are FSO/random forest (RF) [5] and FSO/FO [5], [6], the optical hybrid link FSO/FO could overcome the limitations of the bandwidth caused by hybrid FSO/RF [6], [7]. The infrastructure fiber-based distortions issue, mile and last mile issue of the optical communication systems have been treated with the FSO/FOC system [8].

The electromagnetic light range consists of numerous types of frequencies, such as ultraviolet light, visible light communication (VLC), and infrared [9]. A light-emitting diode (LED) applied the light flashes to send the information, LEDs have made the Light fidelity (Li-Fi) technology as a good market target because it is commercially available worldwide, LEDs have overcome the classical lights because of their characteristics, they have a longer lifetime, a smaller size and a lesser cost. In radio-frequency communications, such as wireless fidelity (WI-FI), the signal travels freely, making the information easy for hackers to capture. This view is the opposite of VLC technology, where it confers a more secure transmission. Positioning system has been a part of the essential factor in human everyday activities of daily living [10], the disadvantage of VLC is that cannot pass through the objects completely because parts of the rays will pass through and the others will be reflected. As a consequence, the receiver will accept the signal with lower power and a lower bit rate [11].

However, VLC technology has more advantages, in addition to providing higher security; it is not affected by the interference of the radio-frequency issues, making it appropriate for indoor environment communications [12]. The challenges that face the system is the impact of atmospheric attenuation, including dust and rainy weather, in the FSO, FOC, and VLC system's end-user and to check whether the LEDs will perform well under these conditions, where the impact of these weather conditions causes a fall in the power strength and therefore reduces the Q-factor and consequently more closing in the eye-diagram. Moreover, in the VLC system, The LOS propagation demands from the transmitter to have an unobstructed view of the receiver. Power becomes less when the receiver moves horizontally from the incident beam, where the variation in the incident and irradiance angles significantly affects the received power. Therefore, checking whether the LED with the VLC system will cover the entire room with a dimension of 5x5x3 m without losing the received power at the end-user under these circumstances. Also, examining whether increasing the number of LEDs will impact the distributed received electrical power that arrives at the VLC system's end-user.

The study is intended to design a system to study atmospheric attenuation on the FSO link and its effects on the end-users VLC system while making sure that the right power strength arrives at the VLC system's end-user in different environmental conditions, therefore causing and guaranty accepted Q-factor value and wide eye-diagram. Besides, designing the VLC system with more LEDs to guarantee the receiver's movement in all directions without losing the received signal at the end-user. Finally, this study seeks to design VLC system multiple LEDs without impaction on the distributed received electrical power that arrives at the VLC system. This paper is orderly as follows: the second part deals with the related work, the third part explains the method, the forth part illustrates results and discussion, and finally, the fifth part provides the conclusion.

2. RELATED WORK

This part explains the previous studies of VLC systems, VLC systems demand some essentials for the designing, so the researcher intends to investigate these requirements to design the system, such as the distance, the impact of the modulation methodology, the exterior noise, and the impact reflection from the walls. Sindhubala, Vijayalakshmi [13] demonstrated the VLC technology for an internal system, the ability of system could transfer a data rate of about 10 Kb/s and distances of 10m, the ambient light noise point was addressed. Manivannan *et al*. [14] offered an interior VLC system utilizing white LEDs to support a bit rate about 2 Gbps up to a link domain of 3 m; the RZ modulation has been provided better results. Suriza et al [15] investigated the nonreturn-to-zero on–off keying (NRZ-OOK) modulation technique; it was eligible of a high speed for short range and data of about 400 kbps to 2 Mbps for an indoor proposed system. Sindhubala and Vijayalakshmi [16] explained the return -to-zero (RZ)-OOK modulation was used under background noise, the noise was obeyed in fluorescent lamps, shot noise and thermal noise, the system achieved good performance, it had a data rate of about 20 Kb/s and a distance of 20 cm. Poulose [17] illustrated the LOS and non-LOS in two situations of propagations, non-LOS had two situations as a transmitter; in the first case, one source was utilized as a transmitter, and in the second case, two sources were utilized as a transmitter. The signal's amplitude of that received was less than that in the line-of-sight, while in the second situation, the amplitude was extremely less than compared to the prior situations. Selvendran *et al*. [18] investigated an internal system that used white source utilizing OFDM modulation method and the system assured a data rate about 10 Gbps to distance of 2 m. Pradhan *et al.* [19] showed several modulation techniques were implemented in VLC system to evaluate the link in the existence of ambient noise, and the quadrature phase shift keying (QPSK) accomplished better achievement compared to pulse amplitude modulation (PAM), Pulse-position modulation (PPM), and differential phase shift keying (DPSK) modulation. Mat *et al* [20] given a point-to-point as a topology for the VLC system, it gives a high speed of about 1 Gbps. Aziz *et al*. [9] studied the affect of multiple users on a VLC system; the results have shown decrements in bit-error-rate (BER) reading as increase the issue of users.

3. ALGORITHM

The variance in the environmental conditions, like rain, fog, and dust extremely influence the signal power, the ratio between the power of the signal that was sent and received is called signal strength. As shown in (1) explains the value of the atmospheric attenuation coefficient:

$$\boldsymbol{\gamma(\lambda) = \frac{3.912}{\nu}\left(\frac{\lambda}{550}\right)^{-q}}, \quad (1)$$

where the attenuation coefficient is represented byγ, visibility was represented by ν, particle size distribution coefficient was represented by q and wavelength was represented byλ.

Kim and Kruse's model [1] is required to calculate the particle volume distribution and attenuation coefficient, Kim's model is chosen in this study because it can be used for high levels of attenuation. The visibility in (2) can be used [1], [21], where the attenuation coefficients depend on the visibility. Kim's model is shown in Table 1.

$$q = \left\{ \begin{matrix} 1.3 if (6km < \nu < 50km) \\ 1.6 if (\nu \geq 50km) \\ 0.16\nu + 0.34 if (1km < \nu < 6km) \\ \nu - 0.5 if (0.5km < \nu < 1km) \\ 0 if (\nu < 0.5km) \end{matrix} \right\}, \quad (2)$$

Table 1. Attenuation parameters according to the KM model classification

Visibility (KM)	Attenuation (dB/km)	Weather
0.05	340	Heavy fog
0.07	242	Heavy dust
0.2	85	Moderate
0.5	34	Dust-fog
1	10	Rain
2	4	Haze
4	2	
10	0.4	Clear
23	0.2	

The hybrid system was designed utilizing Optisystem tool V17.1.0, the system comprises two parts—the first part consists of FSO and FOC systems, and the second part is a VLC system, where the system supported a data rate of 1 Gbps. The transmitter part of FSO system contains a bit generator, non-return to zero (NRZ) to generate electrical pulses, a continuous wave (CW) laser diode to carry the electrical signal and a Mach-Zehnder modulator.

3.1. Free space optic

FSO is a line of sight (LOS) technology that employs lasers to afford optical bandwidth connections wirelessly, it is also an optical communications system that send data for telecommunications and computer networking. The FSO system is designed to be multi-channel, the parameters adopted are shown in Table 2. The linkage mechanism is illustrated in Figure1.

3.2. Fiber optic channel

The fiber optic channel (FOC) employed in this study comprises a fiber optic link with a length of approximately 40 km as a single mode fiber (SMF), two dispersion-compensating fiber (DCF) with a 3.2-km length, an erbium doped fiber amplifier with 3m length to compensate for the dispersion caused by the fiber optic [22] and pumping power of 40 mW. The second dispersion-compensating fiber is connected to an avalanche photodiode (APD) with a gain of 10 dB and dark current of 10 nA joined by an electrical power splitter. This component splits the signal input power evenly to output ports. The electrical power splitter is connected to the VLC system that includes five LEDs. Figure 2 shows the fiber optic channel with a receiver side followed by the VLC system.

3.3. Visible light communication systems

It is an optical communication utilizing LEDs for illumination and communication in short-range distances [23], [24]. LED is considered a more effective source than the standard light, because of its features, like low power exhaustion, high shine and high bandwidth. VLC data transmission is performed by varying the light intensity variation in amplitudes so tiny, it cannot be predicted by the human eye [25].

Table 2. Channel transmitter parameters of the FSO system

Channel configuration	Parameters
Dynamic range	200 – 3100 m
Attenuation	10 -34 db/km
Aperture's diameter of the receiver	35 cm
Aperture's diameter of the transmitter	2.5 cm
Power of laser	10 dBm
Center wavelength	1,550
Beam divergences	1 mard

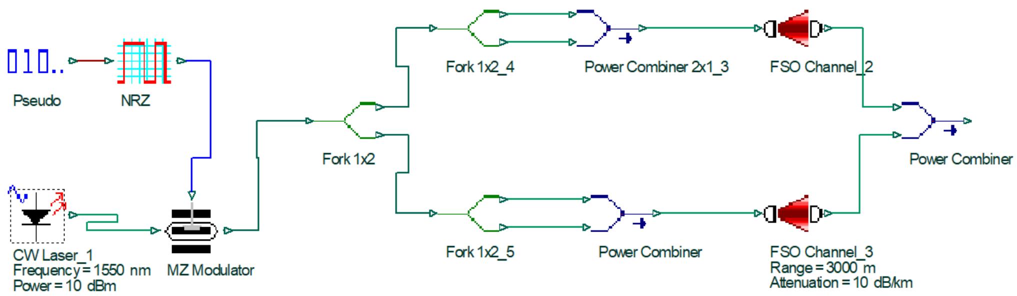

Figure 1. Multi-channels of FSO communication link

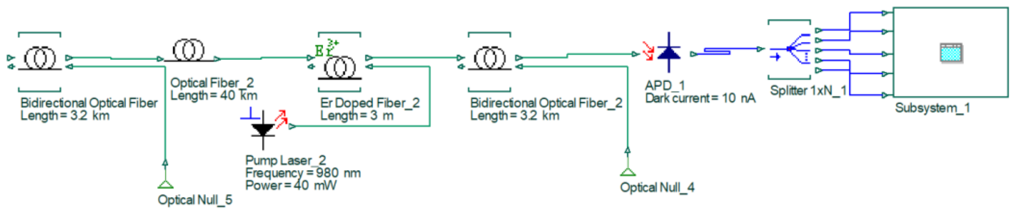

Figure 2. Receiver side components and VLC system in end-user

3.3.1. VLC transmitter

LED is employed through system to send the data. The electrical signal is rescaled to the best level to operate the LED source directly, and then it will modulate with the lights. Table 3 Clarifies LED's specifications value that employed in the system.

Table 3. LED's specifications values

LED parameters	value
Wavelength's center	580 nm
Electron carrier lifetime	1e-012
RC time constant	1e-012
Quantum efficiency	0.65

LED's optical power is given by [25], [26]is explained in (3),

$$p = \eta . h . f \frac{i(t)}{q}, \quad (3)$$

whereas *h* defines plank constant, η illustrates quantum efficiency, *f* describes emission frequency, *q* defines the electron charge and *i(t)* represents modulation current of signal.

LED's Bandwidth is dependent on RC time constant and electron carrier lifetime, according to [26], Equation (4) describes the LED's bandwidth as:

$$H(f) = \frac{1}{1+j.2\pi.f(\tau_N+\tau_{RC})}, \quad (4)$$

whereas τ_N , τ_{RC} define the electron lifetime and RC time constant.

3.3.2. VLC Channel

The LOS and N-LOS of the channel system shown in Figure 3, when the LED delivers the signal straight to the receiver, and the optical beam travels over the medium in a LOS, the signal could be reflected by the objects in a NLOS [27]. In Figure 3, the Φ describes the irradiance angle, which is the angle of irradiance concerning the axis normal of the sender, ψ represents the angle of incidence, which is the angle related to the axis normal of the receiver, and h is the distance between transceiver. Table 4 shows the LOS channel parameters that have been employed.

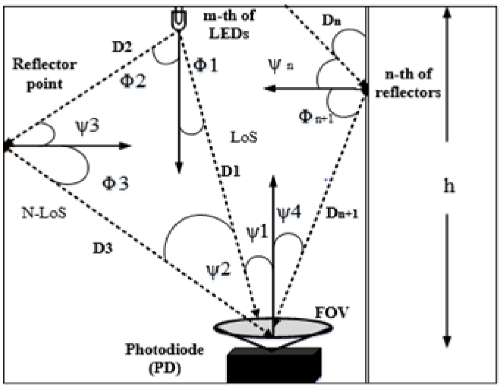

Figure 3. LOS and NLOS of LED arrival angle

Table 4. LOS channel parameters utilized by the system

Parameters of LOS channel	value
Distance	3 m
half-angle of the transmitter	15 degree
Irradiance half-angle	0-31
Incidence half-angle	85-0
Detection surface area	1 cm^2
Optical concentration factor	90 degree
Index concentration factor	1.5
Propagation delay	0 ps/m

In Figure 3, the transmitter is a Lambertian source that obeys Lambert's cosine law, then the radiant intensity in Watt/Steradian (W/sr) of LED can be described in (5),

$$R_o\phi = \left[\frac{m+1}{2\pi}\right] cos^m\, \phi, \quad (5)$$

where $R_o\phi$ is the radiant intensity, ϕ is the radiant angle for the receiver, while *m* is Lambertian order that described in (6).

$$m = \frac{-\,log\,2}{log[\,cos(TransmitterHalfAngle)]}, \quad (6)$$

Considering that the sender emits an axial symmetric radiation pattern in (W/sr), the relationship between the optical sender power and radiant density is given in (7),

$$P_t.R_o(\phi), \quad (7)$$

the irradiance at the photodetector in (W/cm^2) is given in (8),

$$I_s(d,\phi) = \frac{P_t.R_o(\phi)}{d^2}, \quad (8)$$

where the d is the distance between the transceiver, and is the receiver's angle for the transmitter, using (9) to determine the power at the photodetector:

$$P = I_s(d,\phi)A_{eff}(\varphi), \quad (9)$$

where the φ describes the incident angle respective to the receiver axis and A_{eff} is an effective collection area. Thus, the effective collection area described as (10),

$$A_{eff}(\varphi) = \begin{Bmatrix} As\,cos(_{c_{det}} \\ 0 if \varphi > \varphi_c \end{Bmatrix}, \quad (10)$$

where A_{det} defines the detector area, φ_c , $G(\varphi)$ and T_s illustrate the FOV of the receiver, the gain of both lens and filter transmission, respectively. The gain of a lens described in (11),

$$G(\varphi) = \begin{Bmatrix} \frac{n^2}{sin^2\,\varphi_c} if 0 \le \varphi \le \varphi_c \\ 0 if \varphi > \varphi_c \end{Bmatrix}, \quad (11)$$

whereas n defines the lens refractive index, the front end of the receiver consists of an optical concentrator, optical filter, and the transimpedance amplifier for amplification [28].

3.3.3. VLC receiver

The receiver includes a photodetector, a transimpedance amplifier (TIA) for amplification the signal, a DC block to deny the DC voltage from influx to the incoming signals and a low-pass filter to deny the unwanted wavelengths. Table 5 shows the receiver characteristics, Figure 4 shows the VLC system.

Table 5. VLC receiver parameters

Receiver characteristics	value
Photodiode	
The responsively	1 A/W
The dark current	10 nA
TIA	
Transimpedance	2000 Ohm
Noise equivalent bandwidth	1GHz
Noise figure	3db
Absolute temperature	298K
Bandwidth of signal	1GHz
Rectangle Optical Filter	
Frequency	580 nm
Low pass filter	
Cutoff frequency	0.75 * Symbol rate

3.3.4. Total luminous flux incident

Illuminance means to the all luminous flux incident on a specific surface per unit area. It is an amount of light that falls on the surface. The horizontal illuminance at a point (x, y) is given in (12) [29].

$$E_{hor} = \frac{I(0)\,cos^m(\phi)}{d^2.cos(\phi)}, \quad (12)$$

The centre luminous intensity is given by (13) and the radiation intensity $I(\phi)$ is given by (14) at given surface.

$$I(0) = \frac{(m+1)}{2\pi d^2}, \quad (13)$$

$$I(\phi) = I(0).\cos^m \phi, \quad (14)$$

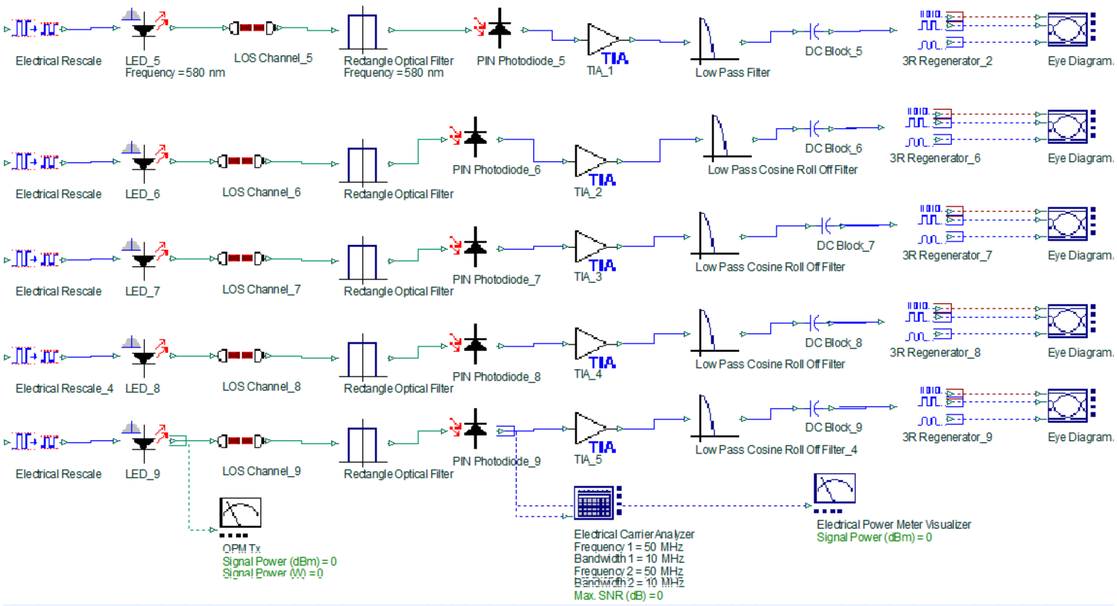

Figure 4. Illustrations of the VLC system

4. RESULTS AND DISCUSSION

This section, the numerical results of BER, Q-factor, and signal power performance based on the above system (FSO/FOC and VLC) model are presented for different distances and attenuations according to the Kim models. The signal power of PIN and BER performances of the VLC system are presented based on a variation of angles. Under the rain-dust scenarios, Figure 5 shows the quality factor of the (FSO/FOC) system. The efficiency of the system shows a promising response under rainy conditions, with a BER of about zero at 500 m distance and 1.58E-09 at 3100 m distance, In the case of dust weather, the BER at a distance of 200 m is zero and 1.84E-10 at 1150 m distance.

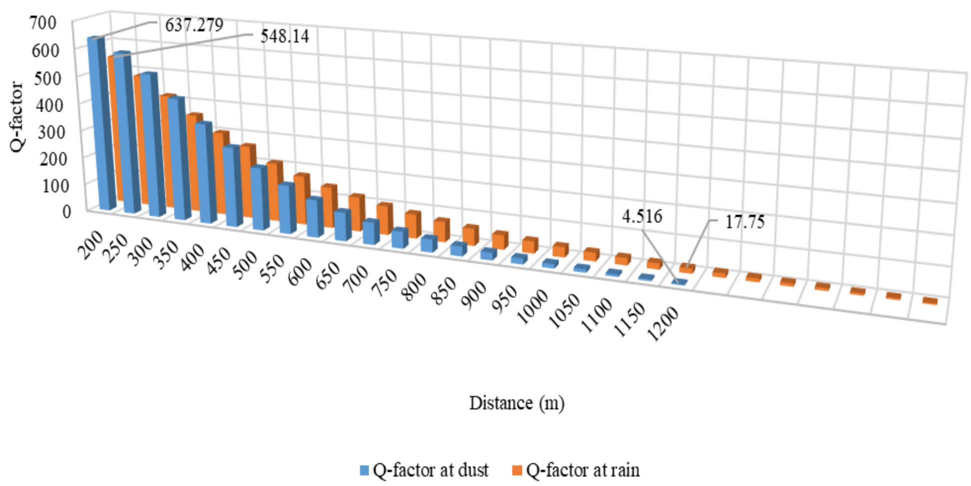

Figure 5. Quality factor of (FSO/FOC) system

This section will study the effects of environmental disturbances adopted on the FSO channel and their effects on the BER and Q-factor of the LEDs. The efficiency of the VLC system indicated a hopeful response under rain-dust conditions, the Q-factor of LEDs at rain-dust scenarios is shown in Figure 6 and the BER is shown in Figure 7 at the same scenarios.

The signal power of LEDs in (dBm) is decreasing as the distance. Figure 8 shows the degradation on the signal power of five LEDs and the eye diagram with a distance under rain-dust conditions where the signal power was measured for a distance of 1000 to 3000 m under rain weather and distance about 400 to 1100 m under dust weather.

The variation in the irradiance and incident angles causes a decline in the receiver's signal power (PIN) of LED. Figure 9 Shows the degradation eye-diagram and decline because of increasing in the irradiance angle under rainy conditions at 3000 m distance, where the BER at 0 degree is 4.04E-10 and 1.08E-7 at 30 degree. While Figure 10, Shows the degradation eye-diagram and decline due to the increase in the incident angle under dust condition at 1100 m distance, where the BER at 10 degree is 4.04E-10 and 0.003 at 89 degree.

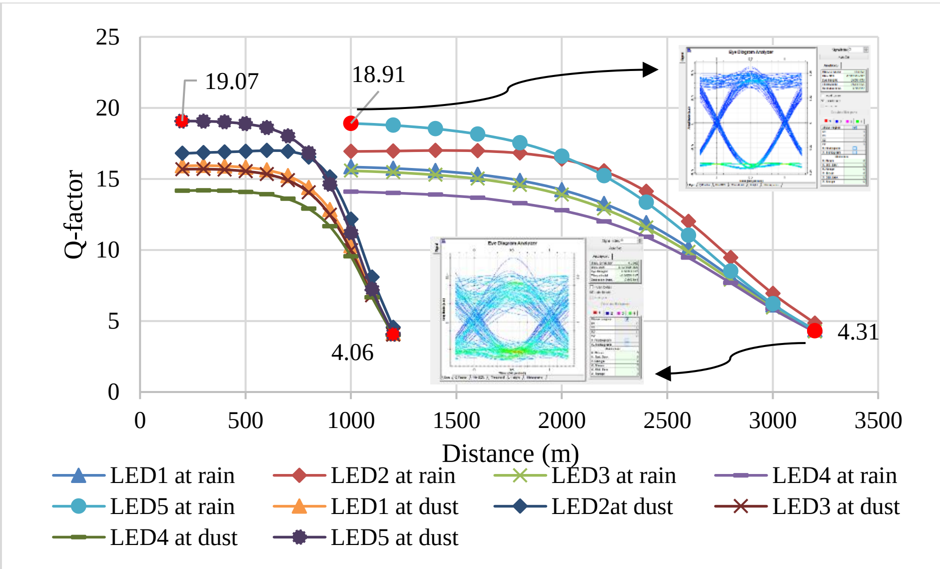

Figure 6. Variations in Q-factor of five LESs

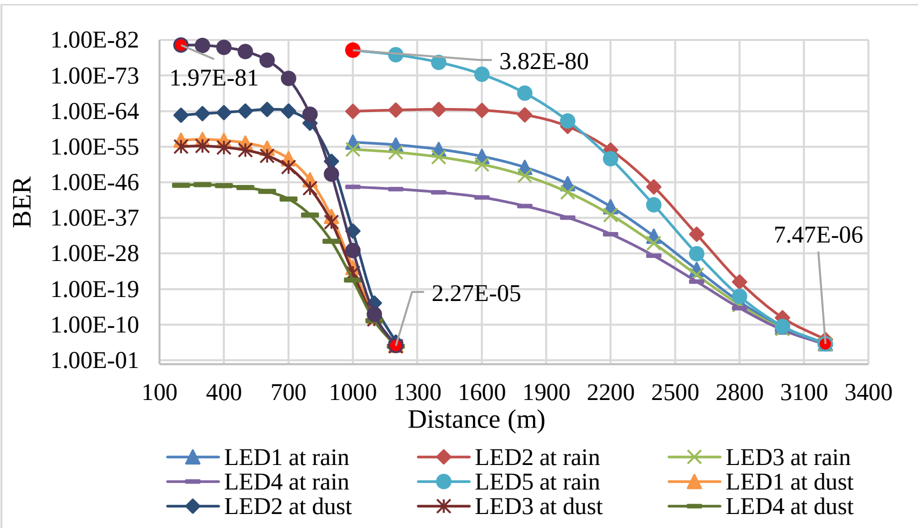

Figure 7. Variations in BER of five LESs

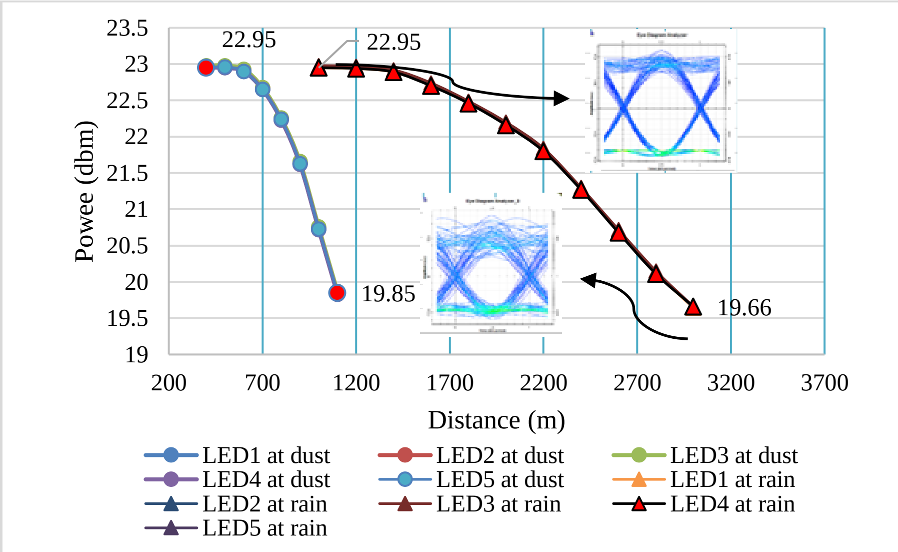

Figure 8. Variation in signal power of five LEDs

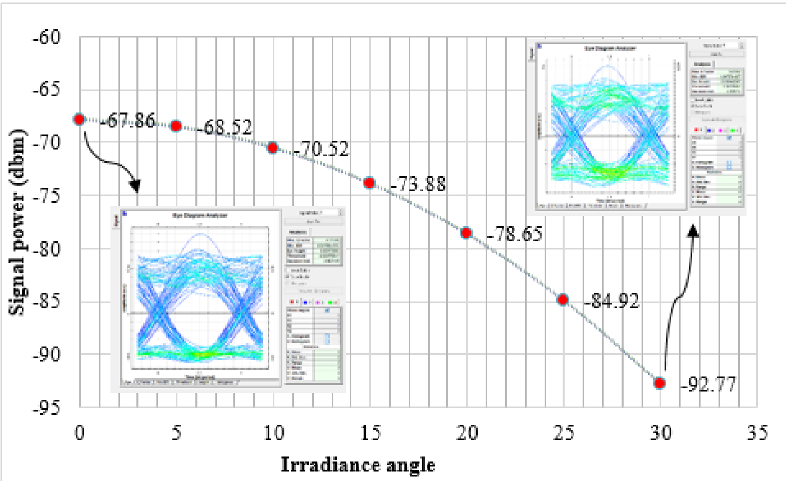

Figure 9. Decline due to increased irradiance angle

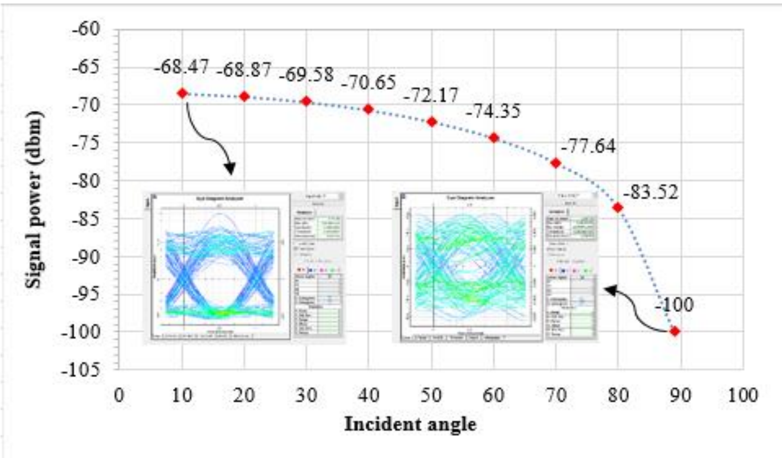

Figure 10. Decline due to increased incident angle

The total illuminance distribution and flux of five LEDs, and degeneration of the illuminance and flux incident on the floor of the room with a dimension of 5 m x 5 m x 3 m was simulated using the MATLAB tool. The results are shown in Figure 11. For the limitations for this research, external noise interference and non-line-of-sight were not assessed. Further research may be needed to study the effects of these cases.

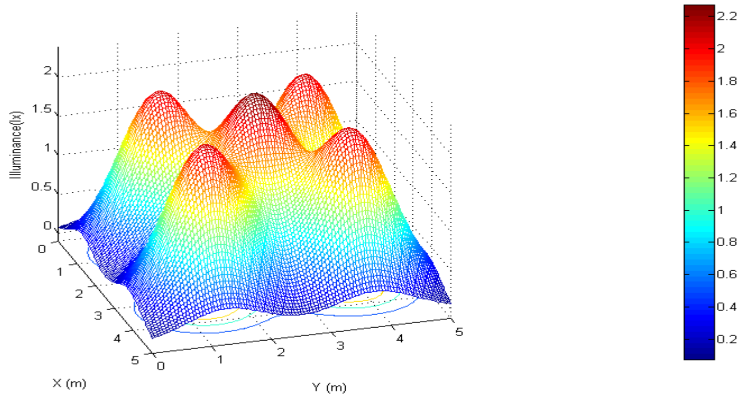

Figure 11. Total luminance distribution and flux

5. CONCLUSION

This study examined the effects of weather conditions on the FSO/FOC and VLC system's end-user performance. In the dust scenario, the FSO/FOC system achieved an acceptable BER and Q-factor performance to a distance of 1100 m. In rainy conditions, the system performed better and achieved a distance rang to 3000 m. The difference in signal strength was reflected in the performance of the LEDs, which was within the acceptable limits under both scenarios. The signal power has measured to a distance of 3000 m under rain weather and distance about 1100 m under dust weather. The variations in the angle of the irradiance and incident angles were verified, where the variation cause degradation in the received power and eye diagram. The variation of angles has been investigated under long-distance (3000 m under rain and 1100 m under dust conditions). The proposed system performance showed a promising response despite the difficult factors to verify performance.

ACKNOWLEDGEMENTS

We would like to thank Mr. Sawyer Jie Ge, and Dr. Ahmad Atieh, the administrators of optical systems at Optiwave DESIGN SOFTWARE, for supplying the requirements for this study.

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