IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 13, Issue 4, Ver. I (Jul.-Aug. 2018), PP 10-16
www.iosrjournals.org

Performance Analysis ofa Visible Light Communication System in ABUAD Communications Laboratory

Jeremiah Oluwatosin Bandele[1], Joseph Akintunde Akinwumi[2], Oladipo Folorunso[3]

[1,2,3](Department of Electrical/Electronics and Computer Engineering, College of Engineering, Afe Babalola University, Ado-Ekiti, Ekiti State, Nigeria, P.M.B 5454)
Corresponding Author: Jeremiah Oluwatosin Bandele

Abstract : *The performance of an indoor visible light communication (VLC) system is investigated with the assumption that LED lights are installed on the ceiling of Afe Babalola University, Ado-Ekiti (ABUAD) communication laboratory. By taking the direct and reflected lights into consideration, the received power at different points on the laboratory floor, minimum signal to noise ratio, minimum bit error rate (BER) and outage are obtained. Results obtained show a consistent power difference of about 2dBm (1.6mW) between the minimum BER performance of systems with wavelengths corresponding to the lower and upper ends of the visible light wavelength range. Also, systems having high bit rates will require higher transmitted powers per LED to achieve the same target BER with systems having low bit rates. Therefore, when designing a VLC system, a trade-off has to be made between increasing performance and reducing cost.*

Keywords -*Visible light communication (VLC), Light emitting diode (LED), Signal to noise ratio (SNR), Bit error rate (BER), Outage.*

Date of Submission: 06-07-2018 Date of acceptance: 21-07-2018

I. Introduction

Visible light communication (VLC) technology is a form of wireless optical communication technology that involves using light emitting diodes (LEDs) for communication in addition to their inherent illumination function [1, 2]. In contrast to radio frequency (RF), microwave or other forms of signals, VLC and infrared LED communication (either wireless or fibre) uses modulated light signals to transmit data.VLC has attracted worldwide interest from researchers due to the advantages it offers compared to other communication techniques. For indoor applications, VLC offers various advantages such as higher data rates, higher security (since with all care taken, interception from outside is almost impossible), wide spectrum, better energy efficiency, no electromagnetic spectrum regulation and it requires less system components (unlike other techniques that require special circuits and antennae) [3-6]. It should be noted that visible light is rather arguably complimentary than competitive with RF as RF is preferable for applications where users are required to roam about a large area consisting of many rooms [7]. Visible light is advantageous where high data rates are required for indoor wireless applications such as video conferencing, video on demand, music live streams, voice over IP, network attached storage and digital television. Besides the indoor application, VLC using LEDs are also applicable in airplane cabinets, shops, traffic lights, passenger trains, coaches, buses, car to car communication and street lamps. The traffic lights and street lamps provide drivers and pedestrians with traffic related information and local information respectively [8-10].

Nowadays, LEDs are preferred for illumination purposes when compared to other available lightning sources (i.e. fluorescent and incandescent) due to their high tolerance to humidity, minimal heat generation lightning and various applications such as street lightning and traffic displays [3]. RGB LEDs (formed by mixing lights from red, green and blue LEDs) are more promising for high speed transmission unlike the phosphor-based LEDs (formed by coating a particular colour of LED made of Indium Gallium Nitride with a different colour of phosphor) where the phosphor slows down transmission speed [11, 12]. Generally speaking, compared to other lighting techniques such as incandescent and fluorescent lamps, white LED's are preferred because of their high brightness, long lifetime, reliability due to their high life expectancy, lower voltage, smaller size, lower power consumption and cooler operation. White LEDs also significantly reduce shadowing since they can be effectively distributed within a room. They are also immune to radio and electromagnetic interference, aesthetically attractive and easy to install [3]. LEDs easily modulate visible light for wireless communication due to its extremely high switching time (i.e. a rapid on-and-off response time that is too fast for the human eye i.e. operating with speed up to millions of cycles per second). For instance, LEDs that can be modulated for signalling by up to 100MHz are commercially available [13]. Interestingly, LEDs can also be used for communication even when the light is turned 'off' (i.e. the term turned off does not mean the LED is totally off, it just means it is so dimmed such that it no longer performs its inherent illumination function). This is due to the fact that residual photons can still be emitted for communication by a low-current power supply even when the LED lights are 'turned off' [14].

Pang [15] and Nakagawa [3] published works demonstrating the possibility of using LEDs as information carriers in addition to their inherent illumination function. In addition, Akanegawa [16] also reported the use of LEDs for broadcasting traffic information from traffic lights to vehicles. Red and yellow LEDs have been commercially available for a long time but the high-brightness bluish-green Aluminium gallium indium nitrate LEDs have been designed to satisfy the brightness and colour requirements of green traffic light signals. The higher tolerance to humidity, greater power efficiency and longer life expectancy of LED traffic lights makes them preferable to incandescent traffic lights. Also, an LED lamp degrades gradually thereby allowing enough time for maintenance or repair unlike traditional lamps which could fail suddenly [17]. A significant issue affecting the use of VLC for outdoor application is the difficulty of controlling environmental conditions. During the day, the outdoor environment contains a strong ambient visible-light radiation emanating from the daylight and sunlight. Also, due to the significant effect of noise due to ambient light, it has to be taken into account when studying VLC systems for outdoor purposes [17]. It should be noted that in contrast to laser emissions which are coherent and monochromatic, LED emissions are incoherent [18, 19]. Hence, for a point-to-point communication where directed light is required, the LED needs to be collimated to have a reasonable signal reception at the receiver [20].

While the VLC technology inherently allows the use of intensity modulation and direct detection (IM/DD) techniques such as the on-off keying, pulse-position modulation and M-ary pulse-amplitude modulation, other techniques (required for high transmission rates) such as orthogonal frequency division multiplexing have been demonstrated [21, 22]. In addition, spatial modulation and multiple-input multiple-output techniques have been shown to improve the bit error rate (BER) and spectral efficiency in VLC systems [23]. The performance analysis of a VLC system installed in ABUAD communication laboratory is shown in this paper. The received power at different points on the laboratory floor, minimum signal to noise ratio (SNR), minimum BER and outage are shown. After this introductory part, a brief description of ABUAD communication laboratory is given in Section 2. An indoor VLC system model and performance analysis is given in Section 3. Section 4 contains the results and discussion of the numerical analysis. A conclusion is given in Section 5.

II. ABUADCommunication Laboratory

The VLC system analysis in this paper is premised on the assumption that LED lights are installed on the ceiling of ABUAD communication laboratory as shown in Figure 1. The receiver is also assumed to be placed on the laboratory floor.

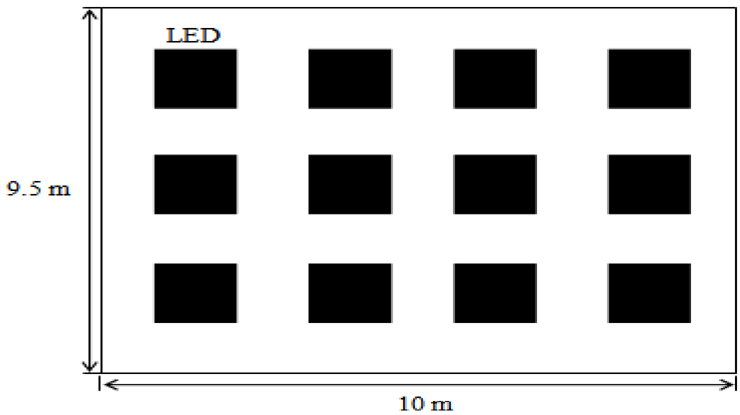


Figure 1: Proposed LED lights installation on the ceiling of ABUAD communication laboratory

III. VLCSystem Model And Performance Analysis

The direct and reflected propagation paths of a ray radiated from an LED is shown in Figure 2 where an LED is installed on the ceiling and a photodetector (PD) is placed on the floor. The total light reaching the PD from the LED is made up of the direct light from the LED (line of sight (LOS) link) and reflected light from the wall (diffused link).

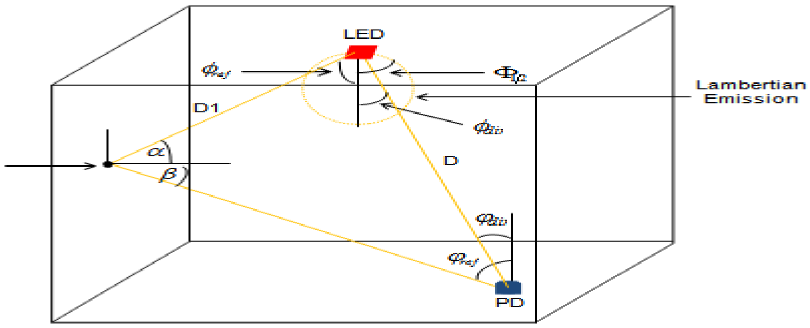


Figure 2: Direct and reflected propagation path of a ray radiated from an LED

In conventional surface-emitting LEDs, the radiation model can be approximated as Lambertian (LEDs have a large beam divergence causing the radiation pattern resemble a sphere) thus obeying Lambert's cosine law. The channel DC gain of the direct light is given as [3, 9],

$$H(0) = \begin{cases} \frac{(m+1)A}{2\pi D^2} \cos^m(\phi_{dir}) T_s(\varphi) g(\varphi) \cos(\varphi_{dir}), & 0 \le \varphi_{dir} \le \varphi_c \\ 0, & \varphi_{dir} > \varphi_c \end{cases} \quad (1)$$

where A is the PD physical detection area, ϕ_{dir} is the irradiance angle of direct light, φ_{dir} is the incidence angle of direct light at the PD, D is the distance between the transmitter and the receiver and $T_s(\varphi)$ is the gain of the optical filter. The order of Lambertian emission (the directivity of the radiation pattern) is given as [3]

$$m = \frac{-\ln 2}{\ln(\cos \Phi_{1/2})} \quad (2)$$

where Φ is the LED semi-angle at half power. The gain of the concentrator is given as [3, 5, 9]

$$g(\varphi) = \begin{cases} \frac{n^2}{\sin^2 \varphi_c}, & 0 \le \varphi \le \varphi_c \\ 0, & \varphi > \varphi_c \end{cases} \quad (3)$$

where n is the refractive index and φ_c is the field of view (FOV) of the concentrator. For the reflected light, the channel DC gain is given as [3],

$$H(0) = \begin{cases} \frac{(m+1)A}{2\pi D_1^2 D_2^2} \rho \partial A_{wall} \cos^m(\phi_{ref}) \cos(\alpha) \cos(\beta) T_s(\varphi) g(\varphi) \cos(\varphi_{ref}), & 0 \le \varphi_{ref} \le \varphi_c \\ 0, & \varphi_{ref} > \varphi_c \end{cases} \quad (4)$$

where D_1 is the distance between the LED and the reflection point, D_2 is the distance between the reflection point and the PD, ϕ_{ref} is the irradiance angle of reflected light, φ_{ref} is the incidence angle of reflected light at the PD, α and β are angles at the reflective point (shown in Figure 2), ∂A_{wall} is the reflection area and ρ is the reflectance factor.

The total energy emitted from an LED is described by the transmitted optical power P_t and the average received optical power at the PD is given as [3]

$$P_r = H(0) P_t \quad (5)$$

Also, the electrical SNR is given as [24]

$$SNR = \frac{(RP_t)^2}{\sigma^2_{thermal} + \sigma^2_{shot}} \quad (6)$$

where the responsivity $R = \eta q / hv$, η is the quantum efficiency, h is the Planck constant, q is the electronic charge and v is the carrier frequency. The thermal and shot noise variances are given as [24]

$$\sigma^2_{thermal} = 8\pi\kappa T_k C_{pd} AB \left(\frac{I_2 B}{G_{ol}} + \frac{2\pi \Gamma C_{pd} A I_3 B^2}{g_m} \right) \quad (7)$$

$$\sigma^2_{shot} = 2qB(RP_r + I_B I_2) \quad (8)$$

where C_{pd} is the fixed capacitance of the PD per unit area, B is the electrical filter bandwidth, T_k is absolute temperature, κ is the Boltzmann's constant, G_{ol} is the open-loop voltage gain, Γ is the noise factor of the field-effect transistor (FET) channel, I_B is the photocurrent due to background radiation, g_m is the FET trans conductance and noise-bandwidth factors, I_2=0.562 and I_3 = 0.0868. Considering an on-off keying modulation scheme, the bit error rate (BER) is given as [24]

$$BER = \frac{1}{2} erfc\left(\frac{SNR}{\sqrt{2}} \right) \quad (9)$$

The system outage 'state' can also be determined by predefining a SNR threshold (corresponding to a target BER i.e. 10^{-12}) and comparing the received SNR with the predefined SNR threshold to know if an outage exists or not. The outage 'state' is described below

$$Out_{st} = \begin{cases} false, & SNR_r \geq SNR_{th} \\ true, & SNR_r < SNR_{th} \end{cases} \quad (10)$$

where $false$ means 'outage does not exist', $true$ means 'outage exists', SNR_r is the received SNR and SNR_{th} is the pre-defined SNR threshold.

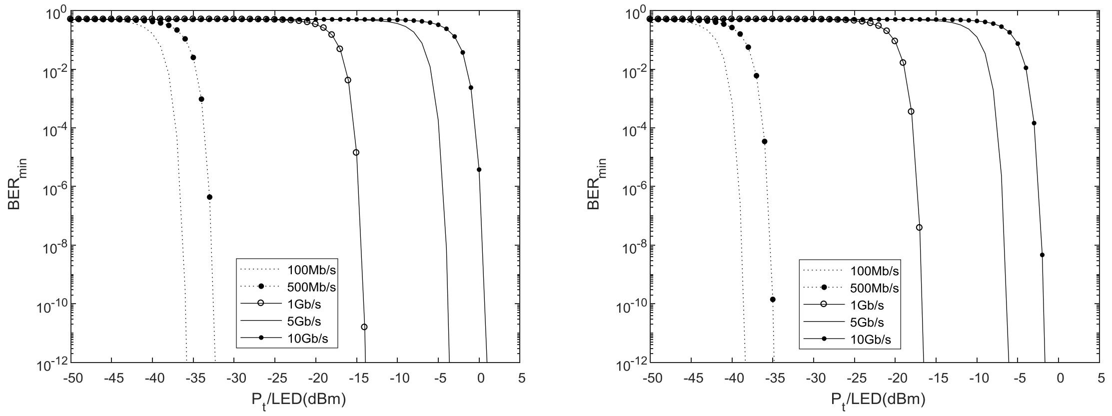
IV. Results And Discussion

Table 1 shows the parameters used for the numerical analysis.

TABLE 1: Parameters used for the numerical analysis.

Parameter	Value
LED semi-angle at half power	70^0
LED height from the floor	2.45m
PD height from the floor	0.45m
number of LEDs per LED light	3600(60×60)
LED size	0.59×0.59m
LED interval	0.01m
PD detector area	$1.0cm^2$
receiver FOV	60^0
gain of an optical filter	1.0
receiver lens refractive index	1.5
PD fixed capacitance	$112pF/cm^2$
quantum efficiency	0.8
electrical filter bandwidth	1.75Gb/s
absolute temperature	298K
open-loop voltage gain	10
noise factor of the FET channel	1.5
background radiation photocurrent	$5100\mu A$
FET transconductance	30mS

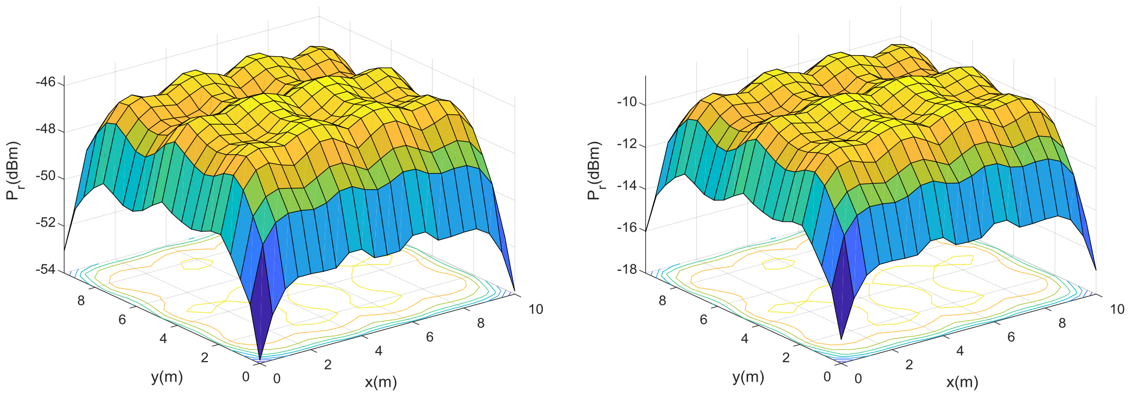
Figure 3 shows the minimum BER obtained in ABUAD communication laboratory for different P_t /LED and bit rate (R_b) values.



(a) (b)

Figure 3: Minimum BER against P_t /LED (a) λ = 390nm (b) λ = 700nm

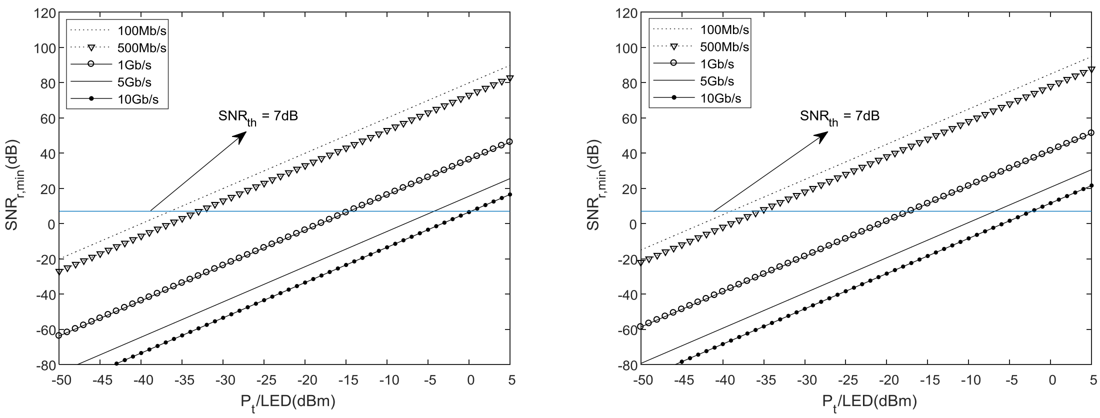
In Figure 3a where λ = 390nm (corresponding to the lower end of the visible light λ range), P_t /LED values of about -36dBm, -33dBm, -14dBm, -4dBm and 1dBm at R_b values of 100Mb/s, 500Mb/s, 1Gb/s, 5Gb/s and 10Gb/s respectively are required to achieve a target BER of 10^{-12}. In Figure 3b where λ = 700nm (corresponding to the upper end of the visible light λ range), P_t /LED values of about -38dBm, -35dBm, -16dBm, -6dBm and 1dBm at R_b values of 100Mb/s, 500Mb/s, 1Gb/s, 5Gb/s and 10Gb/s respectively are required to achieve a target BER of 10^{-12}. The consistent 2dBm (1.6mW) difference noticed between the results in Figure 3a and 3b shows that in VLC systems, the actual λ used will not have a significant effect on system performance as long as it is within the visible light λ range. Note that the lower wavelength (λ = 390nm) is seen to perform better. We can also observe from Figures 3a and 3b that higher R_b values (increased performance) requires higher P_t /LED values (more cost). This means that when designing a VLC system, a trade-off has to be made between increasing performance and reducing cost.



(a)(b)

Figure 4: Received power of direct and reflected light at various PD locations on the floor of the laboratory (a) P_t = -36dBm/LED (b) P_t = 1dBm/LED

Figure 4 shows the received power of direct and reflected light at various PD locations on the floor of ABUAD communication laboratory. In Figure 4a where P_t /LED = -36dBm, a minimum and maximum P_r of about -54dBm and -46dBm is obtained in the laboratory. In figure 4b where P_t = 1dBm/LED, a minimum and maximum P_r of about -18dBm and -10dBm is obtained in the laboratory. Also, as expected and shown in Figures 4a and 4b, P_t is directly proportional to P_r (higher P_t value will result in higher P_r values). It is also observed (not shown in paper) that the SNRs obtained from direct and reflected light at various PD locations on the floor of ABUAD communication laboratory are approximately the same. This is so because the room size is not too large compared to the number and configuration of the LED lights. It is also due to the fact that the horizontal height of the PD is equal at every location in the room. Deploying a VLC system in a bigger room or environment (i.e. a stadium) will be more challenging due of factors such as large distance between the LED lights and the PD, varying horizontal height of the PD at different seating levels in the stadium and the possibility of interference due to environmental conditions (in uncovered stadiums).



(a) (b)

Figure 5: Minimum SNR$_r$ against P_t /LED (a) λ = 390nm (b) λ = 700nm

Figure 5 shows the minimum SNR_r ($SNR_{r,\min}$) obtained in ABUAD communication laboratory for different P_t /LED and R_b values. Note that SNR_{th} = 7dB (corresponding to when the target BER < 10^{-12}). In Figure 5a where λ = 390nm, outage is seen to exist when the P_t /LED values are less than about -36.5dBm, -33dBm, 14.5dBm, -4.25dBm and 0.25dBm at R_b values of 100Mb/s, 500Mb/s, 1Gb/s, 5Gb/s and 10Gb/s respectively. In

Figure 5b where λ = 700nm, outage is seen to exist when the P_t /LED values are less than about -39dBm, -35.5dBm, 17.2dBm, -6.8dBm and -2.3dBm at R_b values of 100Mb/s, 500Mb/s, 1Gb/s, 5Gb/s and 10Gb/s respectively. Results shown in Figure 5 shows that (like Figure 3) systems with lower wavelength (λ = 390nm) values gives better performance. However, unlike Figure 3 where the lower wavelength systems performed better for all R_b values, Figure 5 shows that the higher wavelength (λ = 7000nm) performed better when R_b = 10Gb/s.

V. Conclusion

This paper examined the performance of an indoor visible light communication (VLC) system with the assumption that LED lights are installed on the ceiling of ABUAD communication laboratory. Results obtained in this paper showed that there is a consistent power difference of about 2dBm between the minimum BER performance of systems with wavelengths corresponding to the lower and upper ends of the visible light wavelength range. Also, it was shown that systems with high bit rates will require higher transmitted powers per LED to achieve a target BER unlike systems with low bit rates that requires lower transmitted powers per LED to achieve the same target BER. A small room was analysed in this paper and it has been observed that deploying a VLC system in a bigger room will be more challenging due to factors such as large distance between the LED lights and the PD, varying horizontal height of the PD at different seating levels in the stadium and the possibility of interference due to environmental conditions (in uncovered stadiums). However, the results in this paper show that indoor VLC systems can be used to provide sufficient bandwidth and satisfy the increasing demand for data in ABUAD.

References

[1]. K. Cui, C. Gang, Z. Xu, and R. D. Roberts, "Line-of-sight visible light communication system design and demonstration," in 7th IEEE International Symposium on Communication Systems Networks and Digital Signal Processing, pp. 621-625, 2010.

[2]. T. Komiyama, K. Kobayashi, K. Watanabe, T. Ohkubo, and Y. Kurihara, "Study of visible light communication system using RGB LED lights," in proceedings of annual IEEE Conference, pp. 1926-1928, September, 2011.

[3]. T. Komine, and M. Nakagawa, "Fundamental analysis for visible-light communication system using LED lights," IEEE transactions on Consumer Electronics, 50(1), pp. 100-107, 2004.

[4]. Y. Tanaka, T. Komine, S. Haruyama, and M. Nakagawa, "Indoor visible communication utilizing plural white LEDs as lighting," in 12th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, vol. 2, pp. F-F, September, 2001.

[5]. Y. Tanaka, S. Haruyama, and M. Nakagawa, "Wireless optical transmissions with white colored LED for wireless home links," in The 11th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, vol. 2, pp. 1325-1329, 2000.

[6]. Z. Wu, J. Chau, and T. Little, "Modeling and designing of a new indoor free space visible light communication system," in 16th IEEE European Conference on Networks and Optical Communications, pp. 72-75, July, 2011.

[7]. M. B. Rahaim, A. M. Vegni, and T. D. Little, "A hybrid radio frequency and broadcast visible light communication system," in IEEE GLOBECOM Workshops, pp. 792-796, December, 2011.

[8]. H. Elgala, R. Mesleh, H. Haas, and B. Pricope, "OFDM visible light wireless communication based on white LEDs," in 65th IEEE Vehicular Technology Conference, pp. 2185-2189, April, 2007.

[9]. H. Q. Nguyen, J. H. Choi, M. Kang, Z. Ghassemlooy, D. H. Kim, S. K. Lim, and C. G. Lee, "A MATLAB-based simulation program for indoor visible light communication system," in 7th IEEE International Symposium on Communication Systems Networks and Digital Signal Processing, pp. 537-541, July, 2010.

[10]. H. Elgala, R. Mesleh, and H. Haas, "Practical considerations for indoor wireless optical system implementation using OFDM," in 10th IEEE International Conference on Telecommunications, pp. 25-29, June, 2009.

[11]. S. Tanabe, S. Fujita, S. Yoshihara, A. Sakamoto, and S. Yamamoto, "YAG glass-ceramic phosphor for white LED (II): luminescence characteristics," in International Society for Optics and Photonics Fifth International Conference on Solid State Lighting, vol. 5941, pp. 594112, September, 2005.

[12]. I. Moreno, and U. Contreras, "Color distribution from multicolor LED arrays," Optics express, 15(6), 3607-3618, 2007.

[13]. K. D. Langer, J. Vucic, C. Kottke, L. F. del Rosal, S. Nerreter, and J. Walewski, "Advances and prospects in high-speed information broadcast using phosphorescent white-light LEDs," in 11th IEEE International Conference on Transparent Optical Networks, pp. 1-6, June, 2009.

[14]. T. Borogovac, M. B. Rahaim, M. Tuganbayeva, and T. D. Little, "'Lights-off' visible light communications," in IEEE GLOBECOM Workshops, pp. 797-801), December, 2011.

[15]. G. Pang, K. L. Ho, T. Kwan, and E. Yang, "Visible light communication for audio systems," IEEE Transactions on Consumer Electronics, 45(4), 1112-1118, 1999.

[16]. M. Akanegawa, Y. Tanaka, and M. Nakagawa, "Basic study on traffic information system using LED traffic lights," IEEE Transactions on Intelligent Transportation Systems, 2(4), 197-203, 2001.

[17]. I. E. Lee, M. L. Sim, and F. W. L. Kung, "Performance enhancement of outdoor visible-light communication system using selective combining receiver," IET optoelectronics, 3(1), 30-39, 2009.

[18]. L. C. Andrews, and R. L. Phillips, "Laser beam propagation through random media," vol. 152, Bellingham, WA: SPIE press, 2005.

[19]. R. Ramaswami, K. Sivarajan, and G. Sasaki, "Optical networks: a practical perspective," Morgan Kaufmann, 3rd edition, July, 2009.

[20]. J. J. Chen, T. Y. Wang, K. L. Huang, T. S. Liu, M. D. Tsai, and C. T. Lin, "Freeform lens design for LED collimating illumination," Optics express, 20(10), 10984-10995, 2012.

[21]. L. Yin, W. O. Popoola, X. Wu, and H. Haas, "Performance evaluation of non-orthogonal multiple access in visible light communication," IEEE Transactions on Communications, 64(12), 5162-5175, 2016.

[22]. D. Tsonev, M. S. Islim, and H. Haas, "OFDM-based visible light communications," in Optical Wireless Communications, Springer, Cham, pp. 255-298, 2016.

[23]. A. Stavridis, and H. Haas, "Performance evaluation of space modulation techniques in VLC systems," in 2015 IEEE International Conference on Communication Workshop, pp. 1356-1361, June, 2015.
[24]. Z. Ghassemlooy, W. Popoola, and S. Rajbhandari, "Optical wireless communications: system and channel modelling with Matlab®," CRC press, 2012.

Jeremiah Oluwatosin Bandele"Performance Analysis Of A Visible Light Communication System In ABUAD Communications Laboratory." IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) 14.4 (2018): 10-16.