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# An Enhanced Source Modeling Of A Visible Light Communication System For An Indoor Environment

**Chukwudi Chukwudozie**

**Dr. Chidiebele Udeze**

**Chimdalu Okide**

**Oghenevwaire Akpeghagha**

Department of Electronic Engineering, University of Nigeria Nsukka,
Nsukka City, Nigeria

***Abstract:*** ***Visible Light Communication (VLC) is an emerging technological innovation of modern times that has the potential to revolutionize the future of wireless communication. VLC uses light emitting diode (LED) as the light source and a photodiode as the receiver which must be in line of sight to each other. The light rays emitted from LEDs can simultaneously carry information and provide illumination. Instead of using radio frequency signals to transmit data visible light spectrum is used. The radiant intensity of an LED is usually assumed to follow a Lambertian radiation pattern. In this research done with Matlab, an enhanced visible light communication (VLC) transmitter modeled with optimum Lambertian directional emission order for a line of sight (LOS) channel was demonstrated, which gave a more power efficient source model with improved received power at the photodiode and SNR. The height different between the transmitter and the receiver was varied at certain point. From the results, it shows that the received power of the receiver can be enhanced from the source without necessarily increasing the transmitter power.***

***Keywords:*** ***Visible light communication, channel modeling, LED, line of sight (LOS), Lambertian radiation.***



## I. INTRODUCTION

Visible light communication (VLC) is an innovation that could change the future of wireless communication. The purpose of VLC is to make LED devices serve as information emitting devices, without losing their basic illumination devices as lamps. In VLC, information signals are transmitted by modulating the visible light spectrum (380–780 nm) that is used for illumination [1]. The information signal is simultaneously carried using a light source whose intensity changes quicker than the human eye can notice, making it possible to be used for both illumination and wireless network connection. The rapid growth on the use of wireless communication systems, the quality of service (QoS) in need and the coming of fifth generation (5G) wireless systems, have led to the exploration of new alternatives to the use of the radio spectrum [2]. Two optical spectrum bands that can be used in indoor wireless communication are infrared (IR) and the Visible Light spectrum bands are two optical spectrum bands [3]. The evolution of LED technology has met great expectations that have made different groups and researchers to develop and standardize Visible Light Communication[4,5].

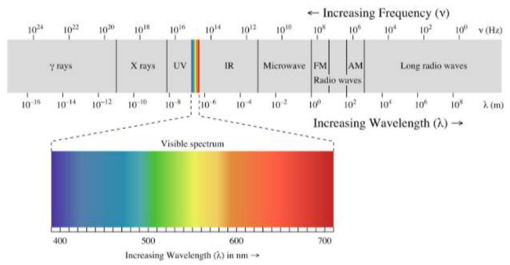


*Figure 1: Visible light spectrum [6]*

The most significant advantage of the LED is its fast switching ability to different levels of light intensity. The rate at which the LED switches is very fast that an end user cannot notice the flickering. This unique characteristic gives LED a dual purpose, to be used for communication in addition to lighting. This dual essential ability of LEDs to provide lighting and communication gave rise to interesting applications in home networking, high speed data transfer around offices, hospitals, traffic light management, communications in airplane cabins and other applications too numerous to mention [6].

## II. RELATED WORK

The system advantages, characteristics, limitations and existing problems in the enhancement of VLC technology which uses light emitting diodes as a transmitting module was expounded in [11, 12]. With the rapid growth recorded in data demand and smart application devices, numerous researchers have seen the need to look for Wi-Fi alternative. Hence, choice of using visible light for indoor communication has drawn many attention from researchers [10]. This unlicensed and cheap optical wireless communication system, is the optical equivalent of Wi-Fi. Its modulation is through On and Off switching of the LED. When it receives a high, a digital '1' is transmitted and on the other hand when it is low, a '0' is transmitted [13,14]. LED has a fast switching ability so an observer cannot notice the flickering, making the light source to appear steady. The transmission rate of VLC can be enhanced through different modulation techniques. Instead of the conventional use of radio waves, VLC uses light pulses for signal transmission and would utilize LED lights fitted transceivers that can illuminate a room as well as transfer information [12]. The user connectivity (access points) can be many as simple light sources are used.

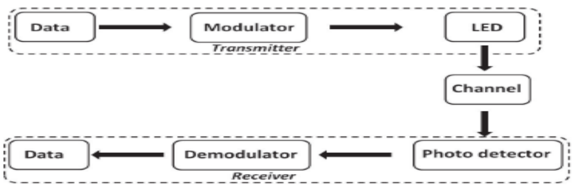


*Figure 2: Basic transmission blocks in VLC systems [9]*

We could see from research that several authors have carried some works on the modeling and simulation of VLC system. The authors in [15] proposed a VLC system line of sight channel model with a simulated analysis of the VLC performance. Some other researchers have studied and modeled the received signal strength (RSS) in an optical channel for different cases [16]. Of these various channel models, most VLC applications mainly use the channel model in the case when the luminance of LED follows the Lambertian radiation pattern at Line of Sight (LOS) condition. For some of these models, many authors have modeled the transmitter, mostly LED as been placed in parallel to a receiver. [17, 18]. With this setting, the performance analysis for the system is more convenient. Although, the VLC system performance also reduces drastically when the distance between the two planes is large [19]. In [25], a study on the LEDs position was carried out which shows that the amount of received power within a room also depends on the selection of LEDs location. In other to investigate the performance of an indoor VLC system with the LED light installed on the ceiling the author in [20] evaluated the received power at different points on the photodiode. The authors of [21], [22] looked on the impact of using several LED array to achieve a better VLC system performance and minimize the resulting overlap between LED lighting points by achieving optimum distance between different LED's position. It was also shown in [23] that the number and arrangement of LEDs have some effect on the received power at the photodiode. The effect of interference and disturbances on VLC systems coming from different light bulbs were studied in [24] and it was obtained that the fluorescent bulbs emit high frequency distortions on the system.

From the literature survey, many works have been proposed on the best way to improve the preformance of VLC. This was with the idea of handling the issues of received optical power also refered to as received signal strenght (RSS), medium range communication, LED positioning, shadowing and many other things mitigating the VLC performance. Increasing the VLC systems received signal power at the receiver is an important aspect in the system. Inview of the upper-mentioned context, this paper provides the preliminary way of enhancing the model at the transmitter level in other to achieve an improved communication system.



## III. VLC SYSTEM OVERVIEW

VLC is a short range optical wireless communication technology which could be greatly used for both illumination of a room and data transfer. The VLC basically uses white LED as the light source, FSC as the transmission path rather than the conventional fibre optic cable and Photodiode as the receiver for the transmitted signals.

## IV. VLC TRANSMITTER

VLC makes use of white LED as its optical transmitter which has better advantages over some other conventional light sources such as incandescent bulbs and fluorescent bulbs. White LEDs are widely considered and it's envisaged to be the next generation of light source due to features like low power consumption, high brightness and long lifespan that it possess.[8].

## V. VLC RECEIVER

On the part of the receiver, photodiode is used to convert the optical signal into electrical signal. The receiver also has an amplifier, filters and demodulator used in for original signal recovery. Avalanche photodiode (APDs) and positive intrinsic negative (PIN) photodiodes are the two types of photodiode with the latter been mostly used due to its features, like linear response over large ranges, high temperature tolerance and cost effectiveness.[5].

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## VI. SYSTEM CONFIGURATION

In this research, matlab was used for the simulation. We took cognizance of different parameters for a room dimension of (W × L × H) m³ (width, length, and height). The LED transmitter was considered to be at the center of the ceiling, facing the receiver plane. At the receiver plane, the light emission will be captured by the photodiode which has a specific FOV. It is paced upward toward the transmitter to ensure seamless connectivity.

### CHANNEL MODEL

The radiation path of LED follows this lambertian radiation intensity [7].

$$R_{(\emptyset)} = \frac{m+1}{2\pi} \cos^m(\emptyset),\ \emptyset \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right] \qquad \text{Eq. 1}$$

$$g(\varphi) = \begin{cases} \frac{n^2}{\sin^2\varphi_c}, & 0 \leq \varphi \leq \varphi_c \\ 0, & \varphi > \varphi_c \end{cases} \qquad \text{Eq. 2}$$

The signal to noise ratio

$$SNR = \frac{\gamma^2 P_r^{\,2}}{\sigma_{shot}^2 + \sigma_{thermal}^2} \qquad \text{Eq. 3}$$

$$\sigma_{shot}^2 = 2(P_{rx} + P_n)qBn. \quad \sigma_{thermal}^2 = I_{am}^2 Ba \qquad \text{Eq. 4}$$

The DC gain of the indoor VLC channel is given by [7].

$$H_{(0)} = \begin{cases} \frac{(m+1)A}{2\pi d^2} \cos^m(\emptyset) T_s(\theta) \cos(\theta), & 0 \leq \theta \leq \theta_c \\ 0 \end{cases} \qquad \text{Eq. 4}$$

Where A is the photodiode surface area Ø is the irradiance angle of the LED, $\theta$ is incidence angle of the photodiode, $\theta_c$ is the field of view (FOV) of the receiver and d is the distance of separation between the transmitter and the receiver. Also $T_s(\theta)$ is the gain of the optical filter and $g(\theta)$ is the optical concentrator gain, m is the lambertian order of emission relating to the transmitter semi-angle (at half power), which is given by.

$$m = \frac{-In2}{In(\cos\varphi_{1/2})} \qquad \text{Eq. 5}$$

Optimum Lambertian order is given by

$$m_{opt} = -\{In[\cos(\varphi_{1/2})]\}^{-1} - 1 \qquad \text{Eq. 6}$$

The received power $P_{RX}$ is given by

$$P_{RX} = P_{TX}\, H_{(0)} \qquad \text{Eq. 7}$$

Where $P_{TX}$ is the transmitted optical power of LED.

## VII. RESULTS AND DISCUSSIONS

In this section, we will be presenting the performance analysis of a single-LED. The communication signal which is transmitted from the LED will be fading while being transmitted on the free space channel, it implies that farther the distance of the LED from the photodiode, the weaker the signal received, and in some cases, the signal may not be received at all. In this scenario, the solution normally would be to increase the transmitter power or to increase the number of LED at the transmitter. But then, it is not energy saving

| VLC channel | LOS |
|---|---|
| Power of LED | 20W |
| Room size | (5x5x3)$m^3$ |
| Field of view | $60^0$ |
| Refractive index of lens at photodiode | 1.5 |
| Initial height of the receiver plane | 0.85m |
| Area of the detector | 1e-4$m^2$ |
| Gain of optical filter | 1 |
| For the Lambertian source | |
| Semi-angle at half power | $60^0$ |
| Order of lambertian emission | 1 |
| For the optimum lambertian directional | |
| Semi-angle at half power | $20^0$ |
| Order of Lambertian emission | 11 |

*Table 1: Modelling Table*

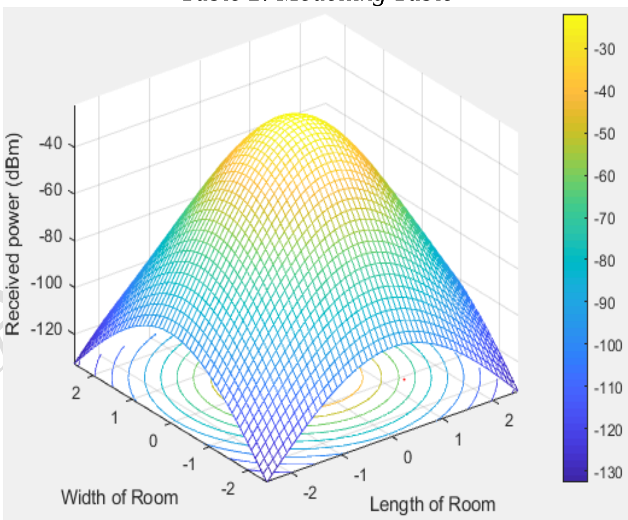


*Figure 3: Recieved Power distribution in the room*

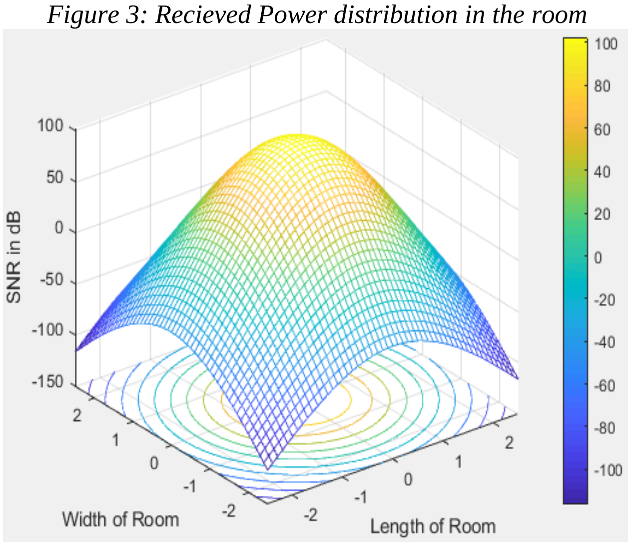


*Figure 4: Signal to Noise Ratio in the room*


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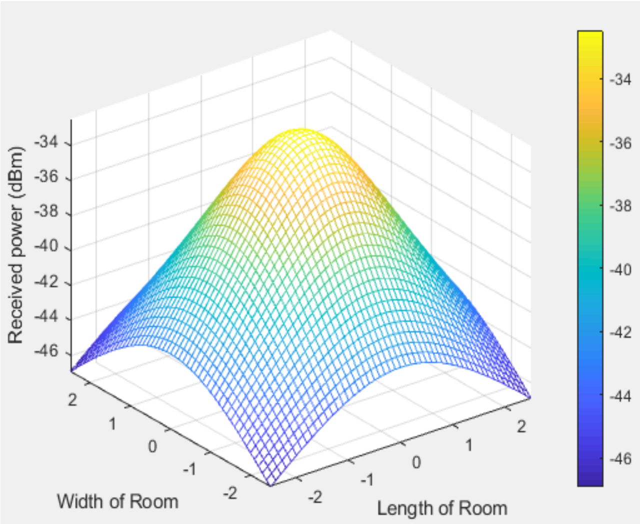


*Figure 5: Recieved Power distribution in the room*

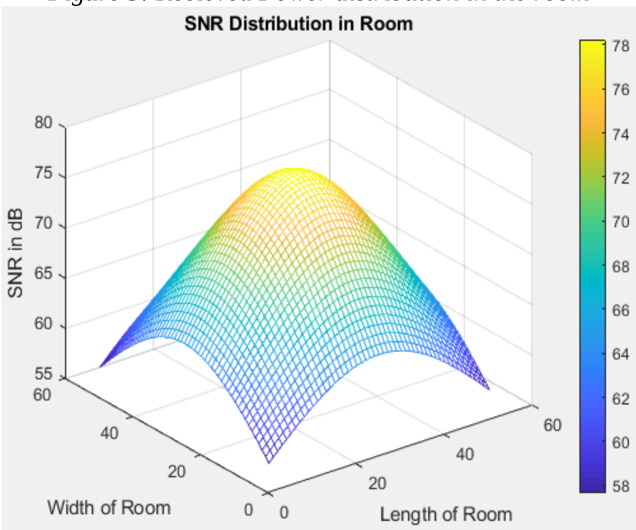


*Figure 6: Signal to Noise Ratio in the room*

Figures 3 and 5 are the received optical power and signal to noise ratio distribution for the optimum lambertian directional respectively while figures 5 and 6 are for the existing lambertian model.

The optimum lambertian directional can best be applied for a fixed device to device communication. The mobility is a big challenge in the VLC environment which can be evaluated by the received optical power at different locations in communication plane. The minimum and maximum optical power values received from lambertian, optimum lambertian directional are (-46.18dBm, -35.31dBm) and (-132.7dBm, -21.79dBm) respectively. From these obtained results we could notice some little variation in the maximum received optical power values from the different sources. Nevertheless, the minimum received power values define the user flexibility with respect to mobility. The lambertian provided a better minimum received optical power which makes it better for user mobility. Also, in the optimum lambertian directional, the signal to noise ratio is 103dB as against 85dB gotten from the lambertian model. This implies that there was an enhancement in the entire system.

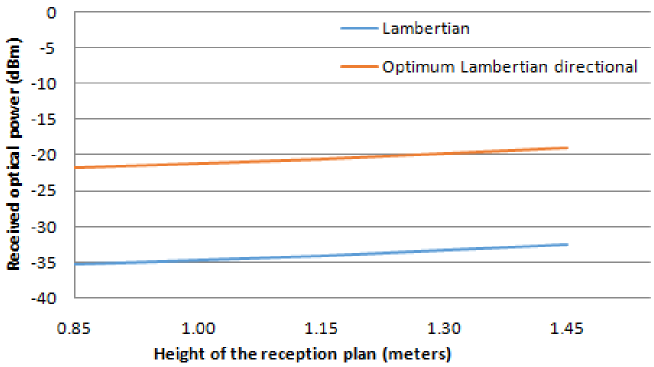


*Figure 6: Height effect of the Reception Plane*

The distance between the communication plane was fixed as 0.85m above the floor. At this height, the result of the received power at the center of the room for the Lambertian and optimum Lambertian directional are -35.31dBm and -21.79dBm respectively. However, with a gradual decrement in the distance between the two planes, in other words, with lesser vertical distance between the LED and photodiode the higher the received optical power.

| Height of reception plane(meters) | Received optical power(dBm) | |
|---|---|---|
| | Lambertian model | Optimum lambertian directional |
| 0.85 | -35.31 | -21.79 |
| 1.00 | -34.68 | -21.16 |
| 1.15 | -34.00 | -20.48 |
| 1.30 | -33.27 | -19.75 |
| 1.45 | -32.47 | -18.95 |

*Table 2: Received power distribution differences of the two model*

## VIII. CONCLUSION

In other to improve the performance of VLC system, a higher level of received signal power and SNR are required. From the simulated results, the received power distribution and Signal to Noise ratio (SNR) differs substantially in the room. So the users at the edges of the room are more likely to receive less signal power for communication than the users in the center where the transmitter is installed, this affects the communication performance of the VLC system. Also, as the distance between the transmitter and the receiver increases, the coverage area or footprint of the LED light increases while the received power decreases.

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## APPENDIX

[1] theta= 20;% semi-angle at half power
[2] m= (-1/(log10(cosd(theta))))-1;%optimum Lambertian order of emission
[3] P_total=20;%transmitted optical power by individual LED
[4] Adet=1e-4;%detector physical area of a PD
[5] Ts=1;%gain of an optical filter; ignore if no filter is used
[6] index=1.5;%refractive index of a lens at a PD; ignore if no lens is used
[7] FOV=60*pi/180;%FOV of a receiver
[8] G_Con=(index^2)/sin(FOV);%gain of an optical concentrator;
[9] lx=5; ly=5; lz=3;% room dimension in metres
[10] h=2.15;%the distance between source and receiver plane
[11] %[XT,YT]=meshgrid([-1.25 1.25],[-1.25 1.25]);
[12] XT=0; YT=0;% position of LED;
[13] Nx=lx*10; Ny=ly*10;% number of grid in the receiver plane
[14] x=-lx/2:lx/Nx:lx/2;
[15] y=-ly/2:ly/Ny:ly/2;
[16] [XR,YR]=meshgrid(x,y);% receiver plane grid
[17] D1=sqrt((XR-XT(1,1)).^2+(YR-YT(1,1)).^2+h^2);% distance vector from source 1
[18] cosphi_A1=h./D1;% angle vector
[19] H_A1=(m+1)*Adet.*cosphi_A1.^(m+1)./(2*pi.*D1.^2); % channel DC gain for source 1
[20] P_rec=P_total.*H_A1.*Ts.*G_Con;% received power from source 1;

```
[21] P_rec_dBm=10*log10(P_rec);
[22] meshc(x,y,P_rec_dBm);
[23] xlabel('Length of Room');
[24] ylabel('Width of Room');
[25] zlabel('Received power (dBm)');
[26] axis([-lx/2 lx/2 -ly/2 ly/2 min(min(P_rec_dBm)) max(max(P_rec_dBm))]);
```