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Visible Light Communication (VLC) Channel Modeling

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Abstract: **- The Radio Frequency (RF) suffers from interference with most electronic devices, limited, scar, expensive and also it can penetrate through walls that make it unsecure. To overcome these limitations, we used Visible Light Communication Technique (VLC) that use Light Emitting Diode (LED) for transferring data, in addition to its main function, lighting .VLC system uses LEDs due to its higher data rate, longer life time, easy to install and low cost, so it is preferred rather than other lighting sources. VLC transfers data over a range in Electromagnetic (EM) spectrum which is visible to human that's from (380-750nm). In this paper, we report a simulation program for indoor visible light communication environment based on Matlab where we introduce both Line of Sight (LoS) and Non – Line of Sight (N-LoS) models for visible light source and photodiode in wireless communication and introduce for the first time the effect of reflections from the room four walls on the receiver surface.**

Index Terms**- Optical Wireless Communication (OWC) , Field of View (FOV) , half power angle , lambertian order , Line of Sight (LoS) , Non Line of Sight (N-LoS).**

I. INTRODUCTION

During last years , more researches have been made trying to find alternative technology to transmit data instead of the traditional way of transmission , I mean , Radio Frequency (RF) spectrum due to , first , its capacity has been almost saturated , second, the multimedia applications and data streaming are growing up every day significantly , third , the radio frequency causes interference with most electronics devices. So , as a result of these huge tries to find another methods , many technologies have been introduced like millimeter waves , terahertz waves and optical waves[1] . The communication using millimeter and terahertz waves require very high frequencies, that make them, don't travel near the earth, so it can't be used in indoor communications. So, scientists turn to use optical waves which represented in the use of optical wireless communication (OWC) or free space optics (FSO) like visible , infrared (IR) or ultraviolet (UV) light to carry signal. Today's, optical communication technique can be divided into two categories: Fiber Optics and Free Space Optics (FSO), the main difference between them is the medium that each one of them uses to propagate and send data. Fiber optics is based on the optical fiber cable which it uses as a medium. On the other side, the FSO uses the air to transmit the data. They both use either LASER or LEDs. both technologies have advantages and disadvantages where fiber optics can achieve much higher data rates than FSO , but FSO can achieve data transfer to places where cables established is impossible or the absence of electromagnetic waves is important. So, besides the already existing IR, a new technology is born: Visible Light ommunication (VLC) or Wireless Light Communication (WI-LI).VLC refers to data communication over a range in the EM spectrum , which is visible to humans that operates in the visible band (380-750 nm)[2][3]. Using visible light as a medium for communication is not a new technique as it was introduced by Graham Bell in 1880s who used sun rays to transmit audio signal using a device known as photophone but it has some drawbacks as it depends on sun light and this is not enough for transmission during the whole day [4].

The first VLC system started at Nakajawa Laboratory in Keio University, Japan in 2003 [5] and more researches followed that.

VLC system uses high brightness LEDs due to its longer life time compared to other sources of lightening, high data rate, data security, no health hazards, low power consumption , easy to install and low cost. All of these advantages make LEDs be the suitable solid state lighting device to meet needs of high speed data rate. Also, according to CISCO [6], overall mobile data traffic is expected to grow to 49 exabytes per month by 2021, a sevenfold increase over 2016. Mobile data traffic will grow at Compound Annual Growth Rate (CAGR) of 47 percent from 2016 to 2021 (Figure 1).

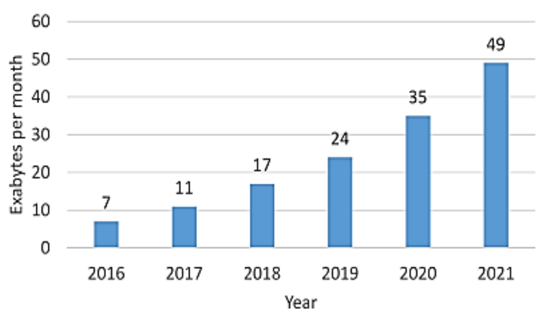


Fig.1 Mobile Data Traffic/Month

This increase due to the increase in the number of devices accessing the mobile networks and also the development of line social applications like face book and twitter has further increase the mobile data traffic. Since all of these devices use radio frequency that has a limited spectrum also, it suffers from other problems like interference, where it is forbidden to use portable devices in aircrafts because of the interference with navigation systems. Also it suffers from security issues, has risks in a human health. So, to overcome these problems, engineers have developed a new wireless communication technique called Visible Light Communication System (VLC).

II. INDOOR VISIBLE COMMUNICATION SYSTEM:

Indoor visible communication system should be implemented to deliver illumination and wireless data transmission simultaneously as it is built on the illuminance infrastructure .Here, LEDs are used as light source in the system because it is more efficient compared with traditional illumination lights. At receiver photodiode or photodiode array is used for signal detection , such typical indoor visible communication system is modeled by the infrastructure shown in figure 2.

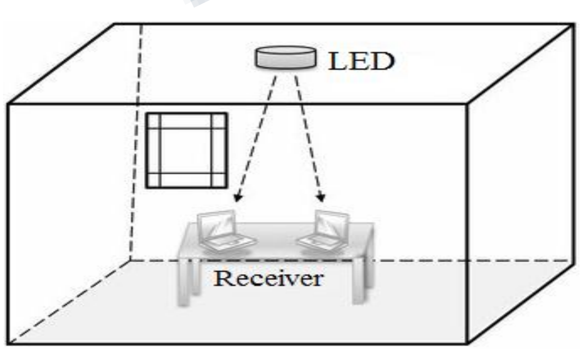


Fig.2 Indoor optical communication system

III. SYSTEM MODEL

A-The communication channel

It can be defined as the physical space between the LED as transmitter and the photodiode as a receiver [7] here, the physical space is referred as optical link which can be divided into two categories, named directed system and diffusive system. In directed system (Line of Sight) a narrow signal beam is established a point to point link between the transmitter and receiver that has a minimum multipath dispersion and give high data transmission rate. In the other side, in diffusive system (multipath link non light of sight signal), several multi path dispersion is existed due to the reflections from walls, ceiling, ground and other physical objects) that limits the communication band width and reduce the energy efficiency.

Besides, the line of sight and non line of sight signals, there is a back ground light that generated from traditional lamps and sunrays are collected at the receiver that reduce the system efficiency as shown in figure 3 and to reduce it , optical band pass filter is used to reject these unwanted lights. Also there is another source of reducing the system efficiency , that's air turbulence that come from air conditioner , fans or heaters , that may change the polarity of the signal at the receiver end. In such indoor system, this effect is negligible.

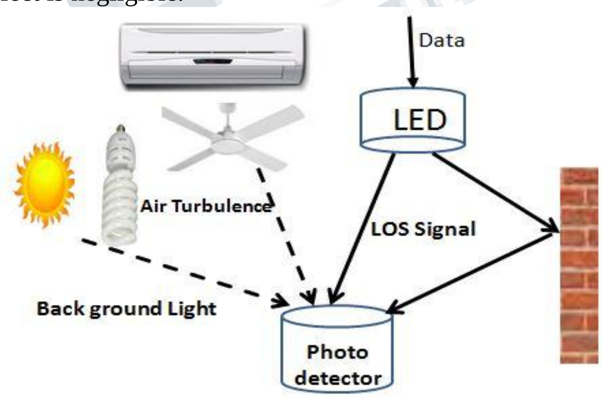


Fig.3 Different Signals that effect on System Efficiency.

B- LED illuminance:

Since LEDs are used not only for illumination but also in the optical communication, it is desirable to define the illumination intensity and the transmitted power so, the intensity is the luminous flux per solid angle and it is used for expressing the brightness of LEDs and the transmitted power indicates the total energy radiated from LEDs.

The luminance intensity is given by [8]:

$$I = \frac{d\Phi}{d\Omega} \qquad (1)$$

Where, Φ is luminous flux that can be calculated from energy flux as follows:

$$\Phi = K_m \int_{380}^{780} V(\lambda)\Phi_e(\lambda)d\lambda \qquad (2)$$

Where,
K_m : is the max. Visibility =683lm/W at λ=555nm.
V (λ): is standard luminosity curve.
Ω : is the spatial angle.

Assuming that, LEDs lightening has a lambertian radiation pattern, then the luminous intensity as a function in ϕ is given by[8]-[9] :

$$I(\phi) = I(0)\cos^m(\phi) \qquad (3)$$

Where,
ϕ: Angle of irradiance w.r.t the axis normal to the transmission surface.
$I(0)$: The centre luminous intensity.
m : The lambertian emission order that's equal to:

$$m = \frac{\ln 2}{\ln(\cos\phi_{1/2})} \qquad (4)$$

Where,
$\phi_{1/2}$: The semi angle at half illuminance of an LED.

At any point (x,y) , the horizontal illuminance as shown in figure (4), is given by :

$$I_{hor.} = I(0)\frac{\cos^m(\phi)}{d^2}\cos(\psi) = \frac{I(\phi)}{d^2}\cos(\psi) \qquad (5)$$

Where,
ψ : The angle of incidence.
d: The distance between LED and photo detector surface, figure 5.

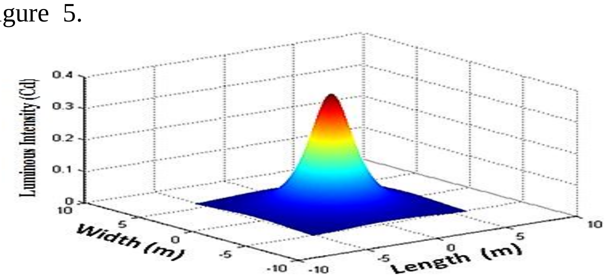


Fig. 4 The Distribution of Horizontal Luminous Intensity.

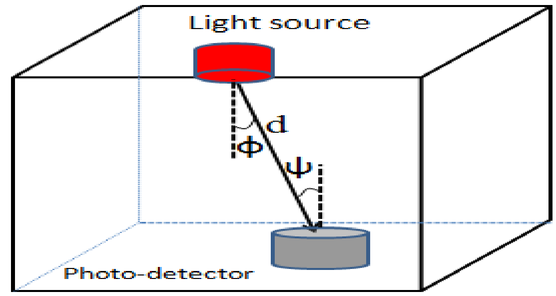


Fig.5 Propagation Model of Directed Link.

C- LoS Propagation Model:

A point to point link between the transmitter and receiver that has a minimum multipath dispersion is established. One of its weak points is on shadowing effect which caused by objects blocking such as human activities also it has a limited coverage area so it is not capable of supporting mobile users. As shown in figure 5, if it is applied to only one LED, the LED is placed at a distance "d" from the photodiode. LED radiation angle of the transmitter to receiver against transmitter normal is denoted by ϕ whereas the radiation angle to receiver against the receiver normal is denoted by ψ.

Now, a possible application is discussed in terms of some numerical analysis. A room is assumed to has a size of 5m x 5m x 3m as shown in figure 6, LEDs are installed at a height of 3m. The height of the desk is at 1m so the distance between transmitter and receiver is 2m. The number of LEDs is 100 per array where we have four arrays, that has a center luminous intensity 0.73cd. The semi angle at half power is 70^o where the transmitted optical power is 1.5W for each LED. These conditions are summarized in table 1.

Table 1 LED Design Parameters.

Room Dimensions	5m x 5m x 5m
Transmitted Optical Power	1.5 W
Semi Angle at Half Power	70°
Centre Luminous Intensity	0.73cd
Number of LEDs / array	100

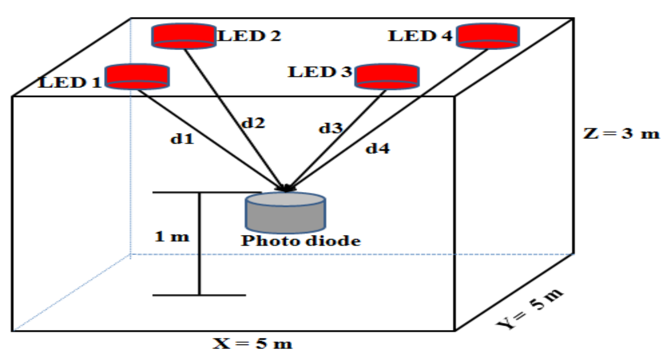


Fig. 6 The model room. The room size is 5m x 5m x 3m. The desk of height 1m from the floor. The LED Light of height 3m from the floor.

The detector is modeled as active area A_r collecting the radiation incident at angles ψ smaller than the detector Field of View (FOV), then the effective area is given by:

$$A_{eff.} = \begin{cases} A_r \cos(\psi) & 0 \le \psi < \frac{\pi}{2} \\ 0 & \psi > \frac{\pi}{2} \end{cases} \quad (6)$$

Then at receiver. Ideally, a large area detector would be suitable for indoor optical communication system to collect much power but practically , it increases the manufacturing cost and junction capacitance that will decrease the system bandwidth thus to overcome this , a concentrator is used to increase the effective area , the optical gain of such concentrator is given by[8]-[10] :

$$g(\psi) = \begin{cases} \frac{n^2}{\sin^2 \psi_{con}} & 0 \le \psi \le \frac{\pi}{2} \\ 0 & 0 \ge \psi_{con} \end{cases} \quad (7)$$

Where,

n: is the concentrator refractive index.

ψ_{con} : The FOV at receiver.

The absorption and scattering caused from walls, ceiling and other physical materials are very low due to the short optical link in the indoor optical system that has a channel DC gain approximated as[6]-[9]:

$$H_{los} = \begin{cases} \frac{A(m+1)}{2\pi d^2} \cos^m(\phi) T_s(\psi) g(\psi) \cos(\psi) & 0 \le \psi \le \psi_{con} \\ 0 & \psi > \psi_{con} \end{cases} \quad (8)$$

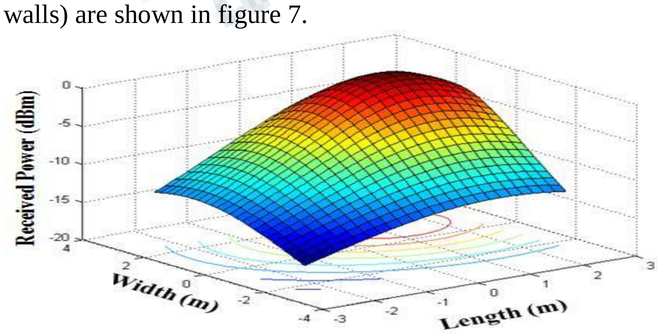
Where:

T_s : Optical filter gain.

The relations between optical received power ($P_{r\text{-}los}$) in watt and optical transmitted power (P_t) could be expressed as:

$$P_{r-los} = H_{los}(O).P_t \quad (9)$$

Referring to figure (6), the optical power distribution from each LED and the total power distribution from all LEDs at receiver plane in LoS path (ignoring the reflections of the walls) are shown in figure 7.



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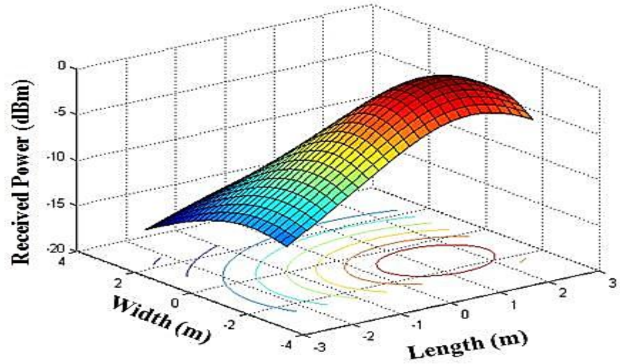

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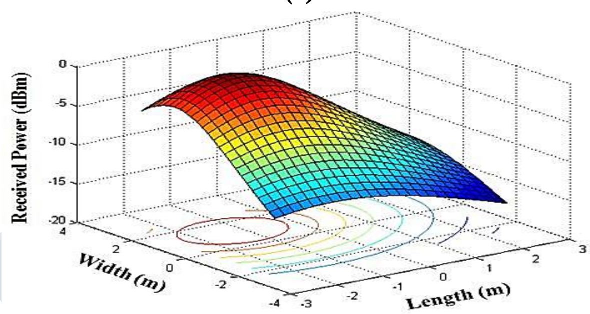

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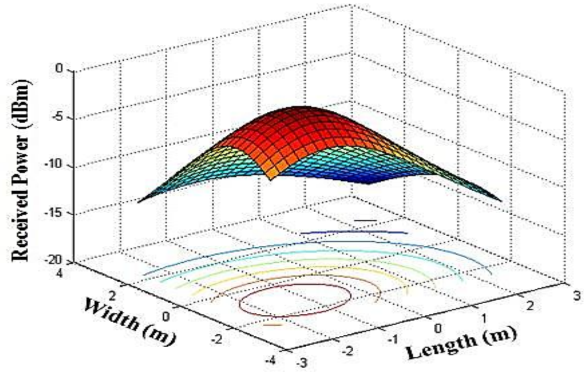

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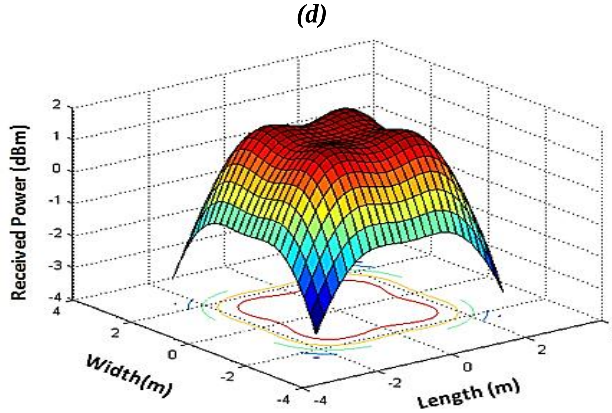

(e)

Fig.7 The Distribution of the Received Power from , (a) LED2 , (b) LED4 , (c) LED1 , (d) LED3 , (e) Total Power from all LEDs.

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It can be seen from figure (7 e), there is almost uniform distribution of optical power at the centre with max. Power of 1.6465 dBm and min. power of -3.2dBm at channel distance 2 meters .Depending on the transmitter's half power angle ($\phi_{1/2}$), we can control on the received power if ($\phi_{1/2}$) is varied from 10^o to 90^o with range difference of 10^o at a fixed channel distance of 2 meters as shown in figure 8.From this figure, as ($\phi_{1/2}$) increased, the received power is decreased and this is matched with the characteristics of LoS. Also the distance between the LED source and photodiode is a function with the received power that is because of the characteristic of the channel LoS, where the closer the transmitter to the photodiode, the higher the intensity of light that is received by the photodiode as shown in figure 9.

D- Non line of sight (N-LoS) propagation Model:
Here, the optical path is more complicated as it depends on many factors like reflectivity of the walls, ceiling, objects inside the room, room

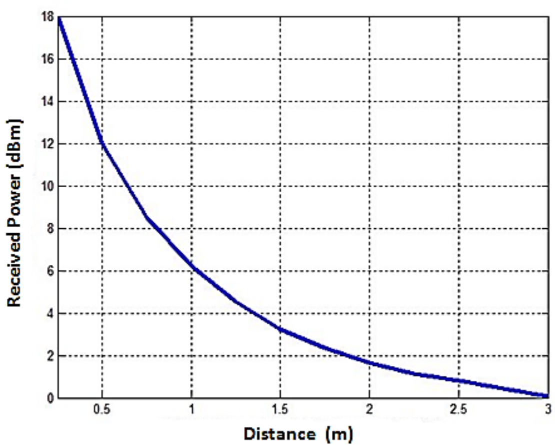

Fig.8 Distance vs Photodiode's received power.

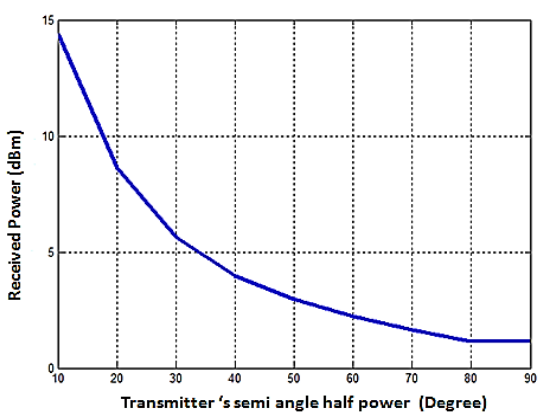

Fig. 9 Semi angle half power v.s photodiode received power.

dimensions, position of transmitter and receiver, as a simple model for such propagation is shown in figure 10. In this figure, an optical wave is generated from LED source, has two propagation paths. The first one is directed path, denoted by (d) and the other one is non directed (N-LoS) path that incident on the wall (for simplicity, we consider it is reflected by only one wall) by an angle (α_{ir}) and this path is reflected again from this wall and incident on the photo detector surface by an angle (ψ_r).

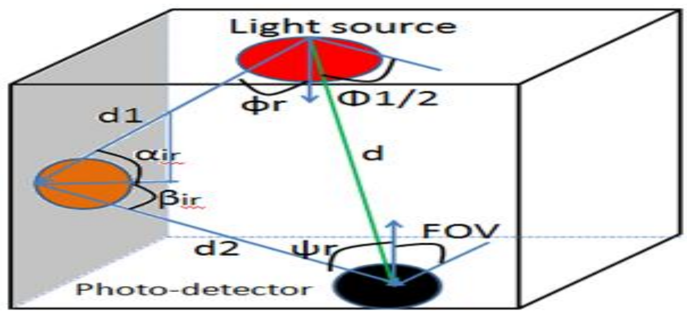

Fig.10 Propagation model of diffused link.

A more complicated model is shown in the following figure 11. Here , in this figure a room with a size of 5m x 5m x 3m with four LED arrays installed on the ceiling of the room in symmetrical arrangement (3m from the floor), each LED of 1.5 Watt, has many reflected beams , reflection from each wall from the four walls that has a reflection coefficient of 0.8, ceiling, floor, any object inside the room like(tables, desks,…..) and human but in a simple approach, we consider that there is a reflection from only one LED to each wall from the four walls but in numerical results, we take into account the effect of each LED in computing the received power at the photo detector surface after reflections on all walls and the effect of all LEDs together to compute the total received power at the receiver plane. So, when computing the received power, we must include the channel gain of the directed path and non directed path as follows [8]-[11]:

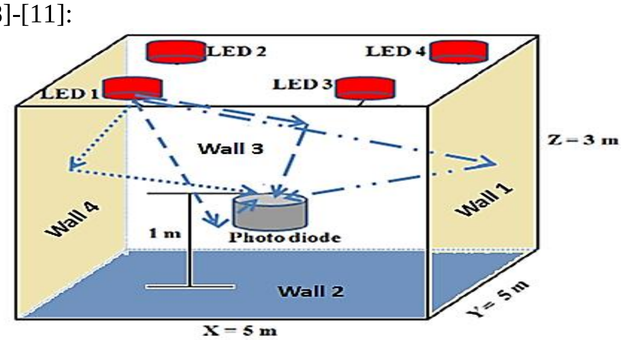

Fig. 11 The model room. The room size is 5m x 5m x 3m. The photo diode of height 1m from the floor. The LED Light of height 3m from the floor.

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$$P_{r-nlos} = \left(H_{los}(0) + H_{nlos}(0)\right) P_t$$

$$= \left(H_{los}(O) + \sum_{refl.} H_{ref.}(O) \right) P_t \quad (10)$$

Where,

$$H_{los} = \begin{cases} \frac{A_r(m+1)}{2\pi(d_1 d_2)^2} \rho d A_{wall} \cos^m(\phi_r) \cos(\alpha_{ir}) \text{ x } \cos(\beta_{ir}) \\ T_s(\psi) g(\psi) \cos(\psi_r) & 0 \le \psi \le \psi_{con} \\ 0 & \psi > \psi_{con} \end{cases} \quad (11)$$

Where,

d_1 : The distance from LED to reflection point. (figure.10)

d_2 : The distance from reflection point to receiver surface.

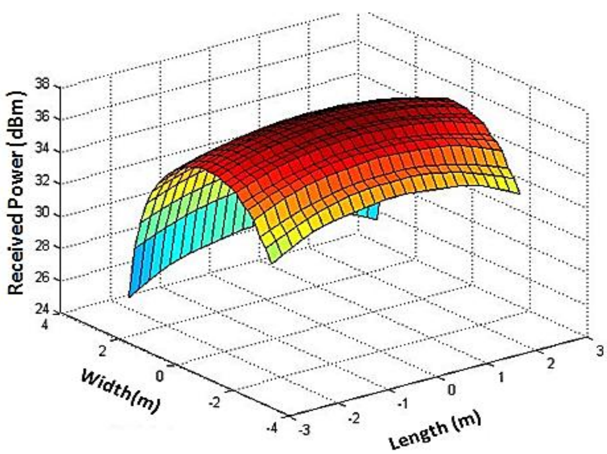
ρ : Reflectance factor.

ϕ_r : Angle of irradiance to a reflection point.

β_{ir} : Angle of irradiance to a receiver.

ψ_r : Angle of incidence from the reflective surface.

Referring to figure 11, the optical power distribution from each LED and the total power distribution from all LEDs at receiver plane in N-LoS path (including the effect of reflections from all walls) are shown in figure 12.



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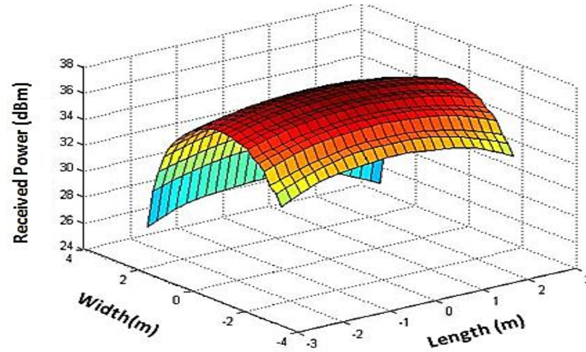

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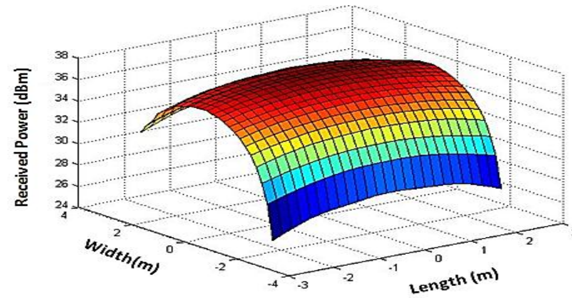

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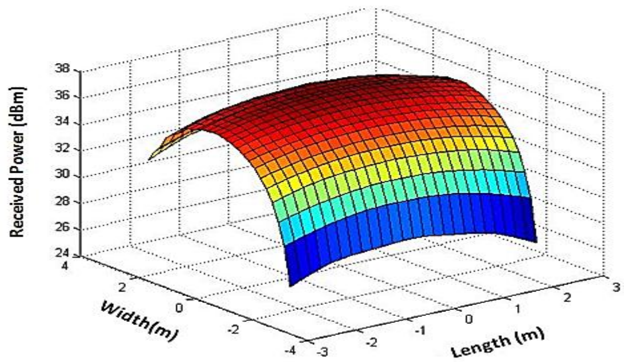

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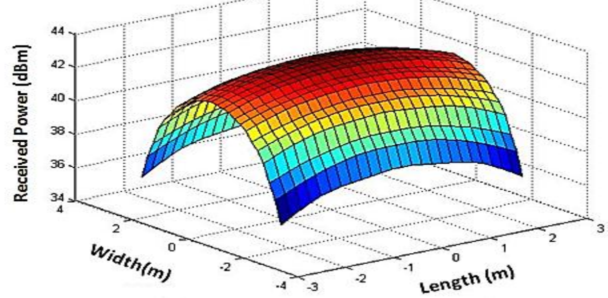

(e)

Fig. 12 shows the 3D view of the reflected received power generated from the four walls according to (a) LED 1, (b) LED 2, (c) LED 3, (d) LED 4 and (e) total received power from all LEDs.

Finally, the reflections from the walls can be summarized in a flow chart as shown in figure 13 considering that the term (reflection object) can be any point of reflection. Here the objects were walls.

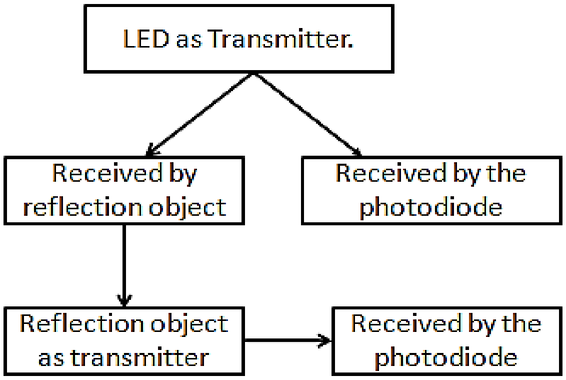

Fig. 13 flow chart of different signals paths.

IV. CONCLUSION

In this paper, an indoor visible light communication system taking into account direct propagation (LoS) and non direct propagation (N-LoS) including the reflection from walls models are investigated for a typical room. Equations of the received power of both different models are applied to calculate and simulate the received power at the receiver plane.

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