# Simulation of Indoor Visible Light Communication System

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***Abstract* -** Visible Light Communications (VLC) is a field which witnessed increased level of research activities in the last decade. VLC is a wireless communication technology which uses visible light from our daily life lighting equipment's to transmit data.The growing demand of VLC is due to several characteristics, such as large bandwidth, unlicensed spectrum, low cost. It can be used to overcome Bottle-Neck problem that arises due to the wide gap between the bandwidth of providers and access points. VLC utilizes Light-Emitting Diodes (LED) for dual purpose that is illumination and data communications. A spatial diversity technique-Multiple Input Multiple Output (MIMO) is proposed to alleviate the shadowing problem. This technique also overcomes the Inter-Symbol Interference (ISI) occurred due to optical path difference between multiple paths.In this paper, performance analysis of Indoor MIMO VLC system using typical room dimensions (5x5x3m) is done. The parameter variation by varying position of receiver in XY plane is simulated. Luminous intensity, radiation pattern and optical power distribution is detected at receiver and is plotted.

***Index Terms*** *-VLC; Bottle-Neck problem; LED; MIMO; ISI.*

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## I. Introduction

In the last two decades, unprecedented spread of wireless communication systems has been witnessed. With the increasing popularity of smartphones, the wireless data traffic of mobile devices is growing exponentially. There have been many independent warnings of a looming "RF spectrum crisis" as mobile data demands continue to increase, while the network spectral efficiency saturates despite newly introduced standards and great technological advancements in the field[1]. Since the RF spectrum is limited and expensive, new and complementary wireless transmission techniques are currently being explored that can relieve the spectrum utilization. One such promising emerging alternative approach is optical wireless communication, which offers many advantages over RF transmission.VLC has been identified as a potential solution for mitigating the looming RF spectrum crisis.
VLC is particularly enticing as lighting is a commodity that has been integrated into virtually every inhabited environment, and sophisticated infrastructures already exist. In recent years, a growth in research of visible light communications (VLC) is seen. Thus the concept of using LEDs for both illumination and data communications was proposed.The main drivers for this technology include the increase in popularityof solid-state lighting, longevity of high-brightnessLEDs as compared toincandescent light bulbs and other sources ofartificial light, data rate/high bandwidth, security of data, low power consumptionand no health hazards.VLC has successfully demonstrated data transmission at over 500 Mbps over short links in office and home environment [2].

In a typical indoor scenario especially office or home, VLC is expected to be a strong contender to Wi-Fi for home networking and a reliable successor when the case of Wi-Fi is concerned. The indoor VLC however has to face several major challenges like limited bandwidth of white LEDs, severe path loss, multi-path dispersion and unavoidable background light noise. Additionally, performance of VLC systems majorly depends on the link configurations. In order to provide sufficient illumination, multiple LED arrays are usually positioned, thus the deployment of multiple-input-multiple output (MIMO) systems in VLC is ready to be realized.

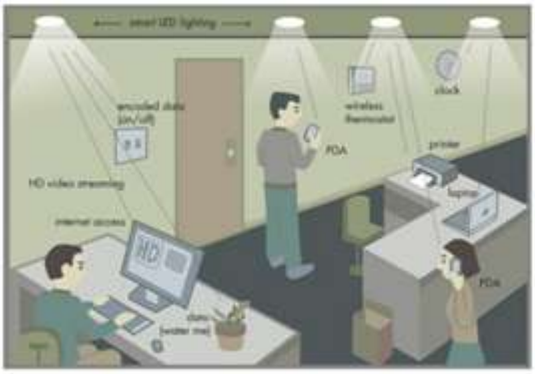

Fig. 1 Indoor VLC scenario [1]

Upon detailed investigation of VLC research, it was found that not a lot of research has been done to develop this technology for commercial use. But because research into VLC is relatively new, the possibilities are wide open. A lot of research is being done to make this technology available for commercial use in various fields, including internet access and vehicle-to-road communication using traffic signal lights. From review ofthe literature, it became evident that work should be done to look into the possibility of designing a new model that could fit the present infrastructure for indoor applications. Every room has a number of lights in it. If basic lights were replaced with LEDs and a VLC system, then a room is being supplied with both light and internet access. For this reason, VLC technology has the potential to become quite popular for indoor local networks.

## II. Indoor Positioning VLC System

LED is considered as a strong candidate for the future lighting technology. An optical wireless communication system is proposed that employs white LEDs for indoor wireless networks. The key techniques in indoor positioning based on visible light communication and the state of the art of this research were surveyed. First, the significance of indoor positioning based on visible light communication from two aspects of the limitations of current indoor positioning technology and the advantages of visible light communication was considered in this study.With the technology matures in visible light communication, indoor positioning based on visible light communication will gradually develop to the practical application. After summarizing the indoor positioning technology, these factors of future research will be considered:

1) Positioning technology should be a considered condition of the rapid movement, rather than static or slow moving movement.

2) At present, the literature researched positioning in a very typically small indoor environment with less obstacle and weak diffuse. But in fact, the indoor environment is full with a lot of obstacle which the diffuse reflection is strong. So, attention should be paid to the positioning technology under the complex environment in the future.

3) VLC can be used for illumination as well as communication, in order to have a large range of lighting, the LED’s angle of emission should not be narrow as a result, the LED beam received by receiver will increase at the same time. So, the positioning system need to solve the problem of the multiple access [3].

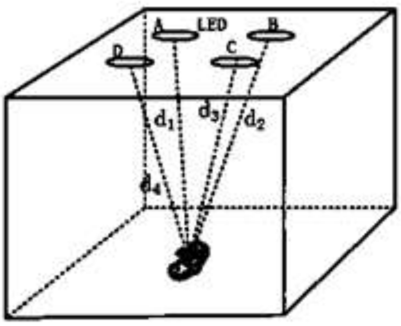


Fig.2 Indoor VLC positioning system [3]

In this system, LED is used not only as a lighting device, but also as a communication device. The transmitter has large optical power and large emission characteristics to function as lighting device. And the system has specific wireless channel impulseresponse differing from infrared wirelesscommunication. Discussion about shadowing effect on thesystem utilizing optimal no of LED lightings including theperformance of ISI based on the impulse response is made in this study. The system with the optimal number of the LED lighting is robust against shadowing and which can accommodate more calls due to high data rate optical transmission [4].

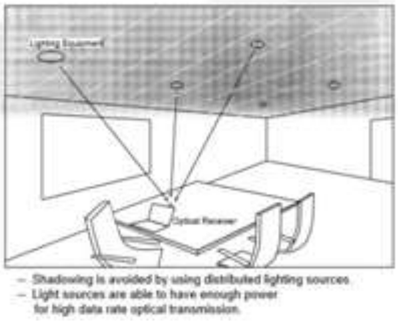


Fig. 3 Lighting Equipment with diversity system [4]

A mobile receiver with angular diversity detectors in Visible Light Communication (VLC) Multiple Input Multiple Output (MIMO) channels is considered. The objective is to improve the rank of the channel matrix and hence system throughput. Repetition Coding (RC), Spatial Multiplexing and Spatial Modulation Positioning (SMP) concepts are used to evaluate throughputs across multiple locations in a small room scenario. Since the receiver is mobile, the channel gains are weak in some locations of the room due to the lack of Line of Sight (LOS) paths between transmitters and receivers [5].

In this paper, among many LOS/NLOS channel models proposed, the LOS channel is used [6]. Optical wireless communication is generally realized in a line-of-sight (LOS) or a non-line-of-sight (NLOS) communication setup. LOS links can be generally employed in static communication scenarios such as indoor sensor networks, where a fixed position and alignment between the transmitter and receiver are maintained. In mobile environments such as commercial offices, mechanical or electronic beam steering can be used to maintain an LOS connection. Such techniques, however, increase the cost of the optical front ends.

The requirements for uniform illumination using white LEDs, showing the balance between lighting and visible light communications. The communications system performance for mobility with a varying field of view at the receiver is investigated, showing that there is a limit that beyond which there are no longer gains to be made in mobility. The simulation results presented has demonstrated that uniform illumination throughout the room using LED sources for lighting can be closely achieved however at the cost of the maximum luminance power. Thus to achieve higher brightness in conjunction with uniformity, either the number of LEDs used or the power has to be increased. Concerning the communications aspect of VLC, uniform luminance is preferred for mobility [7].

In this paper, we have considered the performance of VLCsystems with two MIMO techniques RC and SMP in nondirectLOS environment. The BERvariates within the room and therefore the optimal transmitterseparation was found. Regarding MIMO techniques, it is seenthat RC can only perform well is the case of low efficiency. Onthe other hand, SMP with its spatial multiplexing gain is shownto be a promising solution to provide high efficiency with lowcomplexity in the presence of high data-rate demandings [8].

## III. Indoor Visible Light Communication System Model

Since LEDs are used for the dual propose of illumination and communication, it is necessary to define the luminous intensity and transmitted optical power. The luminous intensity is used for expressing the brightness of an LED, the transmitted optical power indicates the total energy radiated from an LED.

Luminous intensity is defined as the luminous flux per solid angle and is given as follows:

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

the term Φ is the luminous flux and Ω is the spatial angle and candela (cd) is the unit of luminous intensity.Φ can be calculated from the energy flux $\Phi_e$ as

$$\Phi = K_m \int_{380}^{780} V(\lambda)\, \Phi e(\lambda) d\lambda \quad (2)$$

thus V(λ) is the standard luminosity curve, and Km is the maximum visibility, which is ~683 lm/W at 555 nm wavelength.
The transmitted optical power Pt is given as

$$P_t = K_m \int_{\Lambda\, min}^{\Lambda\, max} \int_0^{2\pi} \Phi_c \, d\theta \, d\lambda \quad (3)$$

where Λmin and Λmax are determined from the photodiode sensitivity curve.

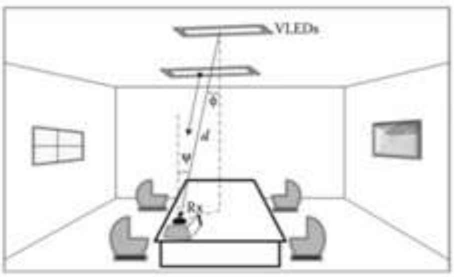


Fig.4 Illumination of LEDs in Indoor VLC scenario [2]

Figure 4 shows a typical office environment. Assuming that an LED lighting has a Lambertian radiation pattern, the radiation intensity at a desk surface is given by

$$I(\emptyset) = I(0) cos^{m_l}(\emptyset) \quad (4)$$

The term∅ is the angle of irradiance with respect to the axis normal to the transmitter surface, I(0) is the Centre luminous intensity and ml is the order of Lambertian emission defined as

$$m_l = \frac{\ln(2)}{\ln(cos\Phi_{\frac{1}{2}})} \quad (5)$$

here $\Phi_{1/2}$ is the semi angle at half illuminance of an LED.

The horizontal illuminance/intensity at a point (x, y) and the received power at the receiver are given as

$$I_{hor} = \frac{I(0) cos^{m_l}(\emptyset)}{d^2} . \cos(\psi) \quad (6)$$

$$P_r = P_t . \frac{(m_l + 1)}{2\pi d^2} cos^{m_l}(\emptyset) . T_S(\psi) . g(\psi) . \cos(\psi) \quad (7)$$

$$where\ 0 \le \psi \le \psi_{con}$$

where ψ is the angle of incidence with respect to the axis normal to the receiver surface, Ts(ψ) is the filter transmission, g(ψ) and $\psi_{con}$ are the concentrator gain and FOV, respectively and d is the distance between the LED and a detector surface.

## IV. System Model

An office room of dimensions 5 m × 5 m × 3 m is assumed in the system model. The VLC link is assumed to be a line-of-sight (LOS) diffuse link. It is assumed that the LED arrays are installed at a height of 2.7m from the surface of the floor, the receiver placement is at the height of 0.85m. Therefore, the distance from the LED arrays to the receiving plane is 1.85m as shown in the model given below.

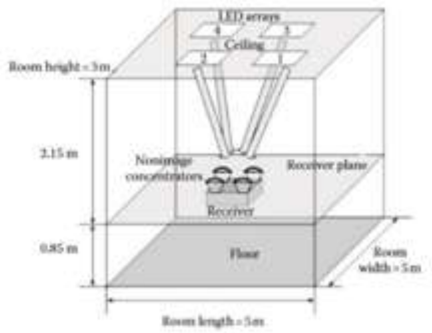


Fig. 5 VLC MIMO system [2]

Simulation of two cases: 1) one-transmitter case 2) four-transmitter case. Each array is composed of one LED. In the one-transmitter case, the transmitter is placed at the center (2.5, 2.5, 3). In the four-transmitter case, the positions of transmitters are assumed to be (1.25,1.25, 3), (1.25, 3.75, 3), (3.75, 1.25, 3), and (3.75, 3.75, 3). Assumptions made for the simulations are 1) Sun light and other ambient lighting are assumed to be negligible with an appropriate optical filtering and indoor environment. 2) Shadowing is reduced by use of multiple light sources to disrupt the communication in this system. 3) The Luminous intensity at the center of each LED is set at 410cd. 4) The physical area of the photodiode detector is assumed to be $1cm^2$, taken from a commercial photodiode (FDS1010, ThorLabs) its bandwidth is 8 MHz and receiver field of view is 50°. In this case the LED arrays with a circular emission cross-section with semi-angle at half power of 30° is considered. Several commercial LEDs have a value of around 30°. The VLC system does not focus on maintaining a high directivity, due to the current limitations in LED modulation.MATLAB is used to program and simulate the system model.

TABLE I
TABLE SYSTEM PARAMETER FOR ANALYSIS [2]

| | Parameters | Values |
|---|---|---|
| Room | Size | $5 \times 5 \times 3\ m^3$ |
| | **Parameters** | **Values** |
| Room | Reflection coefficient | 0.8 |

| | | |
|---|---|---|
| Source | Location (4 LEDs) | (1.25, 1.25, 3), (1.25, 3.75, 3), (3.75, 1.25, 3), (3.75, 3.75, 3)m |
| | Location (1 LEDs) | (2.5, 2.5, 3)m |
| | Semi-angle at half power Full-Width Half-Maximum (FWHM) | $70^0$, $12.5^0$ |
| | Transmitted power (per LED) | 20 mW |
| | Number of LEDs per array | 60 × 60 (3600) |
| | Centre luminous intensity | 300–910 lx |
| Receiver | Height of Receiver plane above the floor | 0.85 m |
| | Active area (AR) | 1 $cm^2$ |
| | Half-angle FOV | $60^0$ |
| | Elevation | $90^0$ |
| | Azimuth | $0^0$ |

## V. Results

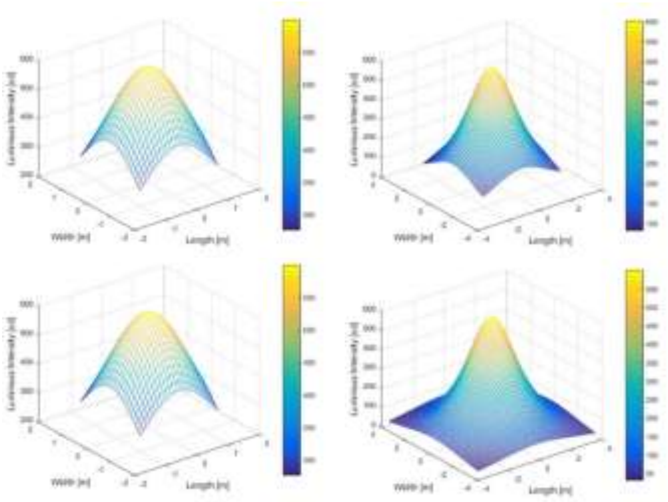

Fig.6 Luminous Intensity of the 4 LED arrays

Simulation of distributed LED arrays (or multisource) for indoor application. Each single LED array can be viewed as a point light source. Therefore, for each LED array can be viewed as a function of the solid angle in the three-dimensional space with a well-defined radiation foot print.

From the above figure it is observed that when Full-Width Half-Maximum (FWHM) is $70^o$ footprint of each array gets overlapped with the footprint of neighboring LED array. It will

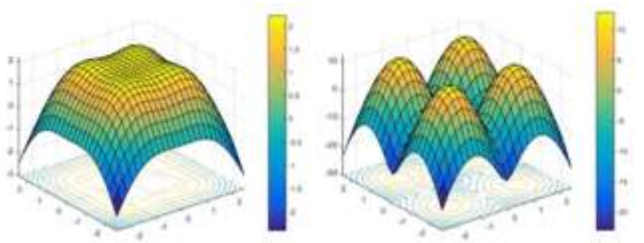

Fig. 7 Optical power distribution in received optical plane for a FWHM of (a) 70° and (b) 12.5°

be helpful when the objective is to cover the entire room, but it causes ISI. When same data is transmitted over different array layout average gain increases. When FWHM is $12.5^o$footprint of each array shrinks and is confined over particular area, in this area detectors are placed, so maximum power can be received. As the footprint are confined and doesn't overlap with neighboring one, ISI gets reduced and gain increases for that particular area.

## VI. Conclusion

In this paper, we have simulated andanalyzedthe performance of VLC system with spatial diversity-MIMO technique in a LOS environment. The simulation for a typical room using multiple LED arrays which ensures sufficient illumination and favorable optical power distribution is achieved. Luminous intensity for the individual LED array is obtained which provides a well-defined radiation foot print for the particular detector. Thus the change in room coverage for illumination is observed with change in field of view. For the same parameters such as channel gain and power distribution are simulated for different field of view. Therefore during system implementation a tradeoff must be made between room coverage and gain with reduced ISI.

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