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Coverage Area Control Approach using Dimming Factor of LED Transmitter in Light Fidelity (Li-Fi)

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Abstract

In indoor Light Fidelity (Li-Fi) system the position of transmitter and receiver bring different impact on coverage area. Due to Line of sight (LOS) characteristics of Li-Fi, coverage area of a light emitting diode (LED) transmitter plays a vital role for efficient reception of data. In this paper we considered the case when 1 optical receiver can simultaneously receive signal of 2 LED transmitters and present an optimal solution of controlling coverage area of LED transmitter using dimming factor. This paper focuses on efficient reception of data by controlling coverage area of multiple LED transmitters. The performance of proposed dimming factor approach is evaluated by using different dimming based modulation schemes.

Keywords: *Li-Fi, VLC, coverage area, indoor positioning system, dimming control, LED*

1. Introduction

In Indoor wireless communication system, Visible light communication (VLC) is one of the most fundamental part of Optical wireless communications (OWC). Indoor VLC draws attention in recent years because of the use of solid state semiconductor lighting technology. The characteristics of low power consumption, small size, long service time and faster response time make Light Emitting Diode (LED) suitable for both indoor lighting and high speed optical communication system. Li-Fi which is an emerging branch of VLC takes it further by establishing fully networked optical wireless systems and it is a continuation of trend to move toward higher frequency spectrum for 5G networks. Li-Fi technology uses 300 THz optical spectrum for wireless communications. Li-Fi system is a bi-directional multiuser communication system and it could be classified as nanometer-wave communication system and one of the future 5G wireless communication technology [1]. Li-Fi based communication system is different from VLC system [1] because VLC is only a point to point communication system while Li-Fi is a proper wireless based networking system which supports point to multipoint communication. In Li-Fi system, signals are transmitted through a light emitting diode (LED) in the form of optical power.

Over the year many researchers have been focused on different indoor positioning system (IPS) based on light Emitting Diode(LED) bulbs called Light positioning system (LPS).Different researchers gave their model with different scenarios based on different modulation schemes while taking into account parameters like Received Power and throughput. Some of the IPS are based on assumptions such as alignment between transmitter and receiver with respect to ceiling, information regarding the coordinates of transmitter and receiver and complete knowledge of height of transmitter. In [2]–[5] researchers assumed that the height of the receiver must be known and both transmitter and receiver axes are assumed to be aligned and normal to the ceiling. In [6] researchers proposed an IPS model by considering an assumption that the complete knowledge of the attenuation model must be available in advance at the receiver. Similarly In [7-8]

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researchers assume that the vertical distance between the ceiling and the receiver is known. Several algorithms are proposed to calculate the receiver coordinates. In [9] received signal strength(RSS) information is detected at Photo detector (PD). Attenuation of power is used as a parameter to find the distance between transmitter and receiver and coordinates of receiver are calculated using lateration algorithm. In past many researchers had given many assumptions for an efficient indoor IPS but still there is a significant issue in controlling the coverage area of a LED transmitter. In multiple LED transmitter case there is always a possibility of overlapping of coverage area which can affect the data transmission therefore in this paper we considered a new approach to control coverage area of a LED transmitter by using dimming factor.

Li-Fi system can provide both illumination and communication services simultaneously therefore Dimming control is a significant issues. Dimming control in an important feature for Li-Fi system because by using it we can increase the energy efficiency of a system by controlling the average brightness level of light source. Digital modulation technique is one of the areas that VLC and Li-Fi have in common [11]. For VLC various modulation schemes have been proposed by researchers to control dimming and flicker mitigation. ON OFF keying (OOK) modulation [10] sends binary data via ON/OFF pulses and dimming is controlled through the ratio of ONs to OFFs. OOK modulation is used in the dimming of Li-Fi systems due to its simplicity. Recent research has focused on the development of a dimming support function for Li-Fi by using pulse modulation schemes. A most common pulse modulation scheme is Pulse width modulation (PMW) [10] in which data is represents by pulse width. Pulse width depends on the data to be sent therefore the average power at the transmitter will fluctuate as a result this modulation can also cause a dimming effect on Li-Fi system. PMW has better bandwidth efficiency than OOK. Another most common dimming based modulation scheme is Pulse position modulation (PPM) [11]. In this modulation technique, the data is represented on the pulse position where the pulse width is fixed. Data can be modulated by varying the pulse position.

In this paper we give our indoor LPS model. We will consider some important scenarios by considering coverage area of LED based transmitter. In these scenarios we will also discuss and overcome the conflict of interconnectivity of optical receiver with 2 LED based transmitter at a time. This paper also consists of analysis of dimming based modulation technique suitable for our model with best performance in terms of Spectral Efficiency, Bit Error Rate (BER) and received power. In section II indoor positioning model is discussed then section III has different dimming based modulation schemes for LPS model. Section IV is about performance evaluation of modulation schemes for our model and followed by conclusion.

2. Indoor Light Positioning System

Our model is Composed of 2 LED lights bulbs of 15 Watt each separated by a distance of 1.2 m as shown in Figure 1.

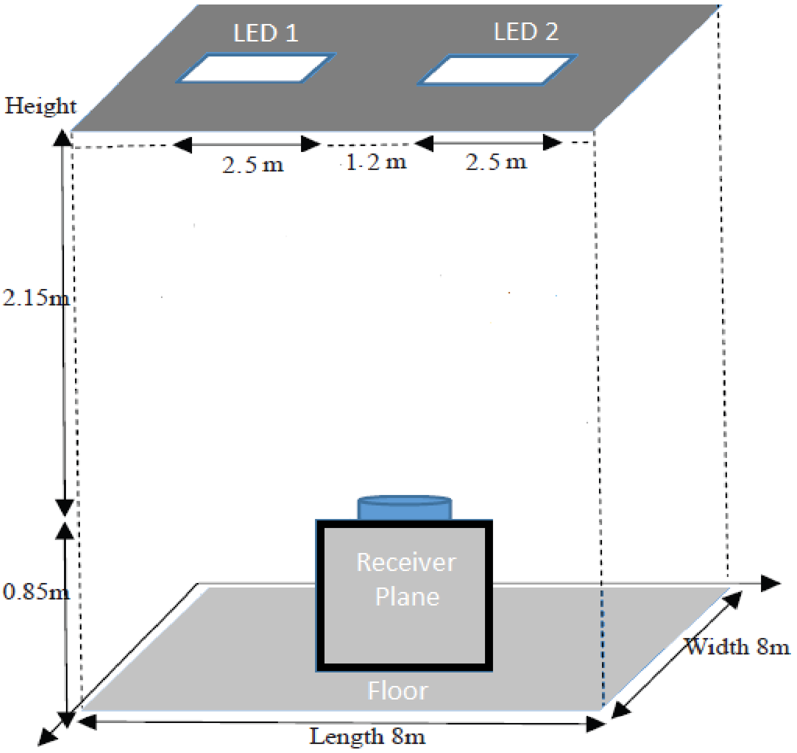

Figure 1. Li-Fi based Indoor Communication Model for 2 LED Transmitters

As LED bulb is used as dual purpose for illumination and communication therefore we have to calculate the luminous flux which is the transmitted power of an LED transmitter. To calculate the luminous flux LED's spatial emission properties are considered by using luminous intensity $g_t(\theta)$ and axial intensity I_o. Luminous intensity measures the brightness of LED in the specific direction. Axial intensity is luminous intensity at 0° solid angle. Another important parameter to be considered is half beam angle (θ_h) which is half of the axial intensity. Half beam angle is calculated from entire beam angle which is given as

$$\Omega_e = 2\pi(1 - \cos\theta_h) \tag{1}$$

So the luminous flux (L_f) of transmitter LED can be calculated by integrating luminous intensity function over the entire beam solid angle.

$$L_f = \int_0^{\Omega_e} I_o g_t(\theta) d\Omega \tag{2}$$

Most LEDs have Lambertian beam distribution therefore luminous intensity distribution is a cosine function.

$$g_t(\theta) = \cos^m(\theta) \tag{3}$$

Where m is the order of Lambertian emission. The value of n depends on semi angle at half luminance $\Phi_{1/2}$.

$$m = \frac{\ln\left(\frac{1}{2}\right)}{\ln\left(cos\left(\Phi_{\frac{1}{2}}\right)\right)} \tag{4}$$

The DC channel path gain from LED transmitter to receiver is

$$H(0) = \frac{m+1}{2\pi d^2} Acos(\alpha)cos^m(\beta)T(\alpha)g(\alpha) \quad , \quad 0 \le \alpha \le \alpha_c \tag{5}$$

$$H(0) = 0 \quad , \quad \alpha > \alpha_c$$

Where A is physical area of PD (Photo detector), α is incident angle, β is irradiance angle, d is the distance between transmitter and receiver, $T(\alpha)$ is gain of optical filter, α_c is FOV (field of vision) at receiver and $g(\alpha)$ is the optical concentrator which can be represented as

$$g(\alpha) = \frac{n^2}{sin^2\alpha_c} \quad , \quad 0 \leq \alpha \leq \alpha_c \tag{6}$$

$$g(\alpha) = 0 \quad , \quad \alpha > \alpha_c$$

Where n is the refractive index.

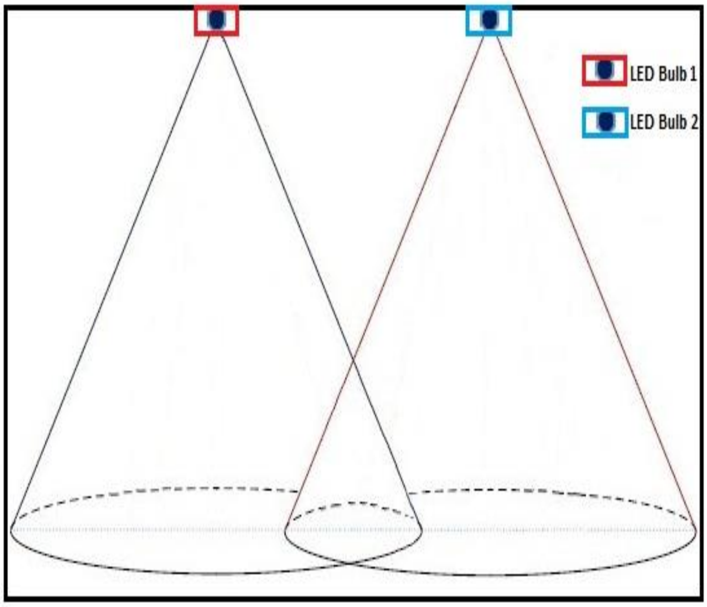

Figure 2. Coverage Area of LED based Transmitters

So received power P_r at receiver can be represented in terms of power transmitted P_t

$$P_r = H(0)P_t \tag{7}$$

The received power depends on three factors *i.e.*, incident angle (α), irradiance angle (β) and the distance between transmitter and receiver (d).In VLC system if we represent the optical transmitted signal from transmitter by x(t) then brightness of light is depending upon LED lighting's dimming factor γ which ranges from 0 to 1 and the average optical power P_{avg}. For our model we handle the coverage area by controlling the brightness level. We have considered some cases which is consists of some practical scenarios in Li-Fi system.

2.1. Case A

In our model, Case A represents a scenario when the brightness level of LED bulb is 50% that means γ = 0.5. Figure 3 represent the coverage area of a LED bulb and receiver placement. In Case A we have considered 2 optical receivers which receives the signal transmitted from a single LED bulb.

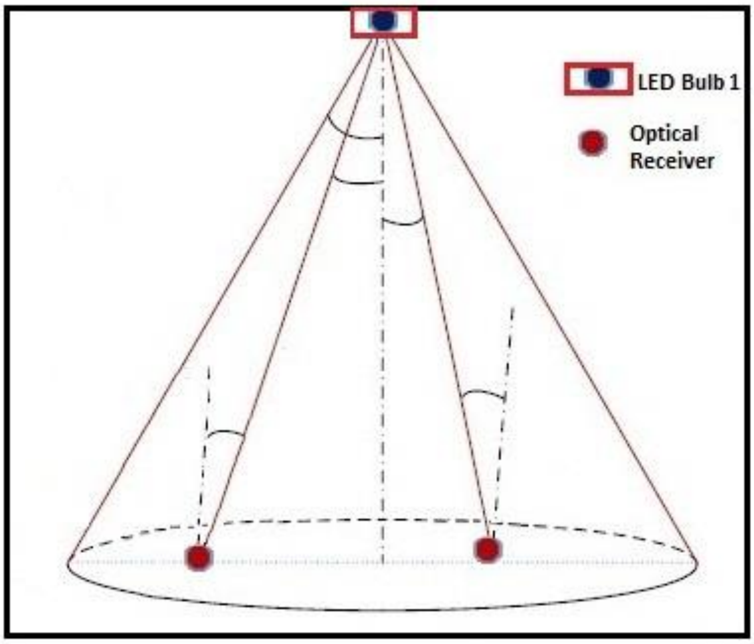

Figure 3. Case A: Coverage Area of a LED Transmitter

2.2. Case B

In our model, Case B represents a scenario when a single optical receiver is placed at a point where it can receive signal transmitted from 2 LED bulbs. Figure 4 represents the coverage area of both LED bulbs and its impact on optical receiver. The value of dimming factor of both LED bulbs is 0.6 that is the brightness level of LED bulb is 60%. As in Figure 4 optical receiver can receive the signal of both LED source bulbs so to avoid interference and have a proper and efficient data reception at optical receiver we give the solution of adjustment of brightness level of LED bulbs.

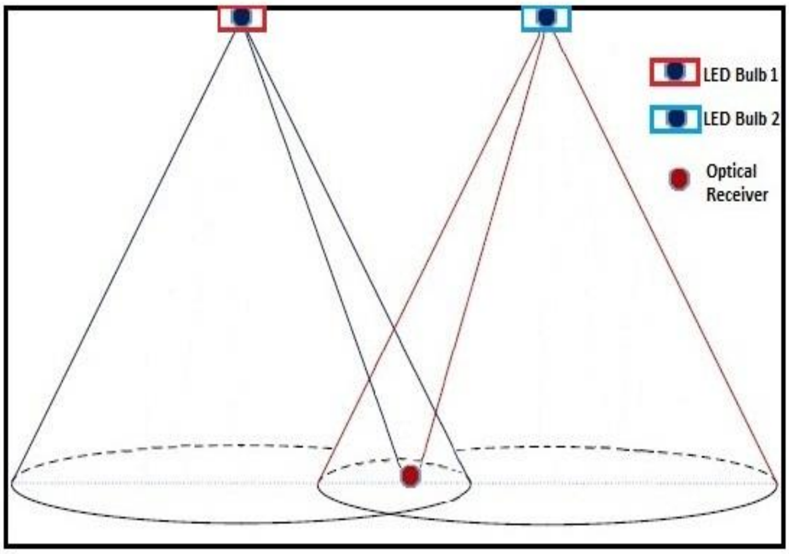

Figure 4. Case B: Receiver is Located in between the Coverage Area of 2 LED transmitters

For Case B the brightness of LED bulb 1 is adjusted to its 50 % (γ = 0.5) and brightness of LED bulb 2 is adjusted to its 70 % (γ = 0.7). As a result of this adjustment as shown in Figure 5 optical receiver can only receive the signal of LED bulb 2 which has dimming factor value of 0.7.

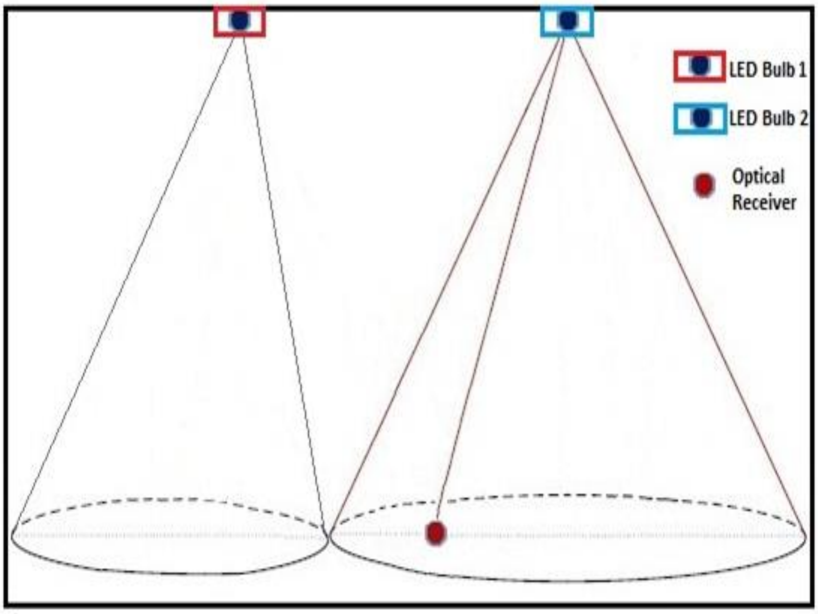

Figure 5. Dimming based Solution to Control Coverage Area

3. Dimming based modulation Schemes for VLC Model

Some of the dimming based modulation schemes are given below:

3.1. Variable On–Off Keying (VOOK)

In VOOK modulation, 1 bit is specifying by transmitting a rectangular pulse of time duration T and no pulse is transmitted to specify 0 bit. Dimming is achieved by using filler bits [12]. These filler bits are used to fill up the portions which do not contain data. The brightness is controlled by varying the data duty cycle δ_{ddc}

$$\delta_{ddc} = \tau_d / T \tag{8}$$

Where T represents the duration of pulse and τ_d represents the time duration when data pulse is ON.

The transmitted signal containing bit information ’1’ for VOOK is represent as

$$x_{VOOK}(t)\text{=}2\, P_{avg}\, rect(\tfrac{t}{T}) \tag{9}$$

The transmitted signal containing bit information ‘0’ for VOOK is represent as

$$x_{VOOK}(t)\text{=}0 \tag{10}$$

In VOOK, no information is transmitted when duty cycle δ is 1 and 0.

The LED lighting’s dimming factor for VOOK is represent as

$$\gamma_{VOOK}\text{=}\begin{cases} \frac{1}{2}\delta_{ddc} & 0 < \gamma \le 0.5 \\ 1 - \frac{1}{2}\delta_{ddc} & 0.5 \le \gamma < 1 \end{cases} \tag{11}$$

3.2. Variable Pulse Position Modulation (VPPM)

In VPPM modulation information is transmitted by varying the position of pulse within the symbol interval and pulse width is used to control the brightness level of transmitter. VPPM is a combination of PMW and PPM schemes in which only a single bit of information is transmitted per symbol period [13].

The transmitted signal containing bit information '1' for VPPM is represent as

$$x_{VPPM}(t)= P_{VPPM}\ rect\left[\frac{t-(1-\gamma)}{\gamma T}\right] \tag{12}$$

The transmitted signal containing bit information '0' for VPPM is represent as

$$x_{VPPM}(t)= P_{VPPM}\ rect\left[\frac{t}{\gamma T}\right] \tag{13}$$

Whereas $P_{VPPM}$is the instantaneous power. At full brightness (γ =1) no information can be transmitted. When the duty cycle is 50 % ($\delta = 0.5$), VPPM becomes the same as 2-PPM. The data duty cycle is same in VPPM as duty cycle ($\delta_{ddc} = \delta$).

So the LED lighting's dimming factor for VPPM is represent as

$$\gamma_{Vppm} = \delta \tag{14}$$

3.3. Multiple Pulse Position Modulation (MPPM)

In MPPM multiple optical pulses can be transmitted in any chip, instead of transmitting a single optical pulse per frame, several pulses are allowed for transmission in order to increase their combinations per frame. Each unique combination of pulses within a symbol period is represented by a code word which represent a symbol [12]. Modulated signal of MPPM is characterized by two values, the number of chips per symbol and the weight of code words [15]. The weight is equivalent to the sum of ones in a code word. Dimming factor is defined as

$$\gamma_{MPPM} = \frac{\omega}{\omega_{max}} \tag{15}$$

Where ω represents the number of optical pulses and ω_{max} represents total number of dimming levels.

Dimming is achieved by varying the optical pulses to generate a code word and weight of the code word can be used to control dimming function. Bandwidth reduction achieved by MPPM is a function in number of optical pulses per frame.

3.4. Overlapping Pulse Position Modulation (OPPM)

OPPM allows multiple positions per pulse width and modulation indices can overlap between adjacent pulse-positions [16]. In other words, each symbol of time duration T is divided into n chips. Each chip has duration of T/n and rectangular pulse consists of w chips is transmitted. In OPPM code word have a weight w where w is the number of ones in a code word and also be constrained to be consecutive. In such a case (n, w) = L code words will exist, OPPM will function as a dimming scheme because w is adjustable and the maximum illumination percentage can be represents as w/n. A larger number of chips increase the extent and resolution of the dimming. OPPM signal has a basic dimming range from 0% to 1/Q where Q is the number of non-overlapping pulse position within the symbol interval. In OPPM dimming control is achieved by using pulse intensity via signal amplitude. A particular dimming level is realized with combination of time sharing of different intensity which minimizes the flickering effects.

4. Performance Evaluation of Dimming Schemes with Respect to Proposed Architecture

The system parameter for simulation is given in Table 1.

Table 1. Li-Fi Indoor Communication System Parameters

Rx effective area, $Ar = 10^{-4}\ m^2$	Distance between 2 Tx, d = 1.2 m
Semi angle at half power of an LED, $\Phi 1/2 = 60^0$	Height between Tx and Rx, $h1 = 2.15$ m
Refractive index, n = 1.5	Transmitted power, $Pt = 100$ mW
Field of view, $\psi = 70^0$	Error probability, $Pe = 10^{-6}$
Room height, h =3 m	Room area, A = $96\ m^2$

The performance of case A and case B of proposed architecture will be evaluated by considering BER and spectral efficiency of different dimming based modulation schemes.

4.1. Bit Error Rate (BER)

BER can be approximately estimated as [12]

$$\mathrm{BER} \approx Q\left[\frac{d_{E\,min}}{2\sigma}\right] \tag{15}$$

Where Q is a quality function, σ represents noise variance and $d_{E\,min}$ represents Euclidean minimum distance between pair of valid signals

For VOOK modulation Euclidean minimum distance can be represent as

$$d_{E\,min}{}^{VOOK} = \begin{cases} P_{avg\_VOOK}\sqrt{\frac{2\gamma}{R_b}} & 0 < \gamma \le 0.5 \\ P_{avg\_VOOK}\sqrt{\frac{2(1-\gamma)}{R_b}} & 0.5 \le \gamma < 1 \end{cases} \tag{16}$$

Here P_{avg_VOOK} is the average power for VOOK and $R_b$represents bit rate.

For VPPM Euclidean minimum distance can be represent as [12]

$$d_{E\,min}{}^{VPPM} = \begin{cases} P_{avg\_VPPM}\sqrt{\frac{2\gamma}{R_b}} & 0 < \gamma \le 0.5 \\ P_{avg\_VPPM}\sqrt{\frac{2(1-\gamma)}{R_b}} & 0.5 \le \gamma < 1 \end{cases} \tag{17}$$

For Euclidean minimum distance for MPPM and OPPM can be represent as

$$d_{E\,min}{}^{MPPM} = \left(\frac{P_{avg\_MPPM}}{\omega}\right)\sqrt{\frac{2n\log_2\binom{n}{\omega}}{R_b}} \qquad \frac{1}{n} < \gamma \le \frac{n-1}{n} \tag{18}$$

$$d_{E\,min}{}^{OPPM} = \left(\frac{P_{avg\_OPPM}}{\omega}\right)\sqrt{\frac{2(n|\omega)\log_2(n-\omega+1)}{R_b}} \qquad \frac{1}{n} < \gamma \le \frac{n-1}{n} \tag{19}$$

By substituting equation [16] in to equation [15] we get average power for VOOK which is equal to

$$P_{avg\_VOOK} = \begin{cases} \sqrt{\frac{2R_bNo}{\gamma}}\; Q^{-1}(BER) & 0 < \gamma \leq 0.5 \\ \sqrt{\frac{2R_bNo}{1-\gamma}}\; Q^{-1}(BER) & 0.5 \leq \gamma < 1 \end{cases} \tag{20}$$

Similarly by substituting equation [17] in to equation [15] we can calculate average power for VPPM which is equal to

$$P_{avg\_VPPM} = \begin{cases} \sqrt{\frac{2R_bNo}{\gamma}}\; Q^{-1}(BER) & 0 < \gamma \leq 0.5 \\ \sqrt{\frac{2R_bNo}{1-\gamma}}\; Q^{-1}(BER) & 0.5 \leq \gamma < 1 \end{cases} \tag{21}$$

Similarly the average power for MPPM and OPPM is equal to

$$P_{avg\_MPPM} = \sqrt{\frac{2\omega R_bNo}{n\log_2\binom{n}{\omega}}}\; Q^{-1}(BER) \qquad \frac{1}{n} < \gamma \leq \frac{n-1}{n} \tag{22}$$

$$P_{avg\_OPPM} = \sqrt{\frac{2\omega R_bNo}{\binom{n}{\omega}\log_2(n-\omega+1)}}\; Q^{-1}(BER) \qquad \frac{1}{n} < \gamma \leq \frac{n-1}{n} \tag{23}$$

Table 2. BER for Dimming based Modulation Schemes

Modulation scheme	Bit Error Rate (BER)
$VOOK$	$\begin{cases} Q\left(P_{avg\_VOOK}\sqrt{\frac{\gamma}{2R_bNo}}\right) & 0 < \gamma \leq 0.5 \\ Q\left(P_{avg\_VOOK}\sqrt{\frac{1-\gamma}{2R_bNo}}\right) & 0.5 \leq \gamma < 1 \end{cases}$
$VPPM$	$\begin{cases} Q\left(P_{avg\_VPPM}\sqrt{\frac{\gamma}{2R_bNo}}\right) & 0 < \gamma \leq 0.5 \\ Q\left(P_{avg\_VPPM}\sqrt{\frac{1-\gamma}{2R_bNo}}\right) & 0.5 \leq \gamma < 1 \end{cases}$
$MPPM$	$Q\left(P_{avg\_MPPM}\sqrt{\frac{n\log_2\binom{n}{\omega}}{2\omega R_bNo}}\right) \qquad \frac{1}{n} < \gamma \leq \frac{n-1}{n}$
$OPPM$	$Q\left(P_{avg\_OPPM}\sqrt{\frac{\binom{n}{\omega}\log_2(n-\omega+1)}{2\omega R_bNo}}\right) \qquad \frac{1}{n} < \gamma \leq \frac{n-1}{n}$

4.1.1. For Case A

In case A brightness level of LED bulb is 50%. Figure 6 represents average power with respect to dimming factor. As in case A MPPM gives best performance at dimming factor

0.5 while VOOK requires low average power to achieve the same BER as compared to OPPM and VPPM at dimming level $\gamma = 0.5$. For OPPM the power required increases as the dimming factor increases as shown in Figure 6.

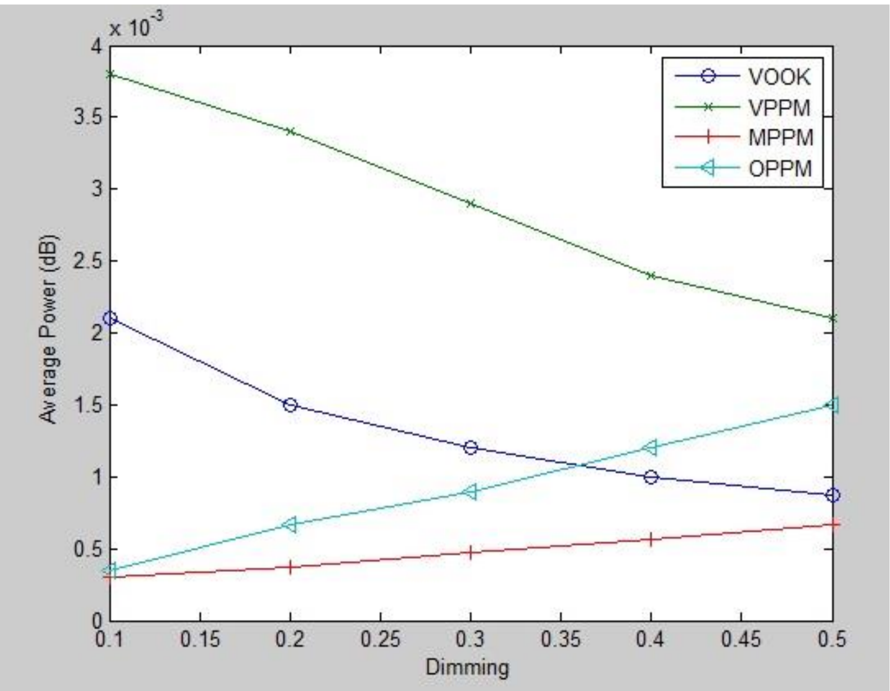

Figure 6. Average Power of Modulation Schemes according to Dimming Factor for Case A

4.1.2. For Case B

In case B brightness level of LED bulb is 70%. Figure 7 represents average power with respect to dimming factor. As in case A MPPM gives best performance at dimming factor 0.7 while VOOK requires low average power to achieve the same BER as compared to OPPM and VPPM at dimming level $\gamma = 0.7$. VPPM and OPPM power required keep on increasing as the dimming factor increases because they sends consecutive pulses, draw a large ascending curve and requires greater power as shown in Figure 7.

4.2. Spectral Efficiency

Spectral efficiency is a ratio between bit rate R_b and required bandwidth B .This parameter can give us an idea how efficiently a modulation scheme utilize the spectrum bandwidth.

For VOOK:

$$V=\begin{cases} 2\gamma & 0 < \gamma \leq 0.5 \\ 2(1-\gamma) & 0.5 \leq \gamma < 1 \end{cases} \tag{24}$$

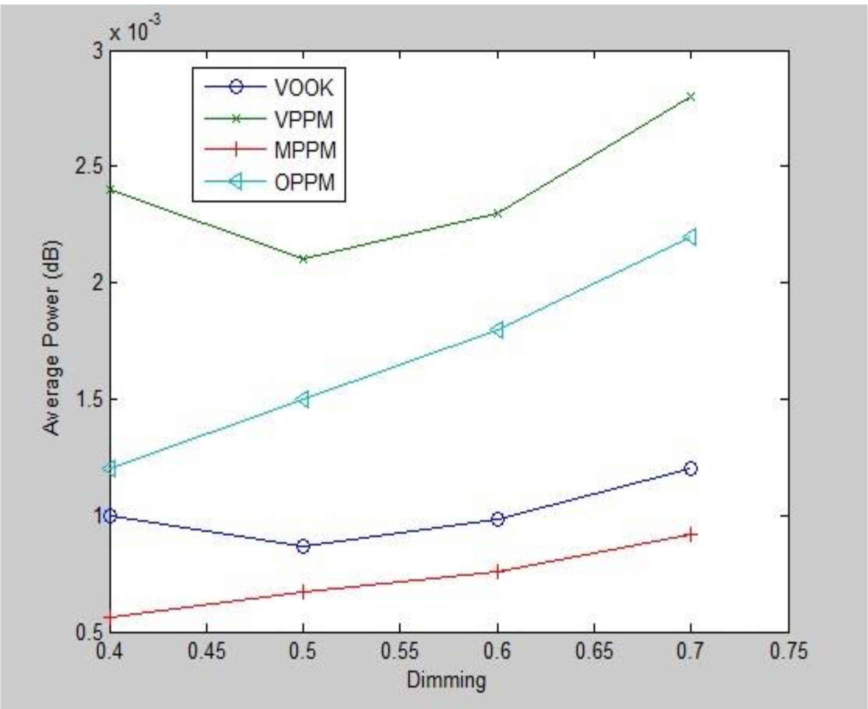

Figure 7. Average Power of Modulation Schemes according to Dimming Factor for Case B

For VPPM:

$$V=\begin{cases} \gamma & 0<\gamma\le 0.5 \\ (1-\gamma) & 0.5\le\gamma<1 \end{cases} \tag{25}$$

For MPPM:

$$V=\frac{\log_2\binom{n}{\omega}}{n} \qquad \frac{1}{n}<\gamma\le\frac{n-1}{n} \tag{26}$$

For OPPM:

$$V=\frac{\log_2(n-\omega+1)}{n/\omega} \qquad \frac{1}{n}<\gamma\le\frac{n-1}{n} \tag{27}$$

4.2.1. For Case A

In case A Figure 8 represents spectral efficiency of dimming based modulation schemes with respect to dimming factor. As for case A OPPM have the highest spectral efficiency at dimming factor 0.5 while VPPM shows lowest spectral efficiency as compare to other modulation schemes. MPPM has a better spectral efficiency as compare to VOOK initially but VOOK has better performance as compared to MPPM at dimming level $\gamma = 0.5$ as shown in figure.

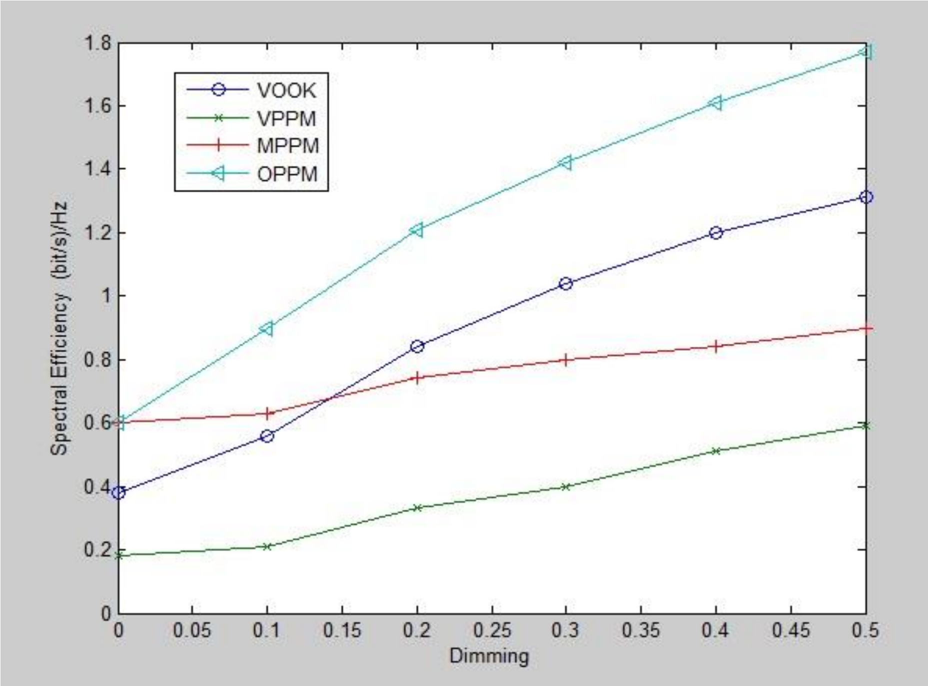

Figure 8. Case A. Spectral Efficiency of Modulation Schemes

4.2.2. For Case B

In case B Figure 9 represents spectral efficiency of dimming based modulation schemes with respect to dimming factor. As for case B at dimming factor = 0.7 OPPM have the highest spectral efficiency while VPPM shows lowest spectral efficiency as compare to other modulation schemes .After $\gamma = 0.5$ VOOK, VPPM and MPPM spectral efficiency keep on decreasing while OPPM spectral efficiency of OPPM starts to decrease after $\gamma = 0.6$ as shown in Figure 9.

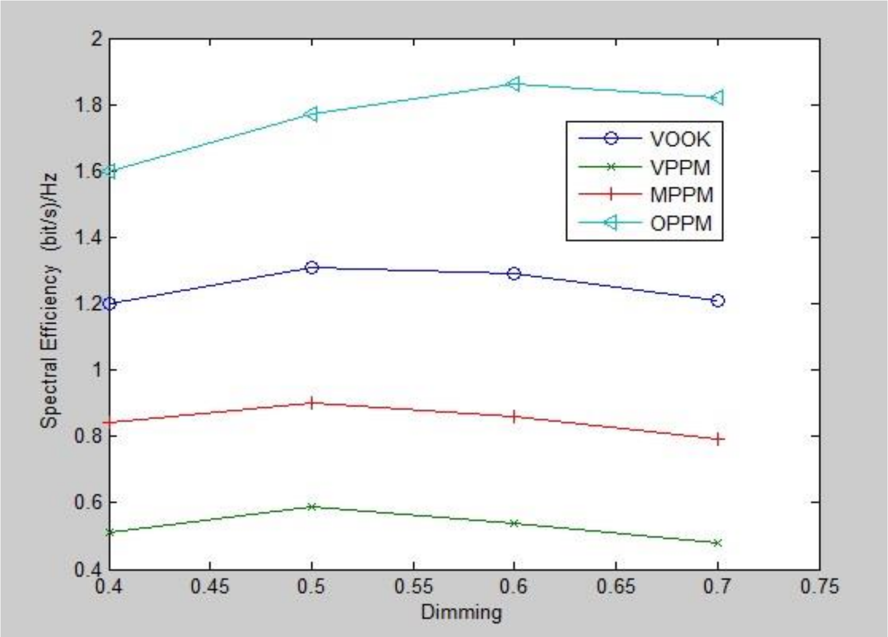

Figure 9. Case A. Spectral Efficiency of Modulation Schemes

5. Conclusion

Coverage area control approach using diming factor is a new approach in which LED transmitter area of coverage is manage according to the placement of PD by using dimming control. We can analyzed a Li-Fi based indoor system by simulating spectral efficiency and power requirement of the modulation schemes by using dimming factor to control the coverage area of a LED transmitter. The results show that in both case A and case B MPPM require less average power to achieve a desire BER and VPPM requires up to two times the power of the other modulations. In terms of spectral efficiency, OPPM has the highest spectral efficiency. MPPM shows a better spectral efficiency as compare to VPPM. Finally through this result, it is confirmed that by using dimming control we can control the coverage area and it can also be identify which modulation scheme will give better and worst performance in our proposed cases for indoor Li-Fi based indoor communication system.

In our future work we will expand our LPS model by increasing number of LED based transmitter. As in our this paper we had considered only the static optical receiver but in future we will discuss the scenario of considering an optical receiver which is moveable and can switch from one coverage area to another. We will discuss and analyze the transmitter handover case when optical receiver will move from one transmitter coverage area to another and its effect on performance of LPS.

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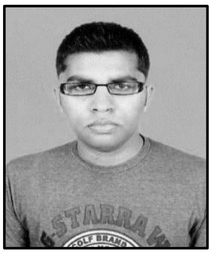
Author



Farooq Aftab received his BS Telecommunication Engineering degree in 2013 from Foundation University, Islamabad, Pakistan. Currently he is pursuing master degree in Information and Communication Engineering from University of Science and Technology Beijing, China. His research area is Mobile Ad Hoc network (Manets) and Light fidelity (Li-Fi).