Global Scientific JOURNALS

GSJ: Volume 8, Issue 7, July 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

The Impact of Layout Shape and Inter-Symbol Interference (ISI) on the Performance of Light Sources Arrangement for Indoor Visible Light Communication

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The impact of layout shape on the performance of light source arrangement is presented in this paper. Unlike what obtains in the literature that a particular layout is used to measure the performance of a proposed light source arrangement, this study examines the performance of a proposed LED (light emitting diode) arrangement using simulations in two different layouts, a square and a rectangular layout. The same number of LED chips were used in the two layouts considered, placing them a distance of 1m apart on the ceilings of the layouts. Simulation results based on received power and SNR (signal to noise ratio) distributions show that the proposed LED arrangement yields better results compared to the commonly used four LED arrays centered on a ceiling of a square layout that was adopted by many studies in the literatures. Although the rectangular layout has better received power and SNR distributions, but fluctuations are more severe in both indices compared to that of a square layout. The results indicate that a layout shape has influence on the performance of a light source arrangement and therefore should be given considerable attention for an indoor visible light communication system. The impact of ISI was also analyzed in the proposed models and found out that in all the cases were this metric was included in the analysis, the maximum value became more spread than the cases where it was not included and hence reduce fluctuations. However, its impact is more noticeable in the rectangular layout.

Keywords: Arrangement, Impact, Layout, Performance and Visible Light Communication.

1. INTRODUCTION

The advances made in solid-state lighting technology in the past few years ignited a growing research in visible light communication (VLC) that can be used as a complement to radio frequency (RF)-based mobile communication [1]. VLC utilizes light emitting diodes (LED) as transmitters for communication purposes in addition to their primary function of illumination. So a robust LED arrangement is very crucial and requires careful consideration in an indoor VLC.

Over the years a common configuration of four LED arrays centered on the ceiling of a square layout has been widely adopted [2-5]. This configuration provides sufficient lighting but yields small amount of received power for communication purposes. Recently authors in [6] proposed a new light source arrangement which involves placing individual LEDs spaced at 0.5m apart as against the traditional LED arrays typically used in buildings. Although the result shows a significant improvement in terms of received power and SNR, but larger number of LEDs will exacerbate inter-symbol interference (ISI) and placing individual LEDs a distance of 0.5m apart will be tedious and labor intensive in practice, especially if the layout is larger than the 5m*5m*3m considered in the study. The result of a novel LED arrangements proposed by [7] with 12 LEDs arranged evenly in a circle and 1 LED placed at each corner of a square

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layout considered shows a considerable reduction in SNR fluctuation within the layout but the arrangement will only be applicable in a square layout.

This study proposes a new LED arrangement for indoor VLC. Unlike what is obtainable in most other studies that a particular layout is used to measure the performance of a light source arrangements, this paper examines the impact of change in layout shape on the proposed LED arrangements. Two layout shapes were considered in the study, a square and a rectangular layout of equal sizes. To be fair to the whole analysis, the same number of LED chips was used in the two layouts considered as in the commonly used four LED arrays. Simulation results based on received power and SNR distributions show that the proposed LED arrangements in both the layouts yield better result compared to that of the four LED arrays centered on a ceiling of a square layout. Even though the rectangular layout has better results, but fluctuations are more pronounced compared to the results obtained from the square layout.

The rest of the paper is organized as follows: Section 2 dealt with the principles and parameters of channel modelling, received power and SNR distributions in indoor VLC, in addition to the system performance under the four LED arrays light source arrangements. The proposed new LED arrangement is described in section 3, followed by a comparison between the two layouts' performances in terms of received power and SNR distributions. The conclusions are given in section 4.

2. RECEIVED POWER AND SNR

In any communication system an appreciable level of received power is paramount, this is usually accompanied by a punishment of interference or high power consumption. There are a number of ways to increase received power, which includes, increasing the number of LEDs or transmitted power. Other ways used in VLC to increase received power are adjustments in LED placement and decreasing the receiver field of view (FOV). Received power is calculated from the channel DC gain of the directed path and that of the diffuse paths as shown in Figure 1.

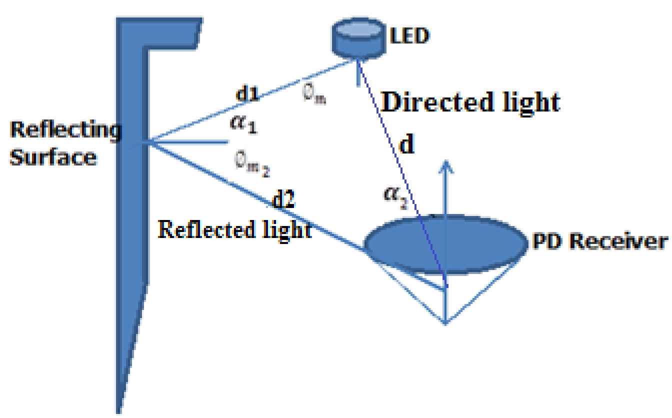


Figure 1 Propagation with first reflection in VLC system

2.1 Received Power of Directed Light

In an optical wireless communication channel, the DC channel gain due to directed light propagation or line-of-sight (LoS) as presented in [8,9] is as follows:

$$H(0) = \left[\frac{(m+1)A}{2\pi d^2}\right].\cos^m(\varphi).T_f(\alpha).g(\alpha).\cos(\alpha) \quad (1)$$

Where the incident angle φ takes the values: $0 \leq \varphi \leq FOV$. It should be noted that the gain $H(0)$ will be null when $\varphi \geq FOV$. $T_f(\alpha)$ is the transmission filter while $g(\alpha)$ is the concentrator gain. The distance between the transmitter and receiver is d and A stands for the physical area of the detector. The concentrator gain is expressed as:

$$g(\alpha) = \begin{cases} \frac{n^2}{sin^2(FOV)}, & 0 \leq \varphi \leq FOV \\ . & \\ 0, & 0 \geq FOV \end{cases} \quad (2)$$

where n is the index of refraction.

The power received P_{rlos} can be derived from the transmitted power P_t as:

$$P_{rlos} = H(0).P_t \quad (3)$$

2.2 Received Power of Reflected Light

For the diffuse signal in an optical wireless communication we adopt an integrating sphere model as described in [10].

In a particular layout or room, the first order diffuse reflection coming from an optical source has an intensity I_1 over the total surface area of the room A_r is expressed as:

$$I_1 = \rho_1 \frac{P_{TLED}}{A_r} \quad (4)$$

where ρ_1 is the surface reflectivity and P_{TLED} the total transmitted power of the LEDs.

The average reflectivity is defined as:

$$< \rho > = \frac{1}{A_r} \sum_i A_i \rho_i \quad (5)$$

where the individual reflectivities $< \rho >$ of walls and various objects in the layout are weighted against their respective areasA_i.

To obtain the total intensity, we sum up the intensities as a geometric series:

$$I = I_1 \sum_{j=1}^{\propto} < \rho >^{j-1} \quad (6)$$

Where the letter j refers to order of reflections. Therefore for first order reflection the received diffuse power $P_{dif.}$ will be given as:

$$P_{dif.} = A.I.\mathrm{T_f}(\alpha).\mathrm{g}(\alpha) \quad (7)$$

Therefore, the total power received considering the effect of diffuse reflection will be

$$P_{rx} = P_{rlos} + P_{dif.} \quad (8)$$

2.3 SNR

The quality of a communication link is determined by the strength of its SNR, higher values yield a better bit-error-rate (BER) performance. Inter-symbol interference (ISI) from optical path difference in VLC is the main factor affecting SNR. In this paper, a simple approach to analyze this factor is adopted from [11] by treating ISI as a noise added to the noise power while assuming the model as additive white Gaussian noise model. This is expressed as:

$$SNR = \frac{(\gamma P_{rxsignal})^2}{((\gamma P_{rxISI})^2 + \sigma_{noise}^2)} \quad (9)$$

Where the terms γ and σ_{noise}^2 are detector responsivity and noise variance respectively, while $P_{rxsignal}$ and P_{rxISI} refers to the optical power of signal and noise power respectively. For a multipath considering ISI the received power will be the sum of the desired signal and signal due to the ISI.

The noise variance is a combination of the shot noise variance and thermal noise variance, this is expressed in simple terms as:

$$\sigma_{noise}^2 = C_1.P_{rxsignal} + C_2 \quad (10)$$

considering the influence of ISI equation (10) will be expressed as:

$$\sigma_{noise}^2 = C_1.(P_{rxsignal} + P_{rxISI}) + C_2 \quad (11)$$

The constants C_1 and C_2 are numerical values from receiver specification, and for the sake of simplicity we adapt the values from [11]. Table 1 shows the VLC system parameters used in the simulations.

Table 1: VLC System Parameters

PARAMETERS WITH SYMBOLS	VALUES WITH UNITS
Gain $g(\alpha)$	1.0
Responsivity γ	0.54 (A/W)
Refractive index n	1.5
Bit Period T	100 (ns)
Detector Area A	1.0 (cm^2)
Noise power Constant C_1	$1.696 \times 10^{-11}(A^2/W)$
Noise power Constant C_2	$1.336 \times 10^{-13}(A^2)$

To be fair to the whole analysis the same number of LED chips were used throughout the process. For the commonly used 4 LED array, each array comprises of 60x60 chips of 20mW LEDs making a total of 3600 LED chips per array. Therefore, for the complete 4 array there are 3600 x 4 = 14,400 LED chips. Table 2 shows the model parameters for the commonly used four LED arrays scenario, while Figure 2 shows the model. LED arrays were placed on the coordinates (1.25, 1.25), (1.25, 3.75), (3.75, 1.25) and (3.75, 3.75) as shown in the Figure.

Table 2: Four LED Array Parameters

PARAMETER	VALUES
Room Size	5m x 5m ($25m^2$)
LED Power	20mW
Half-power angle	70^0
Number of LED per Array	3600 (60x60)
Total Number of LEDs	14,400 (4 x 3600)
Total Power Transmitted	288W

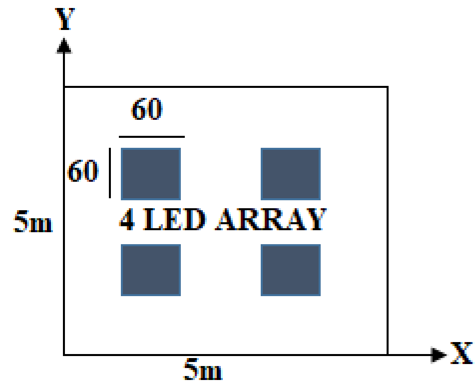


Figure 2 Four LED array model

The results of simulations for the traditional four LED array model in terms of received power distribution and SNR are presented in Figures 3 and 4 respectively. Based on the results, Figure 3 shows the received power distribution considering the directed light LoS and the first diffuse reflection ranging from about -0.8 dB to 2.8 dB. SNR distributions were presented in Figure 4 for LoS with first diffuse reflection. The result shows An SNR distribution range of about 67.6 dB to 70 dB.

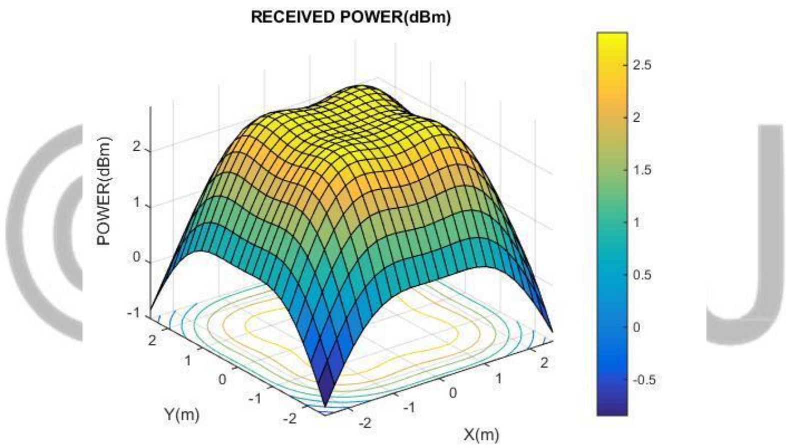


Figure 3 Received power distribution, minimum value of -0.8 dB, and maximum value of 2.8 dB and an average of 1.77 dB

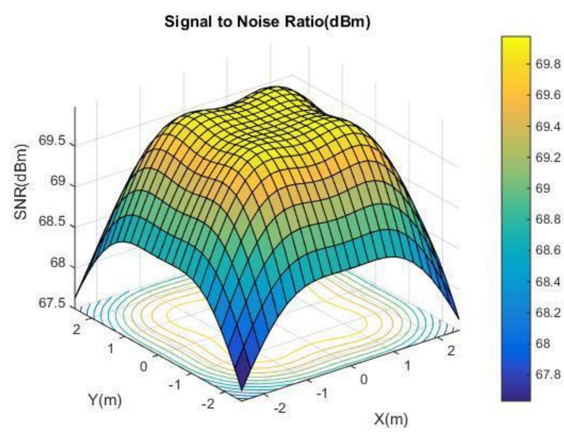


Figure 4 SNR distribution, minimum and maximum values of about 67.6 dB and 70 dB respectively and an average of 69.5 dB

A summary of the results in Figures 3 and 4 is presented in Table 3 below.

Table 3: Summary of results obtained from the four LED array model

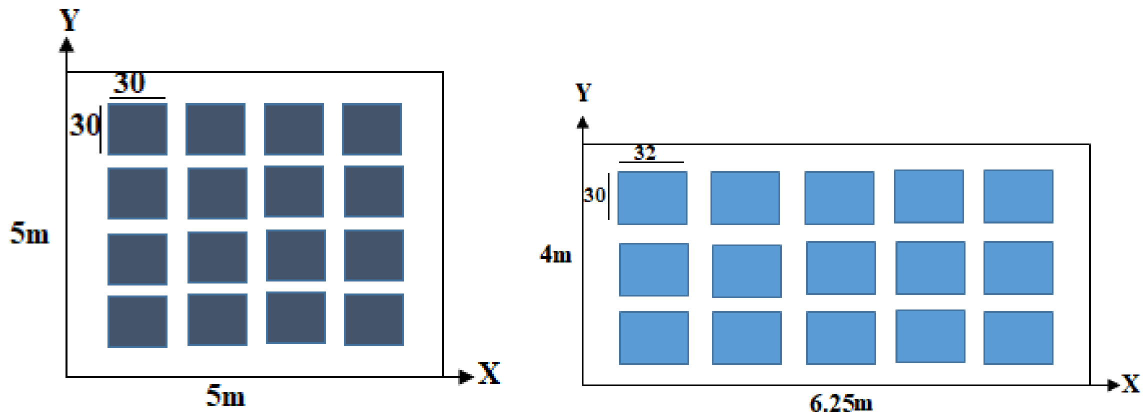
Parameter (dB)	LoS + REFLECTION
$P_{rxMax.}$	2.8123
$P_{rxMin.}$	-0.8437
P_{rxAve}	1.7688
SNR_{Max}	70.2049
SNR_{Min}	67.7520
SNR_{Ave}	69.5058

3. THE PROPOSED NEW LED ARRANGEMENT

For the commonly used 4 LED array as shown in table 2, each array comprises of 60x60 chips of 20mW LEDs making a total of 3600 LED chips per array. Therefore, for the complete 4 array there are 3600 x 4 = 14,400 LED chips. For the proposed square layout, we used 16 array of 30x30 20mW of LED chips which is the same as used in the commonly used 4 LED array, that is, 30x30x16 = 14,400. The Proposed rectangular layout employs 15 LED array of 30x32 20mW LED chips making a total of 14,400 as used in the other two scenarios. Therefore, total transmitted power of 288W is used throughout the analysis. Table 4 shows the summary of parameters used in both the square and rectangular layouts while Figure 5 (a) and (b) shows the two models. LED arrays were placed a distance of 1m apart in both models.

Table 4: Square and Rectangular LED Array Parameters

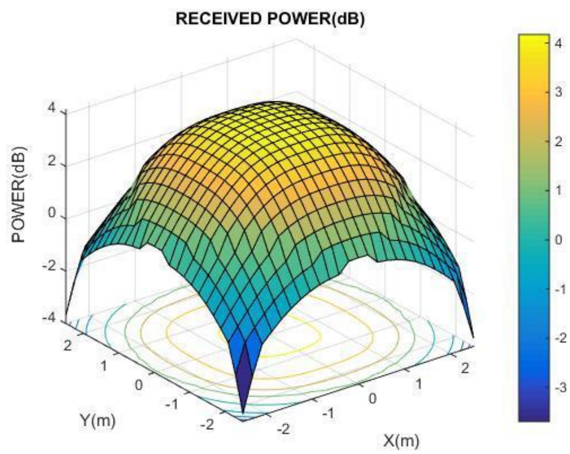
PARAMETER	VALUES	
Layout shape	Square Layout	Rectangular Layout
Room Size	5m x 5m (25m^2)	6.25m x 4m (25m^2)
LED Power	20mW	20mW
Half-power angle	70^0	70^0
Number of LED per Array	900 (30x30)	960 (32x30)
Total Number of LEDs	14,400 (16 x 900)	14,400 (15 x 960)
Total Power Transmitted	288W	288W



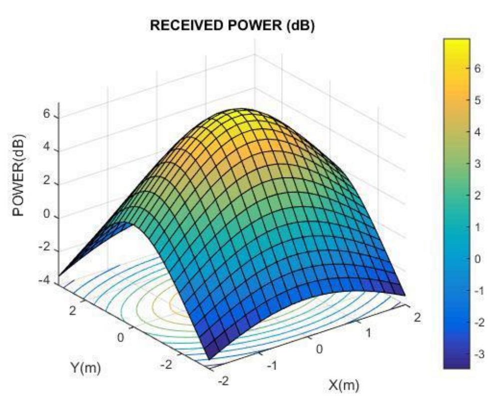
(a) (b)

Figure 5 The proposed models of square and rectangular LED arrangements (a) Square (b) Rectangular

Simulation results based on this two models show that a significant increase in the values of received power and SNR distribution were achieved. Figures 6 and 7 show the results obtained and the results summary is presented in Table 5.

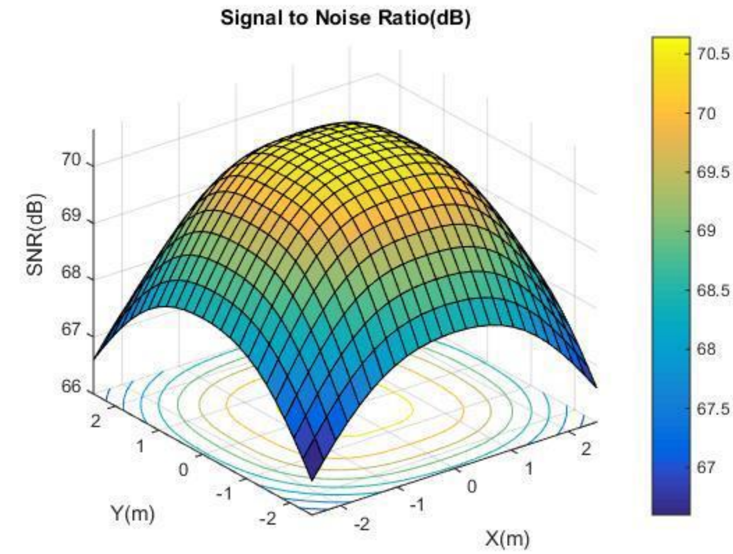


(a)

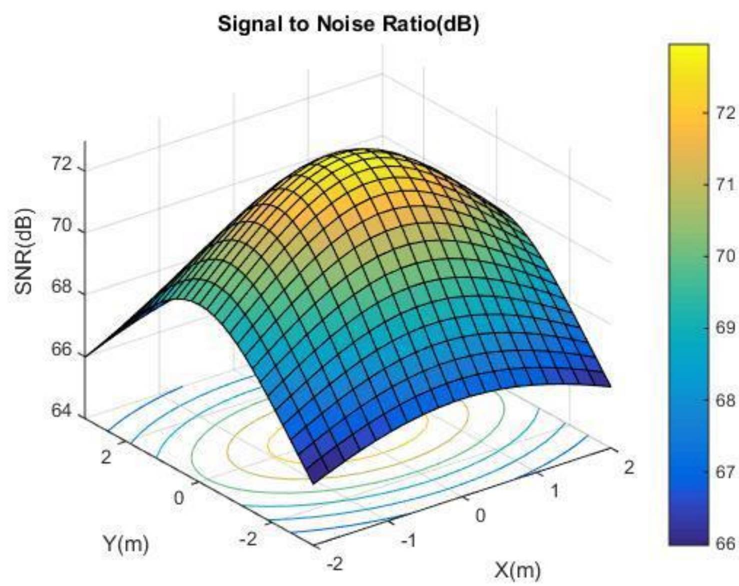


(b)

Figure 6. Received Power Distributions for a Square and Rectangular Layouts (a) Square: min -3.69 dB, max 4.18 dB and Ave. 1.95 dB (b) Rectangular: min -3.47 dB, max 6.93 dB and Ave. 1.82 dB



(a)



(b)

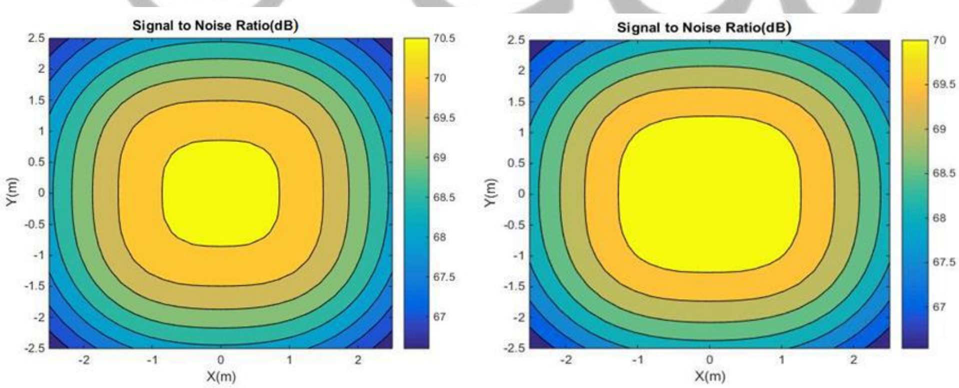
Figure 7. SNR Distributions for a Square and Rectangular Layouts (a) Square: min 65.83dB, max 71.11dB and Ave. 69.62dB (b) Rectangular: min 65.98dB, max 72.96dB and Ave. 69.54dB

Table 5: Square and Rectangular Results Summary

Parameter (dB)	Square	Rectangular
	LoS + Ref.	LoS + Ref.
$P_{rxMax.}$	4.1753	6.9285
$P_{rxMin.}$	-3.6912	-3.4697
P_{rxAve}	1.9472	1.8229
SNR_{Max}	71.1168	72.9564
SNR_{Min}	65.8283	65.9786
SNR_{Ave}	69.6244	69.5393

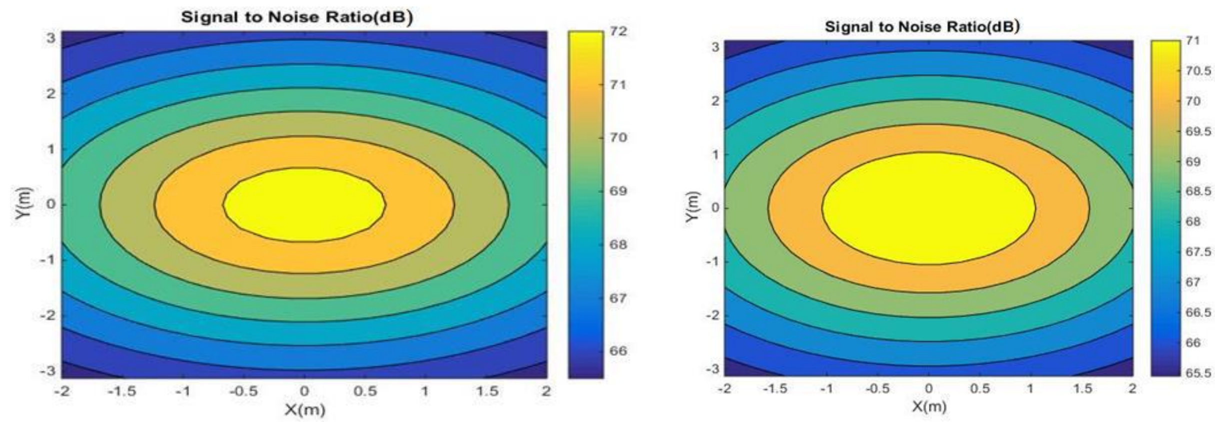
3.1. The impact of Inter-Symbol Interference (ISI) on the proposed layouts

The impact of ISI on the proposed layouts was also analyzed. A contour plots of the result while considering ISI show that the maximum values have more spread than the cases where ISI was not included in the analysis as can be noticed on the yellow portions of the plots. Although an average value of 69dB is achievable in all the cases, fluctuations are more severe in the rectangular layout with a difference of about 7dB between the maximum and minimum values. On the other hand, the influence of ISI can also be observed to be more noticeable in the proposed rectangular layout as the maximum and minimum values differs by almost 0.5dB. Figures 8 and 9 show the plots while a summary of the results is presented in table 6.



(a) (b)

Figure 8. The Impact of Inter-symbol Interference on the Square Layout (a) without ISI (b) With ISI



(a) (b)

Figure 9. The Impact of Inter-symbol Interference on the Rectangular Layout (a) without ISI (b) With ISI

Table 6: Impact of Inter-Symbol Interference on the Two Layouts

	SQUARE		RECTANGULAR	
	LoS + REF.	LoS + REF + ISI	LoS+ REF	LoS + REF + ISI
SNR_{Max}	70.6425	70.3776	72.4828	71.9443
SNR_{Min}	66.5994	66.5351	65.4970	65.4483
SNR_{Ave}	69.2272	69.0547	69.0634	68.8570
Difference	4.0431	3.8425	6.9858	6.4960

4. CONCLUSION

In this paper a comprehensive lighting configuration for a square and rectangular layouts were proposed and analyzed. Simulation results show that the proposed configuration yields better values of received power and SNR distributions compared to the commonly adopted four LED configuration. For the commonly used four LED array, a maximum value of received power and SNR achievable using the simulation parameters were about 2.81dB and 70dB respectively which is less than the results obtained from the new configuration in both layouts. The proposed square layout yields a maximum received power and SNR distributions of about 4.18dB and 71.1dB respectively, whereas the rectangular layout yields a maximum received power and SNR distribution of about 6.9dB and 73dB respectively as shown in Table 5. However, the impact of interference is more noticeable in the rectangular layout as the maximum values differ by about 0.5dB in both cases as seen in the results of Table 6. Therefore, the proposed configuration provides better communication quality achieved using the same transmitted power, same layout size and same number of LED chips. The results also indicate that a layout shape can influence the performance of a light source arrangement and therefore should be given considerable attention when designing a light source configuration for an indoor VLC system.

REFERENCES

[1] M. Mustapha and I. Develi "Visible light communication: a tool for addressing radio frequency spectrum congestion", International Conference on Advances and Innovations in Engineering (ICAIE 2017), Elazig, Turkey, May 10-12, pp. 269-273.

[2] H. Q. Nguyen et al. "A MATLAB-based simulation program for indoor visible light communication", International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP 2010), Northumbria University, New castle, United Kingdom, July 21-23, pp. 537-541.

[3] L. Zeng et al "Improvement of data rate by using equalization in an indoor visible light communication system", 4th IEEE International Conference on Circuits and Systems for Communications (ICCSC 2008), Shanghai, China, pp. 678-682.

[4] T. Komine, M. Nakagawa "Fundamental analysis for visible light communication system using LED light", IEEE Transactions on Consumer Electronics, pp. 100-107, 2004.

[5] T. Chien Bui et al "LEDs configuration method for supporting hand-over in visible light communication" 2014 IEEE region 10 Conference (TENCON 2014), Bangkok, Thailand, pp. 1-6.

[6] Y. Wang et al "A new design of light source arrangements for indoor visible light communication", 3rd International Conference on Systems and Informatics (ICSAI 2016), Shanghai, China, 19-21 September, pp. 705-709.

[7] Z. Wang, C. Yu, W-D. Zhong, and J. Chen, "A novel LED arrangement to reduce SNR fluctuation for multi-user in visible light communication systems", 8th International Conference on Information, Communication and Signal Processing (ICICS 2011), Singapore, December 13-16, pp. 6-10.

[8] C. Han Tan et al "Power optimization in hybrid visible light communication for indoor application", Progress in Electromagnetic Research Symposium (PIERS 2016), Shanghai, China, 8-11 August, pp. 3434-3437.

[9] Z. Ghassemlooy, W. Popoola and S. Rajbhandari "Optical Wireless Communication: System and channel modeling with Matlab", CRC Press, pp. 443.

[10] V. Jungnickel, V. Pohl, S. Nonning and C. Von Helmolt, "A physical model of the wireless infrared communication channel", IEEE Journal on Selected Areas in Communications, 20, (3), 2002. pp. 631-640.

[11] T. Bui et al. "A comprehensive lighting configuration for efficient indoor visible light communication networks", International Journal of Optics, Vol. 2016, Article ID 8969514, 9 pages.