

Optimization of Received Power and SNR for an Indoor Attocells Network in Visible Light Communication

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Abstract—White LEDs Visible Light Communication (VLC) is applied in communication and illumination simultaneously. It provides unrestrained frequency spectrum and a large bandwidth that produces a higher transmission rate and speed in short-range communication. Also, VLC was considered as a promising alternative technology to the radio frequency in the next generation of communication systems. In this paper, the optical attocells configuration and LEDs distribution are proposed for optimizing the received power and Signal-to-Noise Ratio (SNR) in the Line of Sight (LOS) propagation link. Besides that, the trade-off between minimum SNR and received power are investigated. The simulation results showed that the proposed model can save 6.25% of the total transmitted power, and the optical received power versus semi-angle and field of view have with about increased 16.5% and 27.54% respectively. Moreover, the SNR also has 7.4% improvement. Hence, the proposed configuration model has improved the performance of VLC systems and has widen the window for future improvement.

Index Terms—Visible Light Communication (VLC), Light Emitted Diodes (LED), optimization, attocell networks

I. INTRODUCTION

The optical wireless communication is discussed as an emerging technology supplementary to the radio frequency (RF) spectrum. RF will be insufficient to fill the gap of wireless access services in the future because, more than 70% of communication originated from indoor according to the previous reports [1]. Therefore, improvement in the transmission rate, Signal-to-Noise Ratio (SNR), and power improvements are required to face the fast growth in the communication systems and applications in order to provide an acceptable communication performance [1], [2]. Visible light communication is proposed as a promising technology in the indoor environments due to the unlicensed free spectrum, large bandwidth, high security and low power consumption [3].

By definition, the Light Emitted Diode (LED) is a semiconductor element that produces a visible light when an electric current passes via LED. However, the number of LEDs used in most of its area of application is varied

and mostly depends on the coverage area of an indoor environment in order to provide sufficient illumination [4], [5].

Among the numerous application of the VLC of multiple LED lighting is presented in the indoor environment for connecting several devices in a short-range distances, most connection structure applied to the VLC communication system included Line-of Sight (LOS), and Non-LOS [6]–[8]. More so, [9], [10] considered both LOS and non-LOS as propagation link in the VLC channel.

The VLC is suggested as promising key for the fifth-generation cellular system in order to increase the channel capacity. The light distribution inside the room is imagined to work as a tiny optical Base Station (BS) named optical attocells; it's similar to the femtocell in the cellular communication system [10]. Fig. 1 clarifies several cellular coverage zones, included attocells configuration in the VLC.

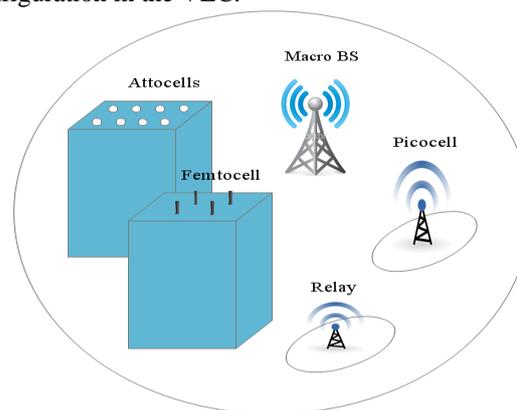


Fig. 1. The attocell in the context of the heterogeneous network

II. RELATED WORKS

The performance of VLC system is highly influenced by LED layout regulation, because SNR and received power can fluctuate up and down based on LEDs distribution. Meanwhile, there are trade-off amidst SNR and received power and this produces the impossibility of modeling a VLC system with maximum received power and SNR simultaneously.

Nonetheless, the quality of any communication link depends on the offering high values of both SNR and received power. T. H. Do and M. Yoo, [11] noted that,

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the two terms can be optimized by using multi-objective optimization algorithm. The discussion showed that both SNR and received power should be high in order to offer an excellent communication link.

In the other hand, the VLC attocell network was proposed as a type of novel integration in order to offer communication as well as illumination for a large area of an indoor environment. But the co-channel interference amidst neighbor attocells is responsible for driving the great coverage area of communication defunct zones. To that effect, [12] applied a genetic algorithm to optimizing the coverage and improving SINR in attocell network. Therefore, the maximization of the effective coverage area for illumination and communication is required in attocell network, and, the coverage area depends on some variable parameters of LEDs, such as distances between attocells, attocell height, semi-angle at half power, etc. It will be correct to add here that by carefully adjusting those parameters, it is easy to mitigate the adjacent interference between attocells to satisfy the communication and illumination requirements. And that was technically performed in this report.

In pursuit of excellence in the indoor application of VLC, researchers like [13]–[15] recommended for in-depth studies for the possible improvement of the system. In the same vein, [16], [17] and [11] upheld that comprehensive improvement of VLC system transmission speed in the indoor environment may be the awaiting miracle. Thus, from the discussion so far, it becomes vividly clear that the VLC possessed the technological wonder required for the future development of optical wireless communication.

However, to the best of our knowledge, such investigation towards improving the VLC system for good performance by optimizing the SNR and optical received power has not adequately been reported. Therefore, in this paper, a novel optical attocells configuration model is proposed in order to optimize the SNR and optical received power. By designing the LEDs array or attocell networks in the room, the proposed model is to be applied for indoor LOS links. This paper also extends the optimization method to take into account the coverage area. The main contribution of this paper is to:

- Investigate the optimization of visible light communication.
- Improve an indoor VLC communication via using a novel attocells configuration model.
- Optimize the cellular coverage area in term of received power, as well as the SNR.

The remainder of this paper is constructed follow up as. Section II shows the related works. Section III illustrates the system model; it subdivided into A. design of white LED Lights B. Light dispersion and received optical power, and C. signal-to-noise ratio (SNR). Section IV shows the simulation study and optimization results. The paper is summarized in section V.

III. SYSTEM MODEL

The system model is subdivided into three stages, which includes: (A) Design of white LED Lights (B) Light dispersion and received optical power, and (C) signal-to-noise ratio (SNR). In depth description is provided in the following sub-sections.

A. Design of White LED Lights

In this subsection, we are shown the proposed attocells configuration that applied to the room of $5 \times 5 \times 3m$ dimensions. The proposed attocells are mounted on the ceiling as illustrated in Fig. 2, besides that, the dimensions and LEDs distribution of attocells are organized as displayed in Fig. 3. The internal area of the room is divided into five attocells networks in order to cover the whole room. From the previous studies, the single and four attocells configurations are insufficient to provide a large cellular coverage, high received power, SNR, and channel capacity as required for 5G. Besides that, the proposed configuration model consumes less radiated power than that used in four attocell configurations, and the co-channel interference problem is solved by adjusting the semi-angle of downlink communication.

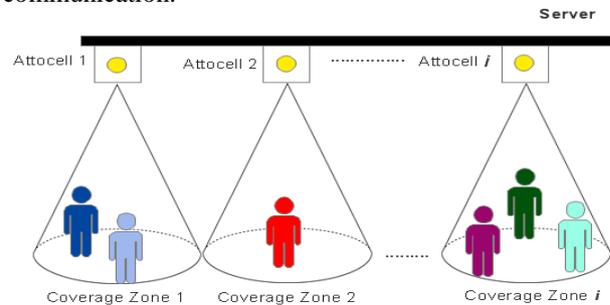


Fig. 2. Attocells distribution on the ceiling

The height of attocells is $2.15m$ above the receiver plane; each attocell was filled with 2704 LEDs. The total transferred optical power is $54W$, and 0.73 cd represents the center luminous intensity, the semi-angle at half-power is variable to evaluate the proposed attocell model.

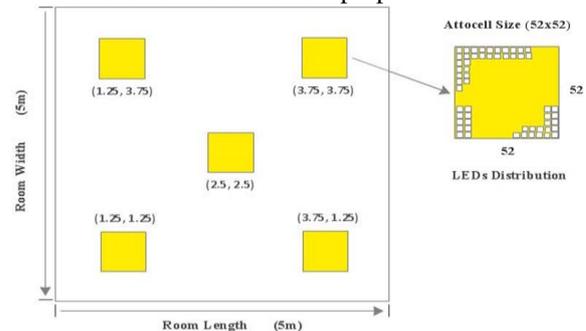


Fig. 3. Proposed attocells configuration with LEDs distribution model at the ceiling

B. Light Propagation and Received Optical power

The geometrical system model of the proposed attocells configuration is shown in Fig. 4. In this paper,

we consider the LOS condition for illumination as well as communication.

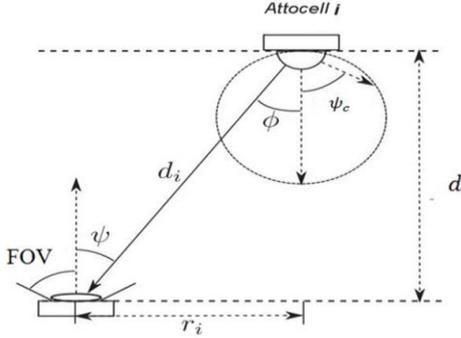


Fig. 4. System model of LOS link

The intensity of illumination in angle ψ_c is expressed as in [18]

$$I(\phi) = I(0) \cos^m(\phi) \quad (1)$$

where ϕ is the irradiance angle, m is the lambertian radiant order, it is defined by semi-angle of half illumination from LEDs ψ_c such as:

$$m = \frac{-\ln 2}{\ln(\cos \psi_c)} \quad (2)$$

The horizontal illuminance E_{hor} is given by:

$$E_{hor} = \frac{I(0) \cos^m(\phi)}{d^2} \times \cos(\psi) \quad (3)$$

The channel DC gain of LOS path is given in (4),

$$H(0) = \begin{cases} \frac{(m+1)A}{2\pi d^2} \cos^m(\phi) T_s(\psi) g(\psi) \cos(\psi), & 0 \leq \psi \leq \psi_c \\ 0, & \psi > \psi_c \end{cases} \quad (4)$$

where A refers to the detector physical area of Photo Detector (PD), ψ is the incident angle. $T_s(\psi)$, is the optical filter gain, and $g(\psi)$ represents the gain of an optical concentrator. ψ_c , denotes to the field of view at a receiver. The optical concentrator gain is given by:

$$g(\psi) = \begin{cases} \frac{n^2}{\sin^2(\psi_c)}, & 0 \leq \psi \leq \psi_c \\ 0, & \psi > \psi_c \end{cases} \quad (5)$$

TABLE I: COMPARISON BETWEEN FOUR AND FIVE ATTOCELLS CONFIGURATION

Attocell Network/Room	Size of Attocell Network (LEDs)	Amount of Power/ LED	Radiated Power of Single Attocell	Total Power Consumption
4	60 × 60	20 mW	72 W	288 W
5	52 × 52	20 mW	54 W	270 W

where n represents the refractive index.

The received optical power at PD P_r is derived from the transferred optical power P_t as follows:

$$P_r = H(0) * P_t \quad (6)$$

C. Signal-to-Noise Ratio (SNR)

When the attocells configuration model is distributed in the room for downlink transmission, the SNR will then be represented as in equation (7) [19].

$$SNR = \frac{[RP_r]^2}{\sigma_{thermal}^2 + \sigma_{shot}^2} \quad (7)$$

where R represents responsivity and it is measured in amperes per watt, while P_r stands as it is mentioned in (6). Where $\sigma_{thermal}^2$ and σ_{shot}^2 represents variances of the thermal and shot noises respectively, and can be defined by:

$$\sigma_{thermal}^2 = 8\pi k T_k \eta AB^2 \left(\frac{I_2}{G} + \frac{2\pi\Gamma}{g_m} \eta AI_3 B \right) \quad (8)$$

$$\sigma_{shot}^2 = 2q [RP_r + I_{bg} I_2] B \quad (9)$$

where $I_3 = 0.0868$, k , and q are constant of Boltzmann and electronic charge respectively, T_k is absolute temperature, η represent a fixed capacitance of PD per unit area, B is known as an equivalent noise bandwidth, I_2 refer to noise bandwidth factor, G represents an open-loop voltage gain, Γ is the channel noise factor of the field-effect transistor (FET), g_m is the FET transconductance, and I_{bg} is the current result from background light. The worth of these parameters are adopted as considered in [18].

The significant contribution of the proposed attocells configuration model is the fact that it is consuming less power in downlink communication as presented in the following paragraph.

Table I shows the numerical comparison of previous and new configuration model. Despite the large number of the attocell network, and the equal amount of power taken by each LED, the new configuration model consumed 270W of power as against 288W by the previous model. To further establish the integrity of the proposed model, the proposed attocells network configuration is simulated by using MATLAB software program and the results are analyzed, validated and presented in the subsequent sub-section.

IV. RESULTS AND DISCUSSION

The Fig. 5 and Fig. 6 are shown the received power of five attocells configuration at 70 and 20 semi-angles at half power respectively. The received optical power was improved as shown in Fig. 11 and Fig. 12 for both semi-

angle at half power and field of view respectively. Fig. 7 and Fig. 8 are shown the optimized SNR at 70 and 20 semi-angles at half power respectively, the proposed attocells improved the SNR as illustrated in Fig. 13.

Fig. 9 and Fig. 10 illustrated the coverage area of the room in term of received power, the result showed that the overall coverage area was improved compared to the four attocells configuration as presented in Fig. 11 and Fig. 12, When compared with the previous work of [11], [16].

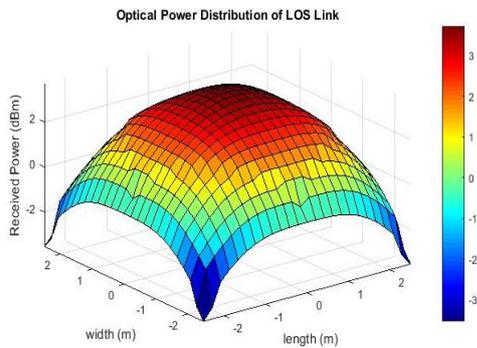


Fig. 5. Received power distribution at semi-angle at half power 70

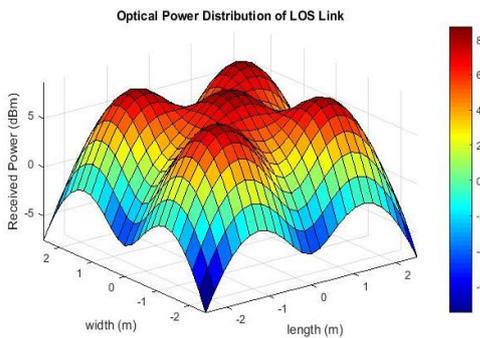


Fig. 6. Received power distribution at semi-angle at half power 20

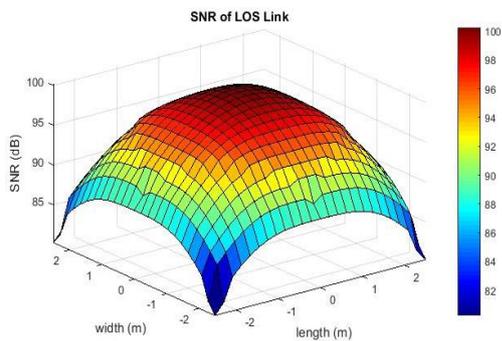


Fig. 7. SNR distribution at semi-angle at half power =70

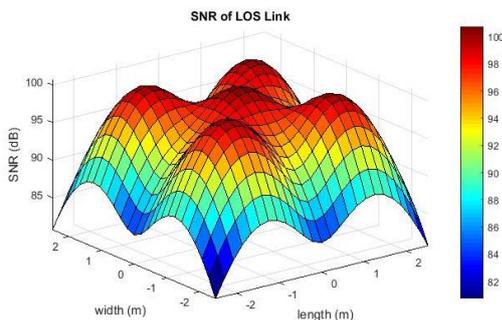


Fig. 8. SNR distribution at semi-angle at half power =20

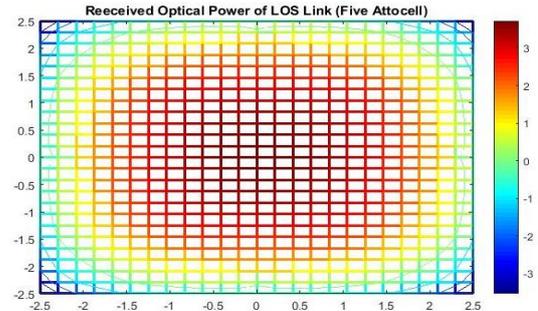


Fig. 9. Coverage area distribution in term of received power at semi-angle =70

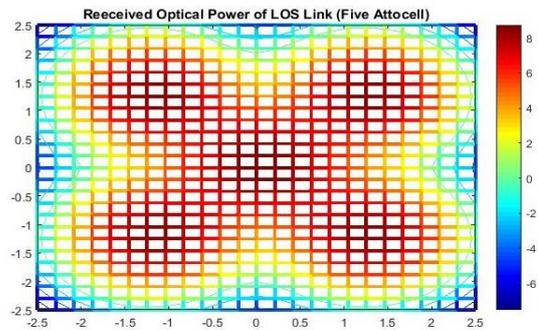


Fig. 10. Coverage area distribution in term of received power at semi-angle =20

Besides that, the trade-off between minimum SNR and minimum received power are studied as shown in Fig 12, the result was improved compared to the findings presented by [11] and it showed a linear relationship at small semi-angle at half power.

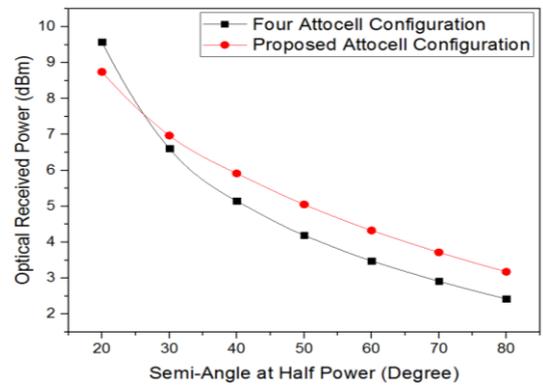


Fig. 11. optical received power vs. semi-angle at half power

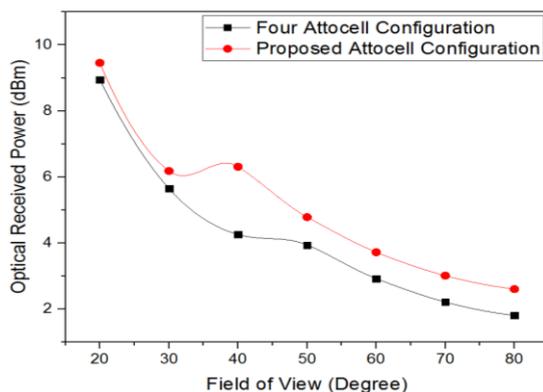


Fig. 12. Optical received power vs. field of view

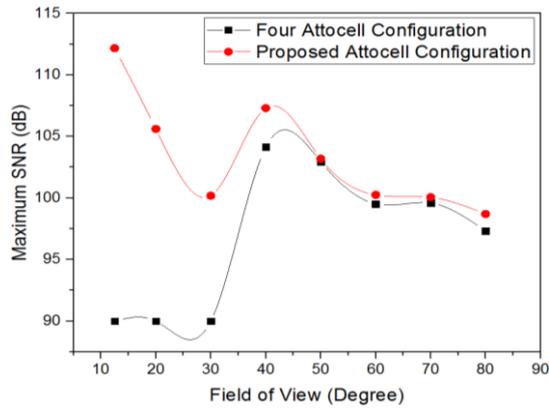


Fig. 13. SNR improvement vs. field of view

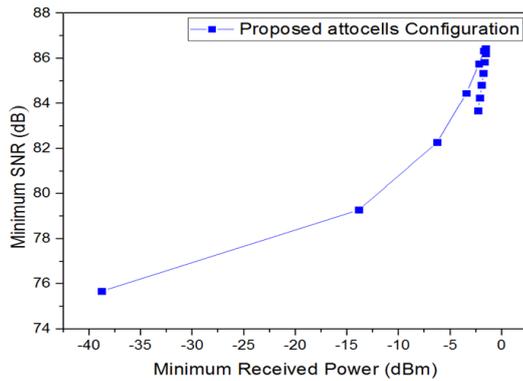


Fig. 14. Optimization solution of minimum SNR and received power

V. CONCLUSION

Visible light communication is deemed as success key supporting the fifth generation and beyond due to the great features and characteristic compared to the RF spectrum. The proposed attocells configuration and LEDs distribution are applied in an indoor environment to satisfy a maximum received power and signal-to-noise ratio, besides that, improves the coverage cellular area. The trade-off between minimum received power and SNR are studied through the proposed attocells configuration model. The simulation results showed that the downlink power is reduced 6.25% from the total transmitted power, besides that, the received power versus semi-angle and field of view is increased 16.5% and 27.54% respectively. Moreover, the SNR is improved 7.4% compared to past studies. In future work, the same configuration with LEDs distribution model will be applied to the diffuse link (Non-LOS), and the effect of multipath will be studied.

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