Performance Study of an Improved Version of Li-Fi and Wi-Fi Networks

Abdulsalam Alkholidi, Sondos Al-shami, Aisha Al-aghbary, and
Habib Hamam, Member, IEEE

Abstract

With the increasing demand and need for telecommunication technologies, wireless communication has become a heavily useful and widely popular utility. Capacity, availability, efficiency, and security are issues generally linked to wireless communications, more specifically Wi-Fi systems. Yet we can exploit billions of light bulbs, which we use anywhere and everywhere on a daily basis and of which the infrastructure is already part of our ordinary life. This study focuses on Li-Fi theory and practices. The purpose of this paper is to demonstrate how these light sources can be used as a transmitter or, to be more precise, as an access point. This idea was proposed for the first time by Prof. Harald Hass in Global TED (2011). During the last two years, Li-Fi technology has been enhanced and improved by many professional and international studies. As new wireless communication technology develops to use LED, the efficiency, availability, security, and safety of light fidelity transform today's telecommunication into tomorrow's visible light communication.

Keywords: *BER, FDMA, Li-Fi, NOMA, OOK modulation, Visible Light Communications (VLC), and Wi-Fi.*

I. Introduction

As technology consumes more and more of our activities, numerous researchers and engineers work to develop old technologies especially in the field of telecommunication. Nowadays, Light Fidelity has become the main and the most popular topic when it comes to the newest telecom technologies. Li-Fi is a new application of VLC, with advanced techniques used to guarantee the highest speed and optimum coverage in several fields. Internet, smart cities, vehicles, hospitals, transportation and many other domains will be linked to this technology in the future. With this study we aim to present, via illustrated simulation results, an improved version of Li-Fi and increase its performance. The remainder of this paper is structured as follows: in the next section, an overview of Li-Fi and VLC is presented; a formulation and some equations used in Li-Fi technology are provided in Section Three; Section Four introduces a series of simulation results and discussions; Section Five is dedicated to the analysis of said results; and finally, we conclude this paper (in Section Six) with a general conclusion and an overview of our future works.

II. Literature Review

In 2011, professor Harald Hass from the University of Edinburgh, UK, suggested an idea called "Data through illumination". He used fiber optics to send data through Light Emitting Diodes (LEDs) light bulbs. Over the past three years, some research papers have been published on this proposed technique of Li-Fi, as shown in [1-7]. The increasing number of multi-media mobile devices and the extensive use of data-demanding mobile applications mean that current mobile networks have reached their maximum capacity due to the limited availability of the Radio Frequency (RF) spectrum [1]. Light Fidelity (Li-Fi) is the term some have used to label this fast and cheap wireless-communication system, which is the optical version of Wireless Fidelity (Wi-Fi). Haas first used the term in this context in his TED Global talk on Visible Light Communication (VLC) [2]. Figure 1 illustrates the history of Li-Fi.

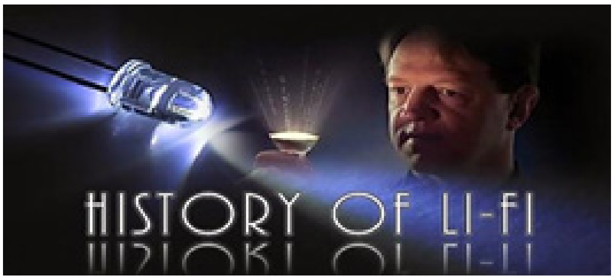


Fig. 1. History of Li-Fi.

New generation of electronics components as high emitting diodes are considered the core of Li-Wi technology. Put simply, when the LED is on, you transmit a digital 1, when it is off, you transmit a digital 0. Accordingly, they can be switched on and off very quickly which gives nice opportunities for transmitted data. By changing the rate at which the LEDs flicker (on and off), we can encode data in the light, resulting in different strings of 1s and 0s. The LED intensity is modulated so rapidly that the human eye cannot notice it, so the output appears uninterrupted. In October 2011, a number of companies and industry groups founded the Li-Fi consortium to promote high-speed optical wireless systems and to overcome the limited amount of radio-based wireless spectrum available by exploiting a completely different part of the electromagnetic spectrum as demonstrated in Fig 2. The consortium believes that it is theoretically possible to achieve more than 10 Gbps, allowing a high -definition film to be downloaded in 30 seconds [2].

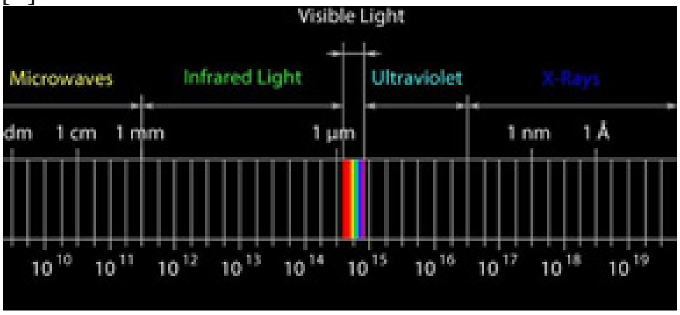


Fig. 2. Part of the electromagnetic spectrum indicated a visible light.

VLC is a short-range communication technology for which the visible spectrum is modulated to transmit data along the propagation distance of LEDs. VLC technology has been around for a while. Its story takes off in 1880, when Alexander Graham Bell invented the photo-phone. This instrument was used to transmit speech by modulating sunlight. Light amplification by stimulated emission of radiation (LASER) and LEDs were invented in the 1960s and marked the first step towards optical communication. Later, in 2003, some work began on VLC technology. Natagawa Laboratory, in Keio University, in Japan, used LEDs to transmit data. In 2006, the center for Information Communication Technology Research (CICTR) in Penn State, USA, proposed the first combination of Power Line Communications (PLC) and white LED to provide broadband access for indoor applications. Since then, there have been numerous research activities on VLC [3]. The dual functionality provided by VLC lighting and data communication from the same high-brightness LEDs has created a whole range of interesting applications, including, but not limited to, home networking, high-speed data communication via lighting infrastructures in offices, car-to-car communication, in-trains data communication, and traffic lights management. Recent research in VLC has successfully demonstrated data transmission at over 500 Mbps over short links in office and home environments. Further research and developments will open up new possibilities to partly resolve some of the issues associated with the present-day infra-red and radio/ microwave communication systems and lighting technologies [4].

VLC uses LEDs to transmit data wirelessly by using Intensity Modulation (IM). At the receiver, the signal is detected by a photodiode (PD) and by using the principle of Direct Detection (DD). VLC has been conceived as a point-to-point data communication technique; essentially, it acts as a cable replacement. This has led to early VLC standardization activities. This standard, however, is currently being revised to include Li-Fi. Li-Fi, in contrast, describes a complete wire-less networking system. This includes bi-directional multiuser communication, i.e. point-to-multipoint and multipoint-to-point communication. Li-Fi also involves multiple access points that form a wireless network of very small optical attocells with seamless handover. This means that Li-Fi enables full user mobility, and therefore forms a new layer within the existing heterogeneous wireless networks [5].

In the paper published by M. S ISLIM et al., as cited in [6], VLC is proven to be a promising solution to the increasing demands for wireless connectivity. Gallium nitride micro-sized light emitting diodes (micro-LEDs) are strong candidates for VLC, due to their high bandwidths. Segmented violet micro-LEDs are reported in this work with electrical-to-optical bandwidths up to 655 MHz An orthogonal frequency division multiplexing-based VLC system with adaptive bit and energy loading is demonstrated, and a data transmission rate of 11.95 GB/s is achieved with a violet micro-LED, when the nonlinear distortion of the micro-LED is the dominant noise source of the VLC system. A record 7.91 GB/s data transmission rate is reported below the forward error correction threshold using a single pixel of the segmented array when all the noise sources of the VLC system are present.

Free Space Optical (FSO) communication is a line-of-sight technology that uses lasers to provide optical bandwidth connections. In other words, FSO is an optical communication technique that propagates light in free space (air, outer space, vacuum, or something similar) to wirelessly transmit data for telecommunication and computer networking. There are three FSO components associated to three stages: a transmitter to send laser or light radiation through the atmosphere, all while obeying Beer-Lambert's law, a free space transmission channel where turbulent eddies (cloud, rain, smoke, gases, temperature variations, fog and aerosol) exist and a receiver to process the received signal. Typical links are between 300 m and 5 km, although longer distances can be deployed in particular cases, such as 8 – 11 km [7].

III. Formulation

In this section, mathematical formulations of digital modulation techniques generally used for LiFi are described briefly, and some channel modeling formulas are discussed.

3.1 Modulation techniques

Power Distribution

The average transmitted optical power in terms of IM signal x(t) can be described as [4]:

$$Pt = Po(1+x(t)) = Po(1 + m\cos wm\ t) \qquad (1)$$

where Po is the DC power; m is the modulation index
m = (ip/Ib– ith); ip is the peak laser diode current, and ith is the threshold current. Concerning Free Space Optical (FSO) links, when the receiver has an aperture diameter of D, the received optical power is defined as:

$$Pr = ((\pi D^{\wedge}2)/8)\ I(0,L) \qquad (2)$$

Conventional modulation techniques applied in RF channels cannot be freely executed in optical channels. Nonetheless, OOK remains the most reported modulation technique for IM/DD in optical communication [4]. The block diagram of an OOK system is illustrated in Fig. 3 below:

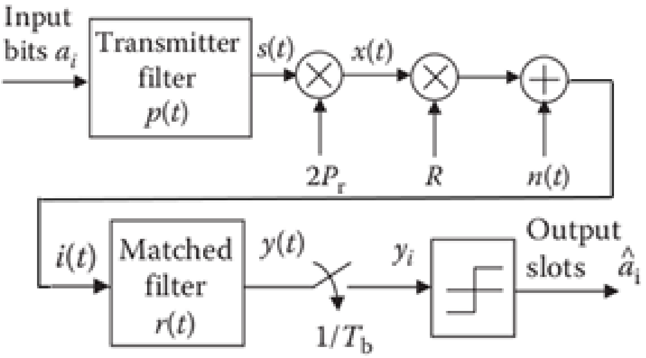


Fig. 3. Block diagram of an OOK system.

The envelop for OOK-NRZ can be described as:

$$P(t) = f(x)=\{2Pr, \text{for } t \in [0,T)\ x, \text{eleswhere} \qquad (3)$$

B. Bit Error Rate

The probability of an error is given as:

$$Pe = Q(\frac{ith}{\sigma}) \qquad (4)$$

where Q( ) is Marcum's Q-function, which is the area under the Gaussian curve, given by:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\frac{\sigma^2}{2}} d\alpha \qquad (5)$$

3.2 Channel modeling

A. LOS channel model

The optical wireless channel has been shown to be a linear, time-invariant, memory-less system with an impulse response of a finite duration [4]. In short-distance LOS links, a multipath dispersion is seldom a problem and LOS links channels are often modeled as a linear attenuation and delay. The optical channel gain in indoor scenarios consists of the line of sight (LoS) component and the multipath reflections. The LoS channel gain is expressed as [8]:

$$\mathrm{Hlos}(0) = \{ \frac{A(m1+1)}{2\pi d^2} (\varphi) Ts(\gamma) g(\gamma) \cos\cos\gamma \ , \ 0 \leq \gamma \leq \gamma c \ 0, \ eleswhere \qquad (6)$$

B. Shannon Capacity

Shannon capacity is used for calculating the achievable data rate between user µ and Li-Fi AP α. Since only half of the bandwidth can be used for data transmission in a DCO-OFDM system, the achievable data rate is expressed as [1]:

$$R(n)\mu = B \log\log 2 \ (1 + SINR(n)\mu) \qquad (7)$$

In multiusers access case, the Shannon limit on spectral efficiency for each user, denoted by τk , can be found as [5]:

$$\tau k = \{ \log\log 2 \left(1 + \frac{(hkak)^2}{\sum_{i=k+1}^{k} (hkai)^2 \ + \frac{1}{\rho}}\right., \ k \neq k$$

$$\log\log 2 \ (1 + \rho (hkak)^2), \ k = k$$

(8)

IV. SIMULATION RESULTS AND DISCUSSION

4.1 Bit Error Ratio

Bit Error Ratio (BER) refers to the number of bit errors divided by the total number of transferred bits. Widely used modulation techniques in Li-Fi technology include on-off keying (OOK), Pulse Position Modulation (PPM), and Pulse Amplitude Modulation (PAM) as stated in [5]. When compared to OOK, PPM is more power-efficient, but has a lower spectral efficiency. There are other digital modulation techniques that can be used for any visible light communication system.

For the sake of this example, the modulation scheme used is OOK-NRZ, which is the common and easiest modulation to be demodulated. In this analysis, path loss factor and no multipath dispersion are not taken into consideration. The noise is assumed as a white Gaussian, an assumption we have made to focus on the probability curve of OOK in order to compare simulations and theoretical results. However, the major effect on the BER curve is a block diagram, as presented in Fig. 3.

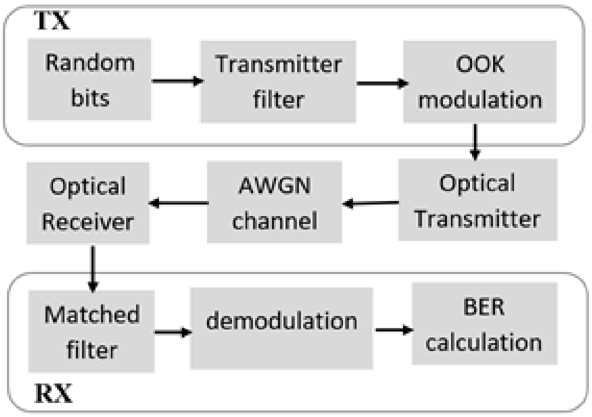


Fig. 4. Block diagram for BER calculation.

Table 1
Parameters in OOK modulation.

Parameters	Value
Charge of Electron	q=1.6e-19
Background Noise Current + interference	Ib=202e-6
Noise Spectral Density	N0=2*q*Ib
Bit rate	Rb=1e6
Bit duration	Tb=1/Rb
Number of bits	sig_length=1e5
Samples per symbols	nsamp=10

Table 1 introduces the main parameters used in this simulation, which are standard values for most VLC systems.

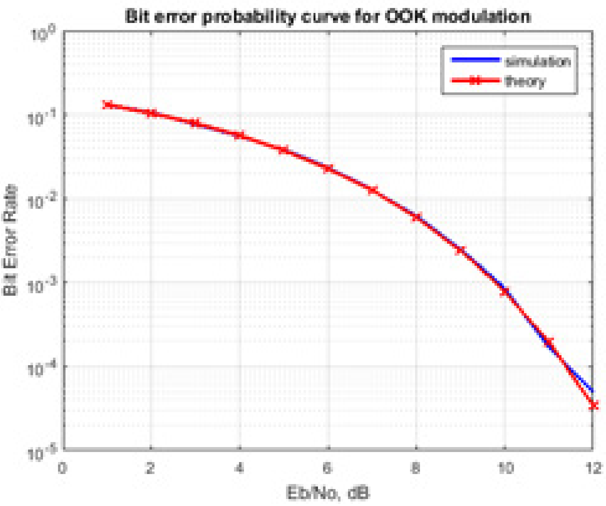


Fig. 5. Bit error curve for OKK modulation.

To illustrate the impact of our proposed approach, we plotted the response of BER, as explored in Fig. 5. For Additive White Gaussian Noise (AWGN), ambient light with double sided power spectral density No/2, zero mean and variant of σ2.An analysis of the BER as a function of SNR (the ratio Eb/No is usually referred to as the SNR per bit) with theoretical and simulation results is shown in Fig.5. All parameters used for this simulation are mentioned in Table 1. In this case, we used a filter for the transmitted signal and a matched filter on the receiver's end. Due to these principles, a transmitted signal, which was generated randomly, is matched to the receiver. Moreover, a rectangular pulse shaping is added to the signal in both sides in order to make a convolution for the received pulses. At the end, a digital symbol '1' is assumed to have been received if the received signal is above the threshold level, and '0' if otherwise.

4.2 Multiuser Access in Li-Fi

Being a wireless broadband technology, Li-Fi provides multiple users with simultaneous network access. In this part, we have done four simulations on this topic using four techniques: FDMA, TDMA, NOMA, and SDMA:

A. Multiuser Access in a LiFi Attocell:

The basic principle of downlink NOMA is shown in Fig. 6, where the LED broadcasts a super positioned version of the messages intended for a group of users of interest. Based on power domain multiplexing, the super positioned signal is given as a summation of signals, with each multiplied by a weighing factor [5].

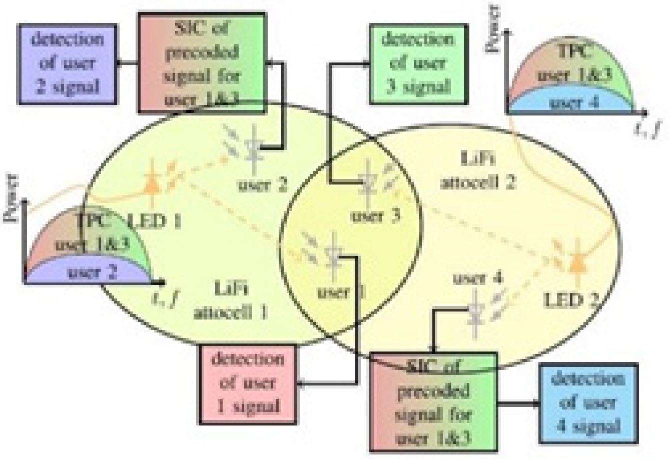


Fig. 6. Illustration of NOMA principle (two users example).

Figure 6 shows the Successive Interference Cancellations (SIC) used at the receiver's end to cancel the inter-user interference.

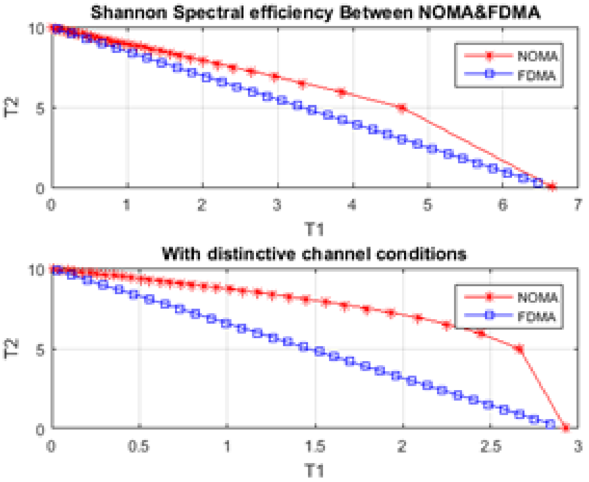


Fig 7. Shannon spectral effciency for NOMA & FDMA,

a) Same channel conditions; b) Distinctive channel conditions.

Figure 7 shows a comparison between FDMA and NOMA in a Li-Fi attocell (two users example). Based on Shannon spectral efficiency and the results presented in Fig. 7, the performance of NOMA is much better when compared to the sum of throughput inside a Li-Fi cell.

The difference between the published results in [5] and our obtained results is that the former simulation and evaluation was between TDMA and NOMA, whereas ours concerned FDMA. However, both present the same results as TDMA and FDMA use appropriate user-scheduling techniques to ensure that fairness in the allocation of resources (subcarriers) is maintained.

The advantage of the proposed results in this paper is the production of a maximum Li-Fi throughput even if there are multiple users, and this can be done using NOMA rather than FDMA or TDMA techniques.

B. Multiuser Access in LiFi Attocell Networks:

In this part, the application of TDMA, NOMA, and SDMA in a LiFi network will be discussed due to the overlapping coverage area of adjacent LiFi Access Points (Aps) as introduced in Fig. 8. According to [5], directly using NOMA in a LiFi network cannot efficiently mitigate interference transmitted from adjacent attocells. One promising and effective solution to enhance the performance of cell edge users in a LiFi network is the combination of NOMA and SDMA.

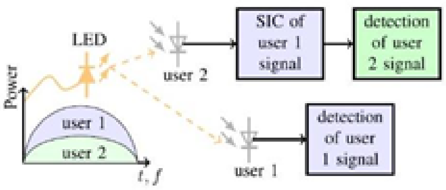


Fig. 8. Illustration of the combined use of NOMA and SDMA in a two-cell Li-Fi network.

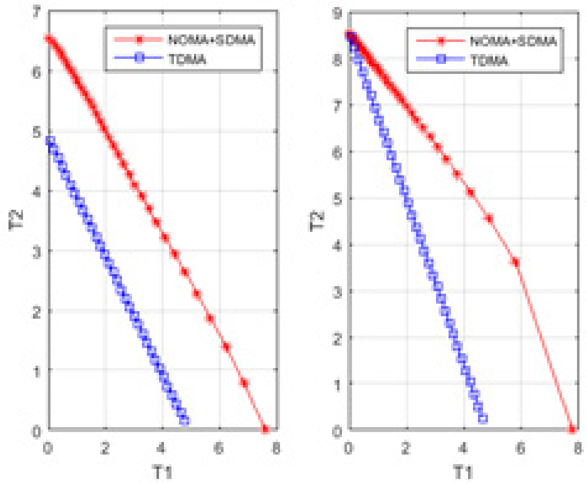
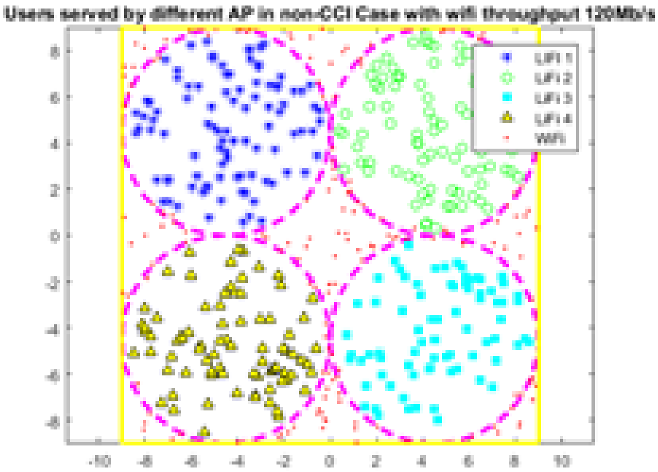


Fig. 9. Shannon spectral efficiency comparison between hybrid NOMA/SDMA and TDMA in a LiFi network. A) user 1 and user 2 are both near the cell edge; B) user 1 is near the cell edge while user 2 is near the cell center.

The results obtained in Fig. 9a and 9b demonstrate a comparison between TDMA and hybrid SDMA/NOMA in a Li-Fi network with two users, of which one is in the intersection area. As a result, we found that, based on Shannon spectral efficiency, NOMA/SDMA can enhance and increase total Li-Fi throughput in an interference area better than TDMA or FDMA.

4.3 Hybrid Li-Fi & Wi-Fi system

Due to the increasing demand for wireless data communication, and the decreasing availability of the spectrum, we expect, in the coming four years, a rise in the use of this hybrid system that may launch the start of the Li-Fi future.



1- Hybrid Li-Fi and Wi-Fi System with One Li-Fi Cell

This simulation focuses on SNR inside a Li-Fi cell as well as its distribution. It is important to note that the size of blue circles changes with SNR inside a Li-Fi cell.

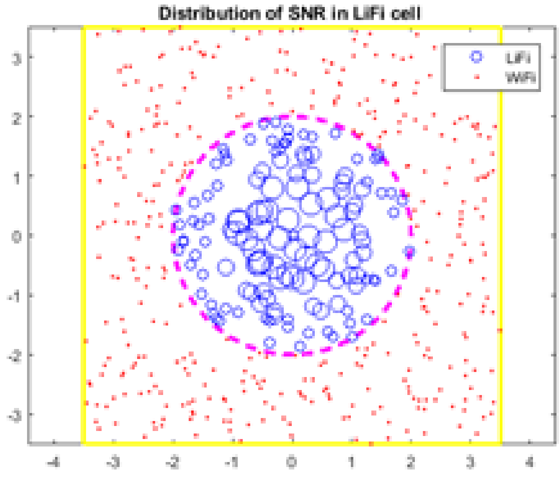


Fig. 10. SNR distribtion in a Li-Fi cell.

Figure 10 shows the distribution of SNR inside a Li-Fi cell, a concept that will be discussed in greater details in the coming section. Following the Shannon capacity law concerning the effect of the distance between each user and the Li-Fi AP, we can detect that in small r, near the center, high SNR is obtained. As r is increased, the SNR decreases until it reaches SNR=0dB outside the cell. At this point, users will have to use Wi-Fi.

2-Hybrid Li-Fi and Wi-Fi System with Four Li-Fi Cells in non-CCI Case

For the sake of this example, we shall consider 4 Li-Fi cells in a non-co-channel interference or non-CCI case (no intersect cells) to study the effect of Wi-Fi throughput in each Li-Fi cell.
In Fig. 11, Wi-Fi throughput is set to 120Mbps, whereas in Fig. 12 Wi-Fi throughput becomes 1Gbps (the effect of each value in non-CCI case is illustrated in this approach).

Fig. 11. Users' dstribution in non-CCi case with Wi-Fi throughput 120Mbps.

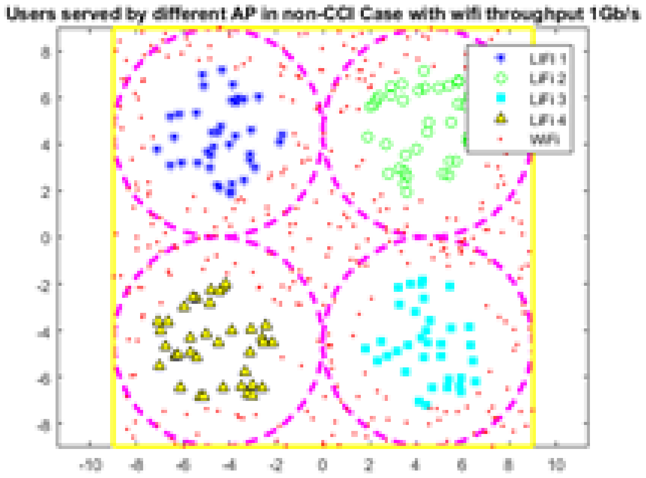


Fig. 12. Users' dstribution in non-CCi case with Wi-Fi throughput 120Mbps.

As aforementioned, these results reveal the effect of Wi-Fi throughput in a non-CCI case with 4 Li-Fi AP. The result obtained in Figs. 11 and 12 correspond with what we predicted based on the SNR distribution results in Fig. 9. Since SNR for each cell is zero at their edges, we have observed some users served by a Wi-Fi signal. Moreover, as we increase the Wi-Fi throughput, more users located at the circle's edge will receive Wi-Fi until it reaches the same Li-Fi throughput. Increasing Wi-Fi throughput, as is the case in Fig. 12, leads to more Wi-Fi users being served in the Li-Fi cell edge, because Li-Fi SNR in the edge will be lower than the Wi-Fi signal, which has a maximum throughput equal to 1 Gbps.

3- Hybrid Li-Fi and Wi-Fi System with Two Li-Fi Cells in CCI Case

Here, we demonstrate what will happen in a CCI-channel case (two intersect cells), when taking into consideration:

1- the distribution of SNR in Li-Fi cells (discussed above);
2- the WiFi throughput effect (explored above);
3- the signal to interference noise ratio.

These three parameters will determine the number of users served by each Li-Fi AP.
First, we will analyze the effects of having an intersecting area between the two cells in case of a CCI-channel with a new major variable called "Signal to Interference Noise Ratio" (SINR).

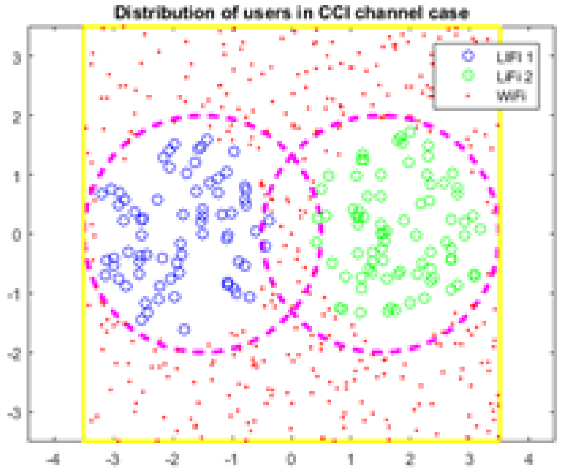


Fig. 13. Users' distribution in CCI-case.

Figure 13 illustrates the distribution of users inside and outside the two cells and the effect of the intersection on the distribution. The results found have shown that users inside the intersecting area will receive Wi-Fi because it has higher SNR and throughput.

4-Hybrid Li-Fi and Wi-Fi System with Four Li-Fi Cells in CCI-channel Case

We will summarize all the situations and main points mentioned in the previous sections to create a real Li-Fi scenario involving SNR, SINR, and Wi-Fi throughput in CCI-channel.

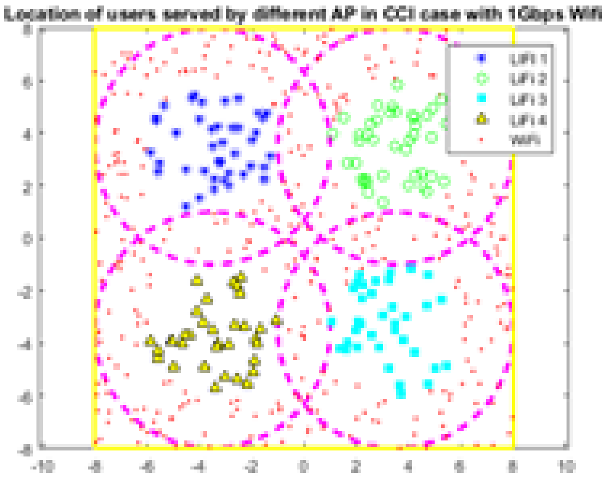


Fig. 14. Users' distribution in CCI-case with Wi-Fi throughput 1Gbps.

Wi-Fi and Li-Fi throughput is set to be 1 Gbps, and the effect of SNR & SINR is demonstrated in Fig. 14. The results obtained are as follows:

1- Users in the intersecting area will receive Wi-Fi.

2- Li-Fi users are located where there is no intersection effect because of SINR.

3- Increasing Wi-Fi throughput decreases the number of Li-Fi users because of the SNR effect.

5-Frequency Reuse Techniques in Hybrid Li-Fi and Wi-Fi system

In previous simulations regarding a hybrid Li-Fi/Wi-Fi network, we considered a Wi-Fi standard, which can almost guarantee a maximum throughput within 12 m to simplify the simulation steps. Now we consider a more practical situation where there is a poor Wi-Fi signal with four Li-Fi cells in the CCI-channel. In this scenario we want to increase the number of users that will use Li-Fi inside the cells, thus, we applied frequency plane techniques and avoided any interference between the cells.

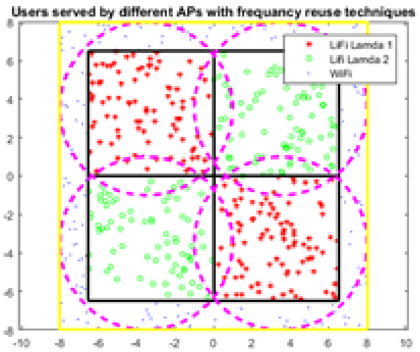


Fig. 15. Users' distribution with frequency reuse plan.

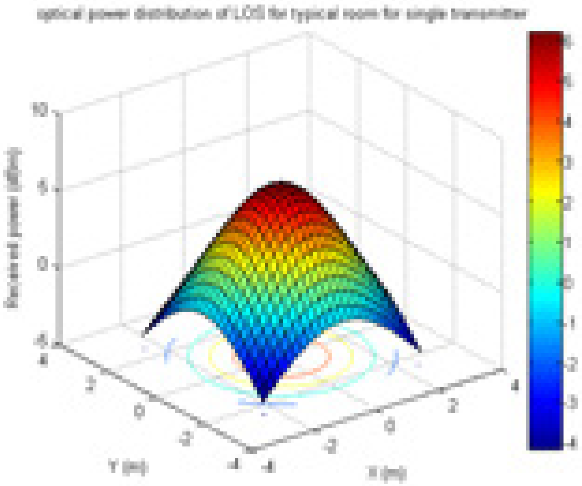
Figure 15 illustrates the application of frequency reuse techniques in a Li-Fi system. The bandwidth for a white LED is 20 MHz and the bandwidth will be divided into two since we have four intersecting cells as shown in Fig 14. The results state that the number of Li-Fi users has increased comparatively to the number in Fig. 13. However, Li-Fi throughput will decrease with the decreasing of its bandwidth, but since we are using square cells, we can ensure that there is no Wi-Fi user inside the Li-Fi coverage and that no interference occurred.

4.4 Power Distribution

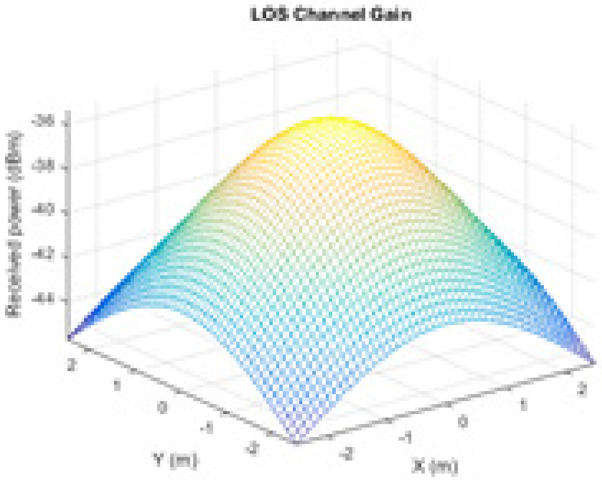
In a LOS path (ignoring the reflection of walls), the optical power distribution for a receiver plane is demonstrated in Fig. 16a for one transmitter and Fig. 16b for the optical channel gain. Figures 16c and 16d present four transmitters, each with a unique sensitive half angle.

Figure 16 shows the total optical power distribution in a room with dimensions of 5x5m, as seen below.

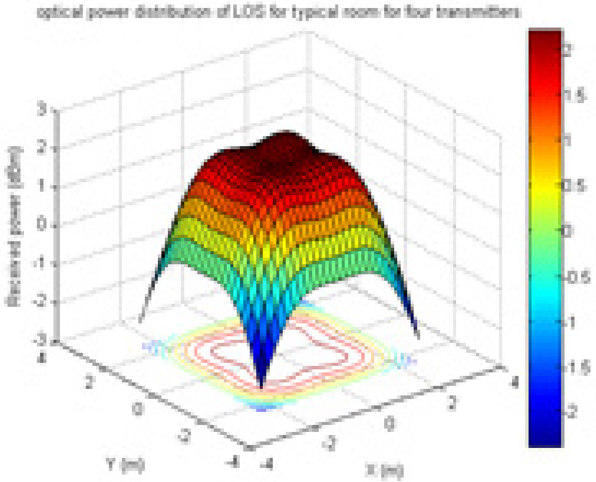
Results obtained in this section are shown in Fig. 16 and we found that the optical power received is distributed throughout the room with four transmitters in a more efficient manner than by only using one transmitter, as illustrated in Figs. 16a and 16c. However, when the sensitive half angle is 12.5 degrees, as is the case in Fig. 16d, users receive greater power comparatively to 70 degrees, as shown in Fig. 16c.



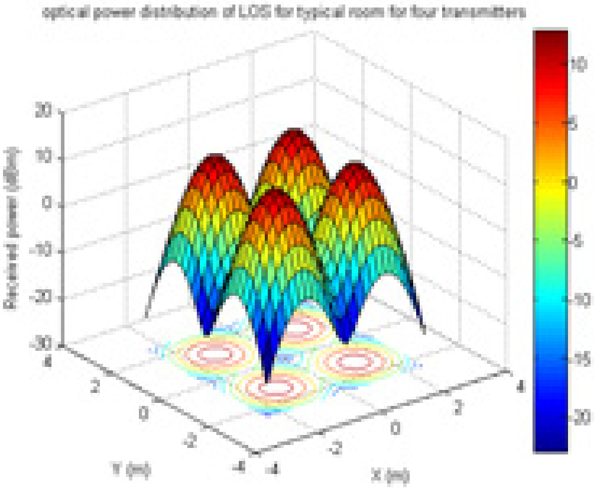
(a)



(b)

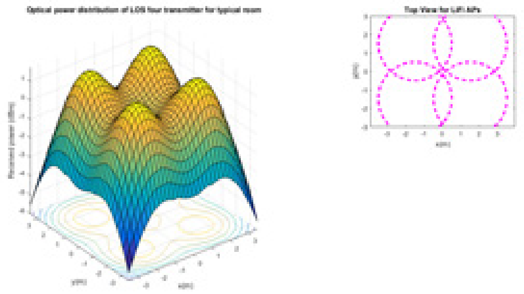


(c)



(d) Figs. 16. Optical power distribution in a typical room (5x5m): a) power distribution for one transmitter; b) LOS channel gain for one transmitter; c) power distribution for four transmitters with a sensitive angle of 70 ; d) power distribution for four transmitters with a sensitive angle of 12.5.

As a result, the advantage of these simulations is to build a good coverage plane for Li-Fi APs in typical areas. Therefore, we have applied these results and techniques in a real office, with dimensions of 7x7m using the standard Li-Fi AP specifications mentioned in [4]. Figure 17 shows a coverage plane in an office with dimensions (7x7m).



(a) (b)

Fig. 17. Li-Fi coverage plane for an office (7x7m), a) Optical Power Distribution, in 3D view; b) Top view for Li-Fi Aps

V. ANALYZING

In this paper, we study the four main aspects relating to Li-Fi technology that are still being enhanced. Firstly, there is BER theoretical and simulation calculations designed for OOK-NRZ modulations. The results are almost identical to those presented in [4]. In addition to the BER curve in reference [5], they used OFDMA techniques with OOK and it differs from our curve.

Secondly, we evaluated the newest multiplexing techniques, NOMA, which have been used recently in 5G. The obtained results show that NOMA is more optimal than FDMA techniques when we compare total user throughput. In [5], they have comparatively evaluated TDMA and NOMA and found that Li-Fi throughput can be efficiently enhanced with the application of NOMA. We also made the same comparison between hybrid NOMA/SDMA and TDMA in a case of interfering channels. Our results were identical to those found in [5]: hybrid SDMA and NOMA can enhance and increase Li-Fi throughput in the network when interference is occurring. SIC in NOMA techniques is used to illuminate the interference using a TCP vector and SDMA.

Hybrid Li-Fi/Wi-Fi network is demonstrated in the third section as follows:

We start by studying SNR with only one cell, and then we add the Wi-Fi throughput effect in a non-CCI channel. We then proceed to study SINR with two cells. Finally, we applied these scenarios in four CCI-channels. Our final results correspond exactly with those stated in [1] & [5]. After achieving the results relating to the load balancing algorithm, we aimed to apply frequency reuse techniques and document the differences. Thus, we created a new simulation with square Li-Fi cells in a hybrid Li-Fi/Wi-Fi system. The results proved that the number of users served by Li-Fi can increase using frequency reuse factors and this can be useful when we cannot guarantee maximum Wi-Fi throughput.

Our last simulation focuses on how we can create a good plan for Li-Fi APs in a typical room. The results obtained are almost identical to those presented in [9] with the exception of the last one, as we used our previous results and applied them in an office with specific dimensions.

Finally, we achieved good results and enhanced certain areas in the previous sections. Considering the positive results obtained, we optimistically aim to continue this study on the proposed topics in this chapter as we believe that this concerns the future of Li-Fi, which is essentially the future of the Internet of Things (IOT).

VI. CONCLUSION AND FUTURE WORKS

In this paper, a Li-Fi technology with several techniques and scenarios is discussed. All information about Li-Fi technology and its formulations are presented with brief explanations. Moreover, this paper also presents and discusses the key research areas that are required to manage Li-Fi attocells. BER and the multiusers access scheme are presented with our simulation results. Hybrid Li-Fi/Wi-Fi networks with load balancing techniques are proposed to mitigate the handover effects before and after the frequency reuse factor.

Throughout our study, we explored many improvements needed to guarantee an optimal Li-Fi future, especially in the field of simulations. This work marks the conclusion of our bachelor's degree project and the beginning of a master's project aiming for greater improvements in simulation results. Hybrid Wi-Fi or RF with Li-Fi systems and multiplexing techniques used in Li-Fi or uplink scenarios will be in our scope in the coming work. On the other side, many projects and studies can be done based on our results. Although we have improved our simulation results, there is still more room for improvement. Firstly, in hybrid Li-Fi/Wi-Fi network simulations, we increased users' throughput via a load-balancing algorithm and we incorporated a frequency reuse plan in order to increase the user's access to Li-Fi APs. Future improvements must focus on hybrid Li-Fi/Wi-Fi systems and how they can increase Li-Fi throughput inside a Li-Fi cell using a frequency reuse plan. Secondly, since our multi-users' access results concerned four types of multiplexing techniques, future works can be done to increase Li-Fi throughput by using new multiplexing techniques considering new scenarios.

Lastly, we must continue to explore Li-Fi/RF systems using the same principles we followed in hybrid Li-Fi/Wi-Fi networks. This topic remains relatively new, having been introduced only in 2016. We achieved all our desired objectives and enhanced this new technology for future use.

References

[1] Y. Wang and H. Haas, "IEEE, Journal of Lightwave Technology," Dynamic load balancing with handover in hybrid Li-Fi and Wi-Fi networks, Vol. 33, Issue 22, pp. 4671- 4682, 2015.
[2] J. Rani, P. Chauhan , and R. Tripathi, "International Journal of Applied Engineering Research," Li-Fi (Light Fidelity-The future technology In Wireless communication, ISSN 0973-4562 (http://www.ripublication.com/ijaer.htm,Vol). 7 No.11, 2012.
[3] A. R. Ndjiongue, H. C. Ferreira, and T. M. Ngatched, " Wiley Encyclopedia of Electrical and Electronics Engineering,"Visible light communication VLC technology"- (DOI 10.1002/047134608X.W8267), pp. 1–15, 2015.
[4] Z. Ghassemloay, W. Popoola, S. Rajbhandari, "Chapters 3, 4, and 8," CRC Press, Optical wireless communication & channel modelling with matlab, ISBN 9781138074804 - CAT# K34043, 2017.
[5] Harald Haas, LiangYin, Yunlu Wang, and Cheng Chen, "Journal of Lightwave Technology", What is liFi?," Vol. 34, Issue 6, pp. 1533-1544, 2015.
[6] M. S. ISLIM et al., "Photonic Research, Research Article" Towards 10 Gb/s orthogonal frequency division multiplexing-based visible light communication using a GaN violet micro-LED, Vol. 5, No. 2, pp. A35-A43, https://doi.org/10.1364/PRJ.5.000A35, 2017.
[7] A, Alkholidi and K. Altowij, "Chapter 5: Free space optical communications – Theory and practices", INTECH. In: Das N, ed, Contemporary issues in wireless communications. Croatia: InTech, pp. 159-212, DOI:10.5772/58884, 2014.
[8] Y. Wang, X. Wu, and H. Hass, "IEEE International Conference on Communications (ICC), Kuala Lumpur, Malaysia", Fuzzy logic based dynamic handover in hybrid LiFi /RF network, pp. 1-6 DOI: 10.1109/ICC.2016.7510823, 2016.
[9] H. Q. Nguyen, J. H. Choi, M. Kang, Z. Ghassemloay, D. H. Kim, "IEEE, 2010 7th International Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP 2010), Newcastle upon Tyne, UK", Matlab-based simulation program for indoor VLC system, 2010.