LEBANESE INTERNATIONAL UNIVERSITY

Testbed for Li-Fi Technology

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Preface

Efficiency, availability, security, and safety of light fidelity, as a new wireless communication technology uses LED, made telecommunication future turn to visible light communication. LiFi is a new application of VLC and advance techniques will be used to guarantee the best and optimum speed and coverage for internet usage or indoor local area networks in uplink and downlink scenarios. First, we had studied and passed through main advanced techniques recently used in LiFi system. After that, we have simulated these techniques to get an optimum result. Finally, we apply many principles, like frequency reuse plan and Shannon Spectral efficiency, to enhance and improve our results. In this project, we study bit error ratio in OOK modulation, multiusers access in LiFi cells, power distribution, and hybrid LiFi/WiFi network.
We have designed a prototype acts as LiFi transceiver to transfer text as well as any binary data. Our main goal is to send text as a serial data using arduino serial port and matlab graphic user interface. So, we used a powerful LED to transmit data and a photodiode in recipient side. Transmitting data will be converting again to its meaningful format using matlab software.

Acknowledgements

We express our deepest gratitude to Professor Abdulsalam AlKolidi, our Bachelor project advisor, for devoting his time and effort to making this project possible. It is our pleasure to dedicate all what we have done to our instructors for all what they taught us during our years of study specially Dr. Fawwaz Annashef from English department, who proofread this thesis.

We also express our thanks to last year's team, around the world, that worked on the original VLC & LiFi project as well as the creators of the works that were cited in this thesis.

Content:

Abbreviations and Symbols

Li-Fi	Light Fidelity
OWC	Optical Wireless Communication
VLC	Visible Light Communication
Wi-Fi	Wireless Fidelity
LED	Light Emitting Diode
BER	Bit Error Ratio
PPM	Pulse Position Modulation
OOK	Off on Keying
OOK-NRZ	Off On Keying-Non Return Zero
OOK-RZ	Off On Keying- Return Zero
PLC	Power Line Communication
IM	Intensity Modulation
DD	Direct Detection
LANs	Local Area Networks
IEEE	Institute of Electronic Engineer
LBS	Location Based Services
IOT	Internet of Things
PD	Photo Diode
RF	Radio Frequency
AWGN	Additive White Gaussian Noise
DC	Direct Current
PSD	Power Spectrum Density
SNR	Signal to Noise Ratio
FOV	Field of View
3G,5G	Third, Fifth Generations
PMF	Probability Mass Function
QOS	Quality of Service
FDMA	Frequency Division Multiple Access
NOMA	Non Orthogonal Multiple Access
SDMA	Space Division Multiple Access
SIC	Successive Interference Cancellations
dB	Decibels
CU	Control Unit
AP	Access Point
OFDMA	Orthogonal Frequency Division Multiple Access
RA	Resource Allocation
TDMA	Time Division Multiple Access
Non-CCI	Non Co-Channel Interference
CCI	Co-Channel Interference
SINR	Signal to Interference Noise Ratio
r	Radius
LOS	Line of Sight
NLOS	Non Line of Sight

List of figures

Chapter One:

General Introduction

This chapter is
a general introduction
that includes a brief definition,
applications, motivations, Importance,
and challenges of Li-Fi
technology.

General Introduction:

Due to the increasing demand for the need of telecommunication technologies, wireless communication has become a utility with a huge and heavy use. Capacity, availability, efficiency, and security are issues occurred generally on wireless communication, more specifically on Wi-Fi system. On the other hand, we have a billion number of light bulbs, which used every day and everywhere, whose infrastructure already has been built and existed in our life. This study concentrates on Li-Fi theory and practices.

The importance of this work is to demonstrate and present the idea of using these light sources as a transmitter or, to be more precise, as an access point. In fact, this idea was presented for the first time by Prof. Harald Hass in Global TED (2011). During the last two years, Li-Fi technology has enhanced and improved by many professional and international researches.

The project goal is to present this technology through a prototype and increase its efficiency as will be illustrated in our simulation and experimental results. What we aim to achieve in this work is to provide enhancement, and to present how transmission with light will be.

The reminder of this thesis is structured as follows: In chapter two an overview of Li-Fi, VLC, Wi-Fi are illustrated. Formulation and the main equations used for Li-Fi technology is provided in chapter three. Chapter four introduces series of simulations results and discussion. Chapter five includes implementation of a Li-Fi transmitter and receiver. Finally, we conclude this work in chapter six by general conclusion. The applications of this technique are vehicles, transportation, hospitals, healthcare, mobile connectivity, and so on. Smart city, IOT and many future concepts will be related to this technology in the future.

Chapter Tow:

An Overview of Li-Fi

Chapter two presents
an overview of Li-fi technology
starting with literature review which
goes through Wi-Fi and a history of
Li-Fi & VLC. This chapter also present
an explanation of Li-fi function,
& it's applications.

2. An Overview of Li-Fi

2.1 Literature Review

2.1.1 History

In 2011, professor Harald Hass from the University of Edinburgh in UK, suggested an idea called “Data through illumination”. He used fiber optics to send data through LED light bulbs. The increasing number of multi-media mobile devices and the extensive use of data-demanding mobile applications means that current mobile networks are at 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 the fast and cheap wireless-communication system, which is the optical version of Wireless Fidelity (Wi-Fi). Harald Haas first used the term in this context in his TED Global talk on Visible Light Communication (VLC) [2].

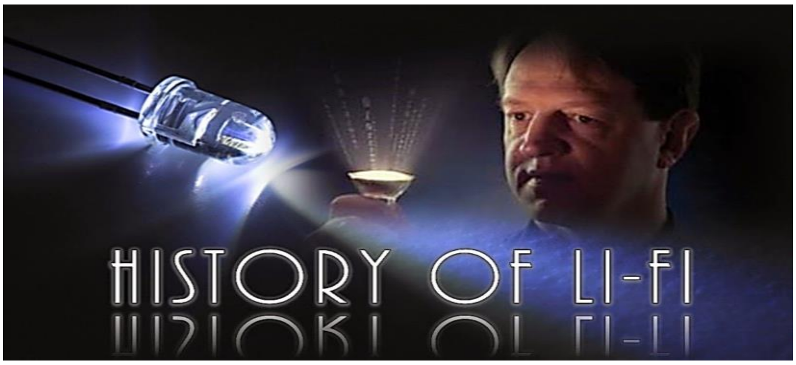


Fig. 2.1. History of LiFi.

“At the heart of this technology is a new generation of high brightness light-emitting diodes” says Harald Haas from the University of Edinburgh UK,” Very simply if the LED is on, you transmit a digital 1; if it’s off you transmit a 0. Haas says, “They can be switched on and off very quickly which gives nice opportunities for transmitted data. It is possible to encode data in the light by varying the rate at which the LEDs flicker on and off to give different strings of 1s and 0s. The LED intensity is modulated so rapidly that human eye cannot notice, so the output appears constant. In October 2011, a number of companies and industry groups formed 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. The consortium believes that it is possible to achieve more than 10 Gbps theoretically allowing a high -definition film to be downloaded in 30 seconds [2].

2.1.2 VLC

Visible Light Communications (VLC) is a short-range communication technology in which the visible spectrum is modulated to transmit data. Due to the propagation distance of the Light Emitting Diodes (LEDs). VLC technology has been around for a while. The history started in 1880, when Alexander Graham Bell invented the photo-phone. This instrument was used to transmit speech by modulating the sunlight. In the 1960s, optical communications were born. Light amplification by stimulated emission of radiation (LASER) and light emitting diodes (LEDs) were invented. Later, in 2003, some work began on VLC technology. Natagawa Laboratory, in Keio University, Japan, used LEDs to transmit data. In 2006, the center for Information Communication Technology Research (CICTR), Pen 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, 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, radio/microwave communication systems and lighting technologies [4].

2.1.3 VLC VS Li-Fi

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 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 forming a wireless network of very small optical attocells with seam-less handover. This means that Li-Fi enables full user mobility, and therefore forms a new layer within the existing heterogeneous wireless networks [5].

2.2 Wi-Fi

Wi-Fi is a blending name for Wireless Fidelity. Generally, Wi-Fi refers to any type of IEEE 802.11 Wireless Local Area Network (WLAN). More specifically, Wi-Fi is the industry standard for products as defined by the Wi-Fi Alliance and conforming to IEEE 802.11 standard as demonstrated in Fig. 2.2. WLANs extend the reach of Local Area Networks (LANs) by providing wireless connectivity. It is designed originally for cable replacement in corporate environments, WLANs have become very popular in providing IP connectivity in residential, small office and campus environments [6].

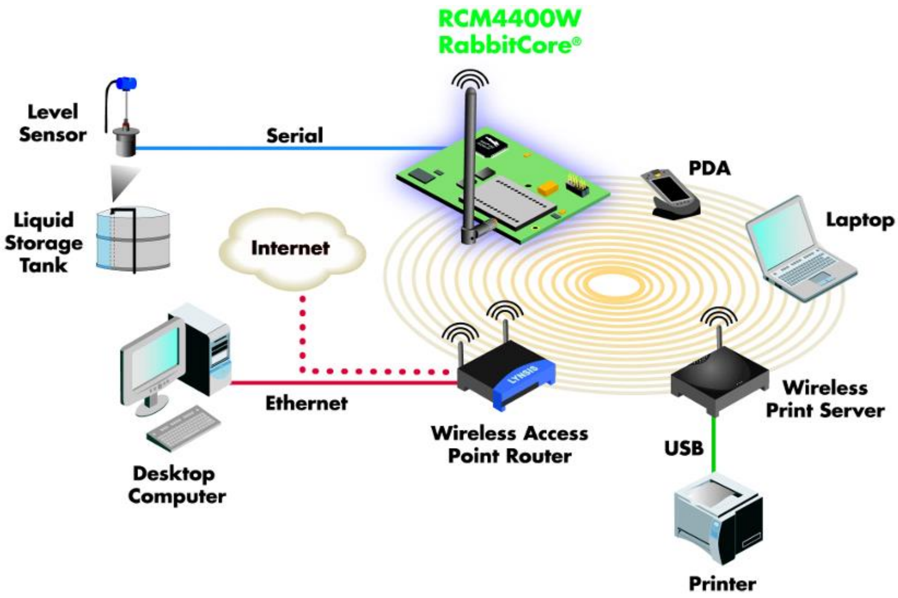


Fig. 2.2. Wi-Fi network.

<u>Benefits of Wi-Fi:</u>

• Wireless Ethernet: Wi-Fi is an Ethernet replacement. Wi-Fi and Ethernet, both are IEEE 802 networks, and they share some core elements.

• Extended Access: The absence of wires and cables extends access to places where wires and cables cannot go or where it is too expensive for them to reach.

• Cost Reduction: As mentioned above, the absence of wires and cables brings down cost. This is accomplished by a combination of different factors, the relatively low cost of wireless routers, no need for trenching, drilling and other methods that may be necessary to make physical connections.

• Mobility: Wires tie you down to one location. Going wireless means, you have the freedom to change your location without losing your connection.

• Flexibility: Extended access, cost reductions, and mobility create opportunities for new applications as well as the possibility of creative new solutions for legacy applications [7].

Li-Fi VS Wi-Fi

Li-Fi is a term that is used to describe visible light communication technology applied to high speed wireless communication. It acquired this name due to the similarity to WI-FI, only using light instead of radio. Wi-Fi is great for general wireless coverage within buildings, and Li-Fi is ideal for high density wireless data coverage in confined area and for relieving radio interference issues, so the two technologies can be considered complimentary [2]. Table 2.1 introduce the main differences between Wi-Fi and Li-Fi.

TABLE 2.1
Li-Fi Vs. Wi-Fi.

S.No.	Parameter	Li-fi	Wi-fi
1.	Speed	> 1 GB/s	Around 150mb/s
2.	Medium of data transfer	Use light as carrier	Use radio spectrum
3.	Spectrum range	Visible light has 10000 times more	Having less spectrum range than VLC
4.	Cost	Cheaper	Expensive
5.	Network topology	Point-to-Point	Point-to-Point
6.	Operating Frequency	Hundreds of Tera Hz	2.4 GHz

Wireless data is transmitted through radio waves which are limited and expensive. It has a limited bandwidth. With the rapidly growing world and development of technologies like 3G, 4G and so on we are running out of spectrum. Light has 10000 times wider bandwidth than radio waves. Also, light sources are already installed. So, Li-Fi has got better capacity and also the equipment are already available [8].

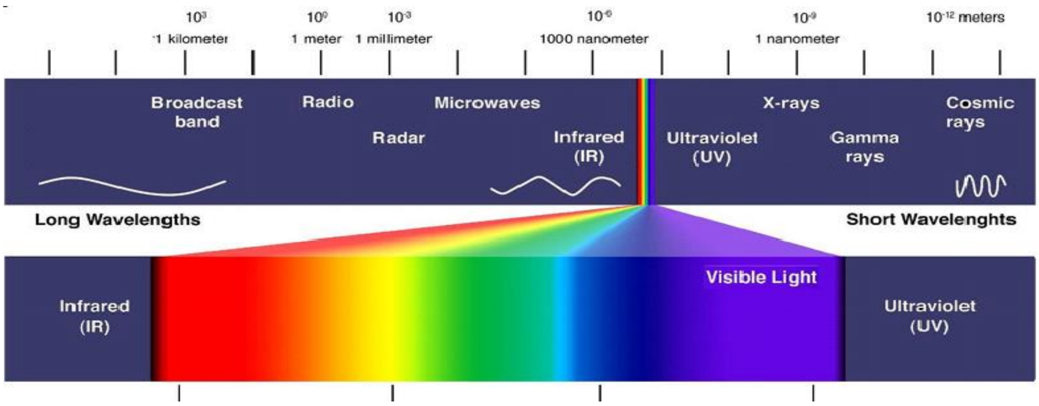


Fig. 2.3. Electromagnetic spectrum.

2.3 How Li-fi operates

Light emitting diodes (LEDs) can be switched on and off faster than the human eye can detect since the operating speed of LEDs is less than 1 μs, thereby causing the light source to appear to be continuously on. This invisible on-off activity enables data transmission using binary codes. It is possible to encode data in light by varying the rate at which LEDs flicker on and off to give different strings of 1s and 0s. Modulation is so rapid that humans cannot notice it [9].

The working of Li-Fi is very simple. There is a light emitter on one end, for example, an LED, and a photo detector (light sensor) on the other. The photo detector registers a binary one when the LED is on; and a binary zero if the LED is off. To build up a message, flash the LED numerous times or use an array of LEDs of perhaps a few different colors, to obtain data rates in the range of hundreds of megabits per second [8]. Figure 2.4 represents simply the concept of Li-Fi working mechanism.

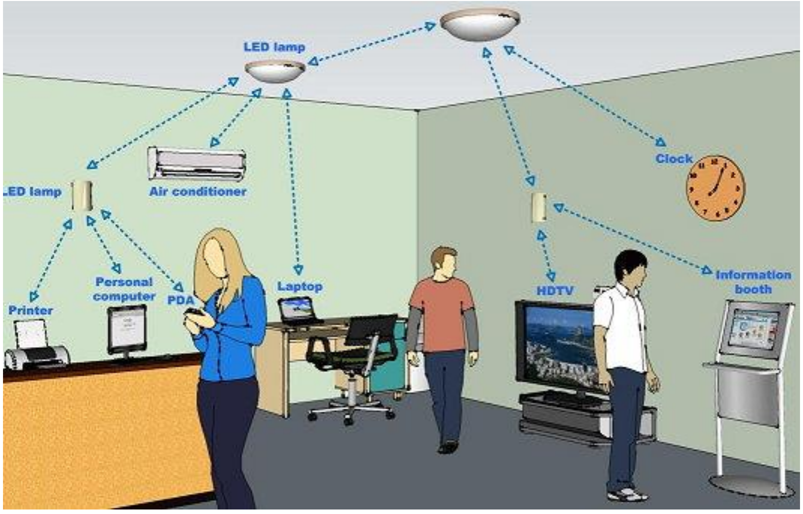


Fig.2.4. How Li-Fi Works.

2.4 Application of Li-Fi

Li-Fi has several kinds of application that is mentioned in [10], such as:

1) Vehicles and transportation.
2) Underwater communications.
3) Aviation.
4) Location Based Services (LBS).
5) Hospitals and healthcare.
6) Hazardous environments.
7) RF spectrum relief.
8) Mobile connectivity.
9) Smart lighting.

In the coming future, Li-Fi will support smart systems which are based on Internet of Things (IOT).

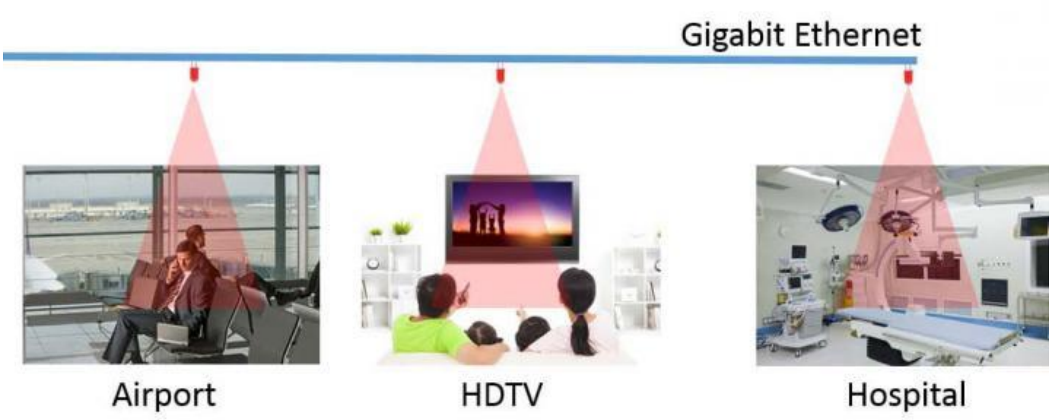


Fig. 2.5. Li-Fi applications.

2.5 Related Work

During the last three years, many researches has been conducted by many groups and teams. However, the most important papers were published by optical wireless communication team at the university of Edinburgh. Professor Harald Hass one of the optical wireless communication team in Edinburgh University and he is the head of Li-Fi, published this idea for the first time in 2011. Yunlu Wang, Laing Yin, Cheng Chen, Xiping Wu and Harald Hass introduced many techniques used in Li-Fi with some simulations. In [5], they mentioned first Li-Fi transmitter and receiver chips with their corresponding curves and simulations. In the same paper [5], Multiuser techniques mentioned with evaluation based on their simulation results. Several researches have been developing Li-Fi technology and the most reported is in [1] [3] [5]. These papers focus on implementing this technology in wide area as integrated hybrid Li-Fi & Wi-Fi system as well as hybrid RF & Li-Fi system.

In our approach, we went through all papers and tried to focus on the main important techniques by simulating and implementing them if possible. In addition, we enhanced most of the results to have better result than what was published with considering them as the main references. Accordingly, we will develop this technique as theory and practices in chapter four and five.

References of Chapter Two:

[1] Yunlu Wang and Harald Haas , "Dynamic Load Balancing with Handover in Hybrid Li-Fi and Wi-Fi Networks," IEEE paper, 2016.
[2] Jyoti Rani , Prerna Chauhan, and Ritika Tripathi, " Li-Fi (Light Fidelity-The future technology In Wireless communication"- (http://www.ripublication.com/ijaer.htm)_ No.11 (2012).
[3] Alian Richard , "Visible Light Communication VLC Technology"-(www.researchgate.net) , June 2015.
[4] Z. Ghassemlooy, W. Popoola, and S. Rajbhandari", Chapter8_ 2013 by Taylor & Francis Group, LLC.
[5] Harald Haas, LiangYin, Yunlu Wang, and Cheng Chen, "What is liFi?," IEEE paper, 2015.
[6] Vijay K. Varma_" Wireless FidelityWiFi." 2006-2012IEEE.
[7] " An Introduction to Wi-Fi"- (www.rabbit.com), 2007-2008.
[8] Rahul R. Sharma, , Raunak, and Akshay Sanganal, " Li-Fi Technology"-(www.ijcta.com) Jan-Feb 2014.
[9] Anurag Sarkar, and Asoke Nath, " Li-Fi Technology: Data Transmission through Visible Light"-(www.ijarcsms.com), June 2015.
[10] V.Padmapriya, R.Sangeetha, and E.Thamaraiselvi, " LiFi Based Automated Smart Trolley Using RFID", March-2016.

Chapter Three:

Mathematical Approach

Chapter three illustrates related mathematical equations used in proposed method regarding these main topics: Modulation techniques, Channels modelling in Li-Fi, Path loss and Load Balancing with dynamic handovers.

1 Modulation Technique

The conventional modulation techniques adopted in RF channels cannot be readily applied in optical channels. Figure 3.1 shows a number of modulation schemes that could be applied for optical channels [1].

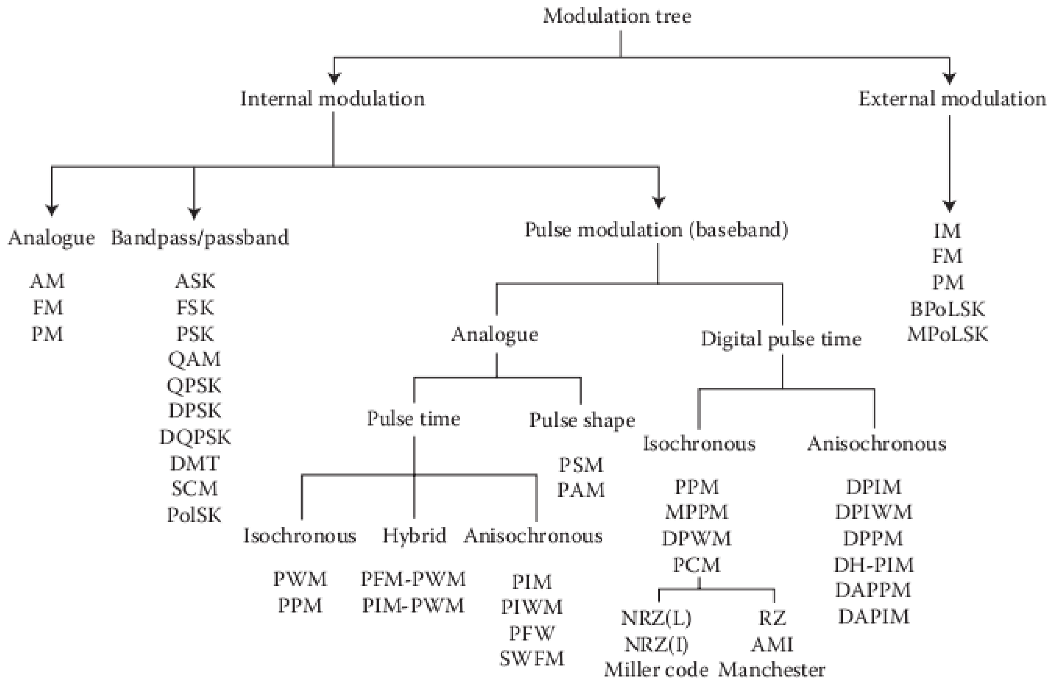


Fig. 3.1. Modulation tree.

3.1.1 Power Distribution

The average transmitted optical power in terms of IM signal x(t) is given by [1]:

$$P_t = P_0(1 + x(t))$$
$$P_t = P_0(1 + m\cos\omega_m t) \qquad (3.1)$$

where P_0 is the DC power; m is the modulation index m = (i_p/Ib− i^{th}); ip is the peak laser diode current; and i^{th} is the threshold current. For Free Space Optical (FSO) links when the receiver having an aperture diameter of D, the received optical power is defined as:

$$P_r = \frac{\pi D^2}{8} I(0, L) \qquad (3.2)$$

The block diagram of OOK system illustrated in Fig. 3.2, below:

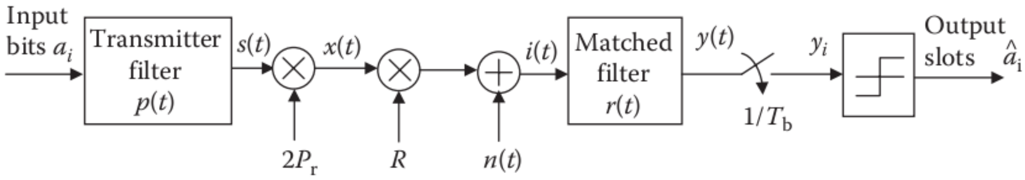


Fig. 3.2. Block diagram of OOK system.

OOK is the most reported modulation techniques for IM/DD in optical communication. the envelop for OOK-NRZ is given by:

$$p(t) = \begin{cases} 2P_r & \text{for } t \in [0, T_b) \\ 0 & \text{elsewhere} \end{cases} \tag{3.3}$$

Where P_r is the average power and T_b is the bit duration.

3.1.2 Bit Error Rate

The probability of error is given as:

$$P_e = p(0)\int_{i_{th}}^{\infty} p(i/0)\,\mathrm{d}i + p(1)\int_{0}^{i_{th}} p(1)\,\mathrm{d}i \tag{3.4}$$

Where i^{th} is the threshold signal level; p(0) and p(1) are probabilities of 'zero' and 'one'; and the marginal probabilities are defined as:

$$p(i/0) = \frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(\frac{-i^2}{2\sigma^2}\right)$$

$$p(i/1) = \frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(\frac{-(i-I_p)^2}{2\sigma^2}\right) \tag{3.5}$$

For equiprobable symbols, p(0) = p(1) = 0.5, hence the optimum threshold point is i^{th} = 0.5Ip, and the conditional probability of error reduces to:

$$P_e = Q\left(\frac{i_{th}}{\sigma}\right) \tag{3.6}$$

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

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\alpha^2/2} \mathrm{d}\alpha \tag{3.7}$$

For a matched filter, the variance of the noise samples at the output of the filter is dependent only on the PSD of the noise input and the energy in the impulse response of the matched filter. Thus, if the input is AWGN with a double-sided PSD $N_0/2$, the variance of the noise at the output of the matched filter is given by:

$$\sigma^2 = \frac{N_0}{2} \int_{t=0}^{T_b} r^2(t)\, \mathrm{d}t \tag{3.8}$$

Hence, the standard deviation σ has the value:

$$\sigma = \sqrt{\frac{N_0 E_p}{2}} \tag{3.9}$$

$$P_{e\_bit\_OOK} = Q\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{3.10}$$

Where average energy per bit E_b is given by:

$$E_b = \frac{E_p}{2} = 2(RP_r)^2 T_b \tag{3.11}$$

In the OOK-RZ formatting, the average energy per bit is increased by a factor of 1/gama which is given as:

$$E_b = \frac{E_p}{2} = \left(2(RP_r)^2 T_b/\gamma\right) \tag{3.12}$$

Matched filter output for detected OOK, NRZ pulse is illustrated in Fig. 3.3:

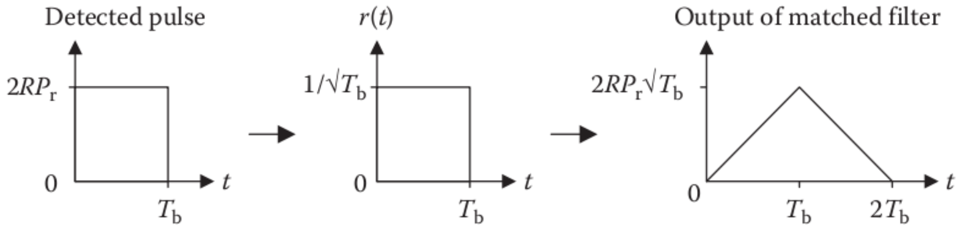


Fig. 3.3. Matched filter OOK-NRZ pulse.

3.2 Channel Modeling

The optical wireless channel has been shown to be a linear, time-invariant, memory- less system with an impulse response of a finite duration. The generalized model of the OWC link in the time domain is illustrated in Fig. 3.4 [1].

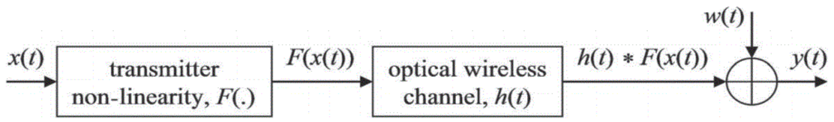


Fig. 3.4. Model of the OWC in time domain.

3.2.1 Li-Fi Channel Model

The angular distribution of the radiation intensity pattern is modeled using a generalized Lambertian radiant intensity with the following distribution [2]:

$$R_0(\phi) = \begin{cases} \dfrac{(m_1+1)}{2\pi}\cos^{m_1}(\phi) & \text{for } \Phi \in [-\pi/2, \pi/2] \\ 0 & \text{for } \phi \geq \pi/2 \end{cases} \tag{3.13}$$

Where m1 is the Lambert's mode number expressing directivity of the source beam; and $\phi = 0$ is the angle of maximum radiated power. The order of Lambertian emission m1 is related to the LED semi angle at half-power Φ1/2 by the following formula [2]:

$$m_1 = \frac{-\ln 2}{\ln(\cos \Phi_{1/2})} \tag{3.14}$$

In short-distance LOS links, multipath dispersion is seldom a problem and LOS links channel 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 in [3]:

$$H_{\mathrm{los}}(0) = \begin{cases} \dfrac{A_{\mathrm{r}}(m_1+1)}{2\pi d^2}\cos^{m_1}(\phi)T_{\mathrm{s}}(\psi)g(\psi)\cos\psi & 0 \le \psi \le \Psi_{\mathrm{c}} \\ 0 & \text{elsewhere} \end{cases} \tag{3.15}$$

The optical gain of an ideal non-imaging concentrator having internal refractive index n is [4]:

$$g(\psi) = \begin{cases} \dfrac{n^2}{\sin^2 \Psi_{\mathrm{c}}} & 0 \le \psi \le \Psi_{\mathrm{c}} \\ 0 & \psi > \Psi_{\mathrm{c}} \end{cases} \tag{3.16}$$

where $\Psi c \le \pi/2$ is the FOV From the constant radiance theorem; and n is the refractive index. From that, we can introduce SNR in Li-Fi cell as [4]:

$$\mathrm{SNR}_{\mu,r}(f) = \frac{|G_{\mu,\alpha}(f)|^2 P_{\mathrm{R}}}{\sigma^2}, \tag{3.17}$$

where PR is the transmit power on each subcarrier, σ*2 is the variance of the additive white Gaussian noise (AWGN); and Gμ,α(f) is the channel gain according to 3.16. For Li-Fi, the signal-to-interference-plus-noise ratio (SINR) for user μ and AP α can be given as [3]:

$$\mathrm{SINR}_{\mu,\alpha} = \frac{(\kappa P_{\mathrm{opt}} H_{\mu,\alpha})^2}{\iota^2 N_0 B + \sum(\kappa P_{\mathrm{opt}} H_{\mu,\mathrm{else}})^2}, \tag{3.18}$$

where κ is the optical to electric conversion efficiency at the receivers; N0[A*2/Hz] is the noise power spectral density; Hμ,α is the channel gain between user μ and Li-Fi AP; and Hμ,else is the channel gain between user μ and the interfering Li-Fi Aps.

Geometry LOS propagation model in Fig. 3.5, below:

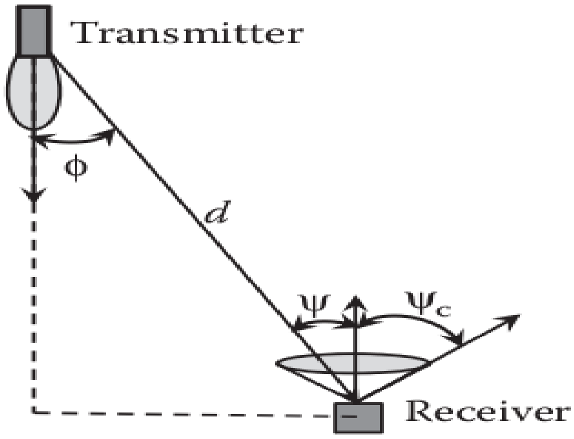


Fig. 3.5. Geometry of LOS propagation model.

3.2.2 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 DCO-OFDM system, the achievable data rate is expressed as [4]:

$$R(n)\mu,= B \log2(1 + SINR(n)\mu) \tag{3.19}$$

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

$$\tau_k = \begin{cases} \log_2\left(1 + \dfrac{(h_k a_k)^2}{\sum_{i=k+1}^{K}(h_k a_i)^2 + \frac{1}{\rho}}\right), & k \neq K \\ \log_2\left(1 + \rho(h_k a_k)^2\right), & k = K \end{cases} \tag{3.20}$$

3.3 Path Loss

The modeling of the path loss in optical wireless channel gained significant interest after the pioneering work of Gfeller and Bapst. They presented an analytical model for the received optical power in LOS and single-reflection NLOS OWC. An illustration of the geometry of this communication scenario is given in Fig. 3.6 describing the mutual orientation of the transmitter and the receiver, as well as their orientation towards the reflecting surface [6].

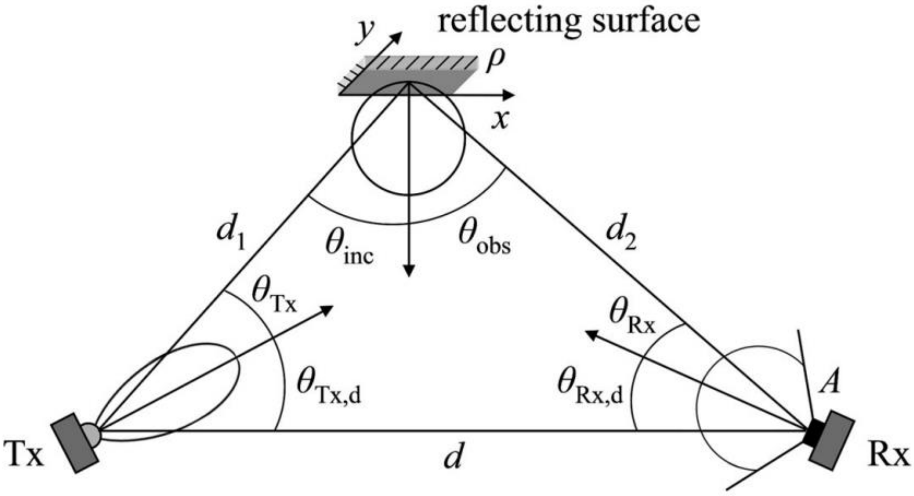


Fig. 3.6. Geometry of an OWK scenario (LOS, NLOS).

The received power according to the deterministic ray-tracing algorithm is generalized to accommodate multiple reflections, and integration is discretized as follows [6]:

$$P_{\mathrm{R}}(\lambda) = \sum_{i=1}^{N_{\mathrm{LOS}}} \frac{P_{\mathrm{LOS},i}(\lambda)}{N_{\mathrm{LOS}}} + \sum_{j=1}^{N_{\mathrm{NLOS}}} \frac{P_{\mathrm{NLOS},j}(\lambda)}{N_{\mathrm{NLOS}}} ,$$

where

$$P_{\mathrm{LOS},i}(\lambda) = P_{\mathrm{T}}(\lambda)\frac{n_{\mathrm{Tx}}+1}{2\pi}\cos^{n_{\mathrm{Tx}}}(\theta_{\mathrm{Tx},i})\frac{A}{d_i^2}\cos(\theta_{\mathrm{Rx},i})\mathrm{rect}(\theta_{\mathrm{Rx},i})$$

and

$$P_{\mathrm{NLOS},j}(\lambda) = P_{\mathrm{T}}(\lambda)\frac{n_{\mathrm{Tx}}+1}{2\pi}\cos^{n_{\mathrm{Tx}}}(\theta_{\mathrm{Tx},j})\left(\prod_{k=1}^{N_{\mathrm{refl},j}} \rho_k(\lambda)\frac{\mathcal{R}_k(\theta_k,\phi_k,\lambda)}{d_k^2}\right) \tag{3.21}$$

Here, NLOS is the number of LOS rays directly impinging on the PD, and NLOS is the number of rays which undergo one or multiple reflections before reaching the PD. In the LOS component, di is the distance of ith ray travels to the PD; θTx,i is the observation angle of the transmitter towards the receiver on the ith ray, while θRx, i is the associated incident angle of the receiver. In the NLOS component, θTx,j is the observation angle of the transmitter towards the first reflection on the jth ray, and θRx,j is the incident angle of the receiver from the last reflection[6].

$$\mathrm{PL}(d) = 10\log_{10}\left(\frac{P_{\mathrm{T}}}{P_{\mathrm{R}}(d)}\right) = \mathrm{PL}(d_{\mathrm{ref}}) + 10\zeta\log_{10}\left(\frac{d}{d_{\mathrm{ref}}}\right) + \xi \tag{3.22}$$

where PL(dref)is the path loss at reference distance; dref,ζ is the path loss exponent, and ξ is a random variable that accounts for shadowing effects. In the logarithmic domain, ξ has a zero -mean Gaussian distribution that corresponds to a log-normal distribution in the linear domain [6].

3.4 Load Balancing and Dynamic Handover

Due to the small coverage area of Li-Fi attocells, the movement of users can probably prompt handover. When the serving Access Point (AP) of a user is switched in two neighboring states, a handover occurs. In general, the handover overhead in an indoor scenario is in the order of milliseconds, which is assumed to be lower than the state interval Tp [4]. The handover efficiency between two adjacent states is defined as [4]:

$$\eta_{ij} = \begin{cases} \left[1 - \dfrac{t_{ij}}{T_p}\right]^+, & i \neq j \\ 1, & i = j \end{cases}, \qquad i, j \in \mathcal{C}, \tag{3.23}$$

Where tij is the overhead of AP switch from AP i to AP j.

The link data rate between AP α and user μ in state n with handover efficiency can be expressed as[4]:

$$r_{\mu,\alpha}^{(n)} = \begin{cases} \eta_{\alpha'\alpha} R_0, & \alpha = 0 \\ \eta_{\alpha'\alpha} R_{\mu,\alpha}^{(n)}, & \alpha = 1, 2 \ldots N_c \end{cases}, \tag{3.24}$$

where R(n)μ, is the Li-Fi data rate according to (5); α′ is the AP allocated to user μ in the state n−1; η′ is the handover efficiency from AP α′ to AP α, according to (7); and R0 is the Wi-Fi throughput. the load balancing algorithm used in each state is:

$$\gamma_\beta(x) = \begin{cases} \log(x), & \beta = 1 \\ \dfrac{x^{1-\beta}}{1-\beta}, & \beta \geq 0, \beta \neq 1 \end{cases}, \tag{3.25}$$

Where β is a proportion coefficient. Specifically, when β = 0، a linear utility function is realised and the maximal system throughput is achieved; when β = 1, the proportional fairness is achieved; and when β → ∞, the max-min fairness is obtained [4].

References of chapter three:

[1] Z. Ghassemloay, W. Popoola, S. Rajbhandari, "Optical Wireless Communication &Channel Modelling with Matlab,"book-chap. [4,3], 2013.
[2] Z. Ghassemloay, W. Popoola, S. Rajbhandari, "Optical Wireless Communication &Channel Modelling with Matlab,"book-chap. [8], 2013.
[3] Yunlu Wang, Harald Hass, Xiping Wu , " Fuzzy Logic Based Dynamic Handover in Hybrid LiFi /RF Network," IEEE paper, 2016.
[4] Yunlu Wang, Harald Hass , " Dynamic Load Balancing With Handover in Hybrid LiFi and WiFi Network," IEEE paper, 2016.
[5] Harald Hass, Liang Yin, Yunlu Wang, Cheng Chen, "What is LiFi?," IEEE paper, 2015.
[6] Svilen Dimitor, Harald Hass, "Principles of LED Light Communication Towards LiFi Network," book-chap. [2], 2015.

Chapter Four:

Simulation Results and Discussion

Chapter four

explores our related work on this project as a simulation and obtained results using matlab. Each section contains simulation results, some enhancement, and discussion concerning the results. In this chapter, we will discuss the following topics: BER, Multiple users Access, Power Distribution, and Hybrid System.

4.1 Bit Error Ratio

BER is the number of bit errors divided by the total number of transferred bits. Widely used modulation techniques in LiFi technology are on-off keying (OOK), Pulse Position Modulation (PPM), Pulse Amplitude Modulation (PAM) as demonstrated in [1].

Compared with OOK, PPM is more power-efficient but has a lower spectral efficiency. There are other digital modulation techniques mentioned in chapter three can be used for any visible light communication system.

For the seek of this example, the modulation schemes used are on-off keying OOK-NRZ which is the most used one and the easiest to be demodulated comparing with other modulation techniques. In this analysis, we ignore path loss factor and no multipath dispersion. The noise is assumed as a white Gaussian and this assumption have made because we want to concentrate on probability curve of OOK as comparison between simulation and theoretical results. So the major effect on BER curve will be as the block diagram presented in Fig. 4.1.

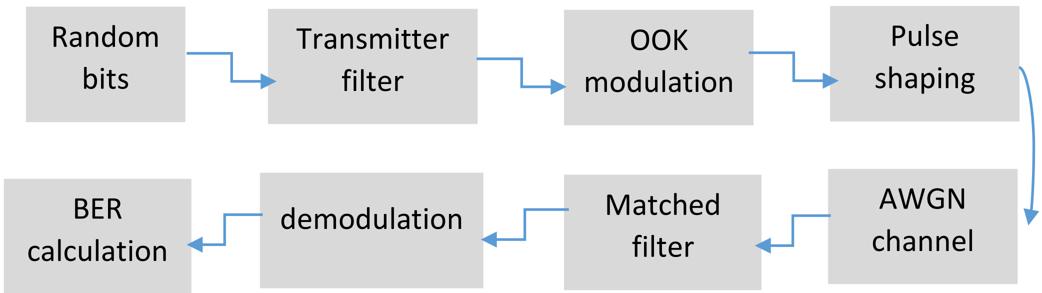


Fig. 4.1. Block diagram for BER calculation.

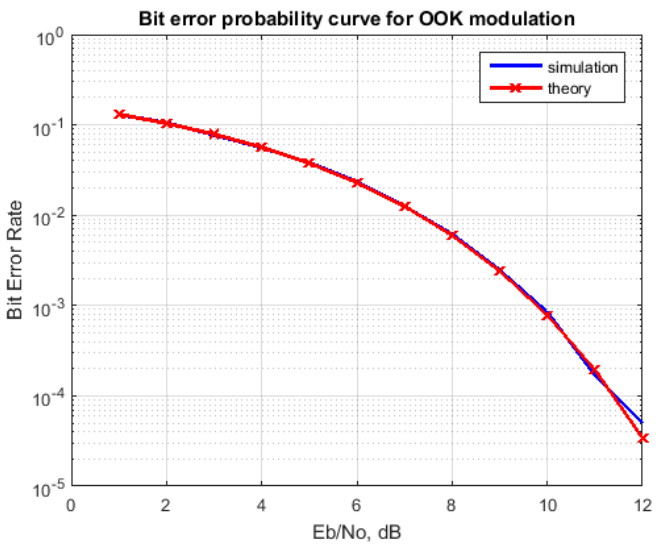


Fig. 4.2. Bit error curve for OOK modulation.

The results according to BER equations are shown in Fig. 4.2 for AWGN due to ambient light with double sided power spectral density No/2, zero mean and variant of σ^2.

TABLE 4.1
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 4.1 introduces the main parameters used in this simulation and they are standard values for most VLC systems.

An analysis of the BER as a function of SNR (The ratio Eb/N0 is usually referred to as the SNR per bit) with theoretical and simulation results is shown in Fig.4.2. All parameters used for this simulation are mentioned in Table 4.1 above. In this simulation we used a filter for the transmitted signal and a matched filter on the receiver side. Due to these principles, transmitted signal, which was generated randomly, is matched in 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' otherwise.
All of the process in this simulation is to reduce errors might have occurred during the transmission time. As a result, we got almost two identical curves for the simulated and theoretical results. In addition, BER curve for the practical results will be mentioned in chapter five to compare our practical results with other results published in papers.

4.2 Multiuser access in LiFi

As a wireless broadband technology, LiFi can provide multiple users with simultaneous network access. In this section we have done four simulations about this topic among four techniques: FDMA, TDMA, NOMA, and SDMA.

A. Multiuser Access in LiFi Attocell:

The basic principle of downlink NOMA is shown in Fig. 4.3 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 [1].

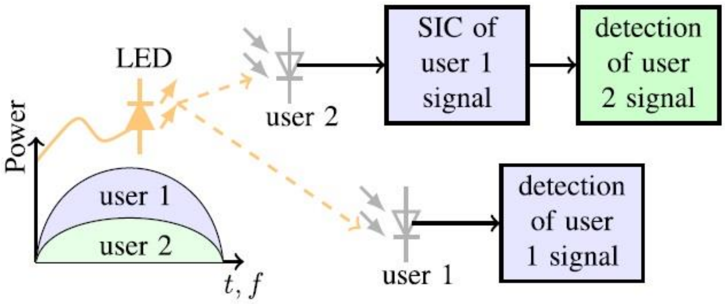


Fig. 4.3. Illustration of NOMA principle (two-user example).

Figure 4.3 shows that SIC that used at the receiver side to cancel the inter-user interference.

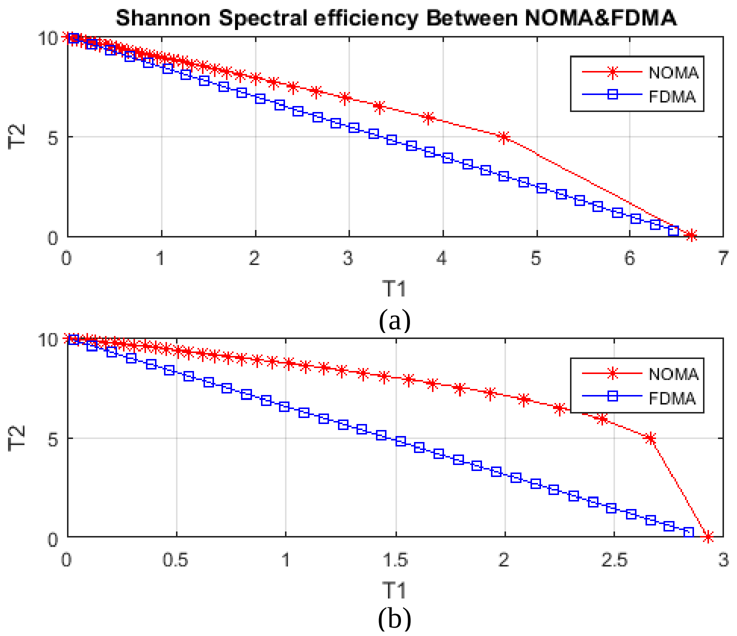


Fig 4.4. Shannon spectral effciency for NOMA & FDMA. a) Same channel conditions; b) Distinctive channel conditions.

In the previous Fig. 4.4, we show a comparison between FDMA with NOMA in a LiFi attocell (two user example). From Shannon spectral efficiency and according to our results seen in Fig. 4.4, the performance of NOMA is much better when compared the sum throughput inside a LiFi cell.
The difference between published results in [1] and our obtained results is: Their simulation and evaluation was between TDMA and NOMA whereas our results was for FDMA. However both have same result because both TDMA and

FDMA use appropriate user-scheduling techniques to ensure that fairness in the allocation of resources (subcarriers) is maintained.
The advantage of our results in this study is to have a maximum LiFi throughput even if there are multiple users and this can be done by NOMA rather than FDMA or TDMA techniques.

B. Multiuser Access in LiFi Attocell Networks:

In this part, the application of TDMA, NOMA, SDMA in a LiFi network will be discussed due to the overlapping coverage area of adjacent LiFi APs as introduced in Fig. 4.5. According to [1], 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.

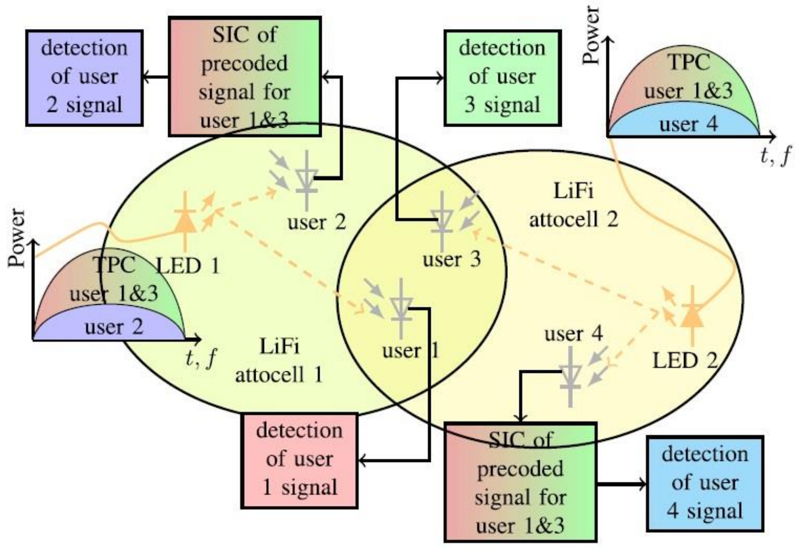


Fig. 4.5. Illustration of combined use of NOMA and SDMA in a two-cell LiFi network.

The results obtained in Figs. 4.6a and 4.6b demonstrate a comparison between TDMA and hybrid SDMA/NOMA in a LiFi network considering two users as an example. One of the users is in the intersection area. As a result, we found that according to Shannon spectral efficiency, NOMA/SDMA can enhance and increase total LiFi throughput with interference area better than TDMA or FDMA.

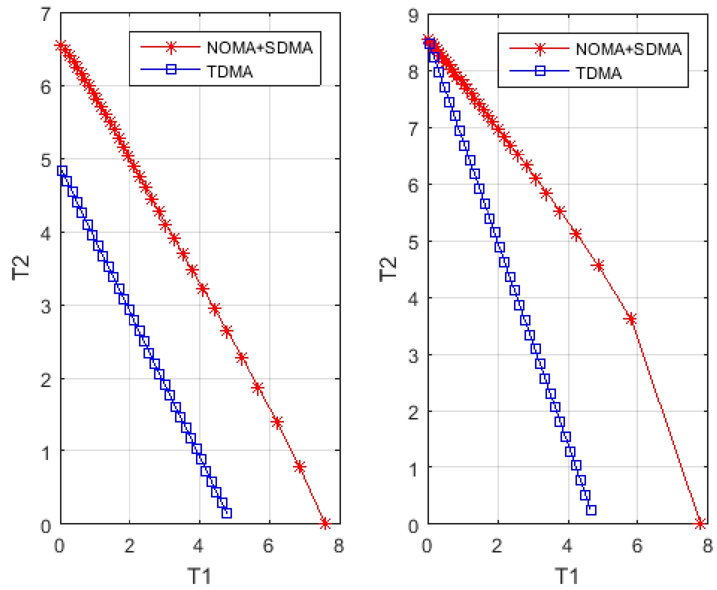


Fig. 4.6. Shannon spectral efficiency comparison between hybrid NOMA/SDMA and TDMA in a LiFi network. A) user 1 and user 2 are both near the cell edge; B) user 1 is near the cell edge while user 2 is near the cell center.

4.3 Hybrid LiFi & WiFi system

Due to the increasing demand for wireless data communication, and the decrease of the available spectrum, we expect, in the coming four years, a huge use of this hybrid system that will make the start of LiFi future.

1- Hybrid LiFi and WiFi System with One LiFi Cell

This simulation is concentrating on SNR inside a LiFi cell and how it is distributed. Note that, the size of blue circles is changing with SNR inside a LiFi cell.

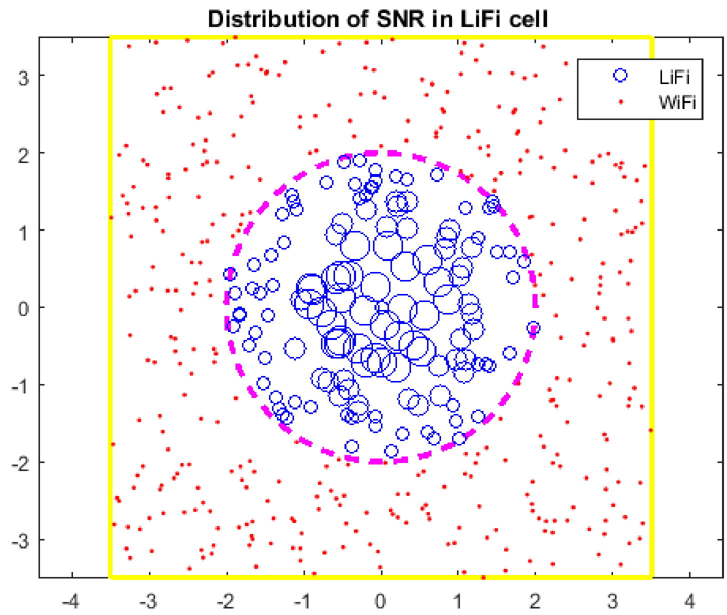


Fig. 4.7. SNR distribtion in a LiFi cell.

Figure 4.7 introduces the distribution of SNR inside a LiFi cell that will be the main idea for the coming section. By Considering Shannon capacity law with the effect of the distance between each user and the LiFi AP, we notice that in small r –near to the center- high SNR is obtained and as we increase r the SNR is decrease until it reaches to SNR=0dB outside the cell then the users in this case will be served by WiFi.

2-Hybrid LiFi and WiFi System with Four LiFi Cells in non-CCI Case

For the seek of this example, we consider 4 LiFi cells in non-CCI case (no intersect cells) to study the effect of WiFi throughput in each LiFi cell.
In Fig. 4.8 Wi-Fi throughput is set to 120Mbps, whereas in Fig. 4.9 WiFi throughput becomes 1Gbps the effect of each value in non-CCI case is illustrated in this approach.

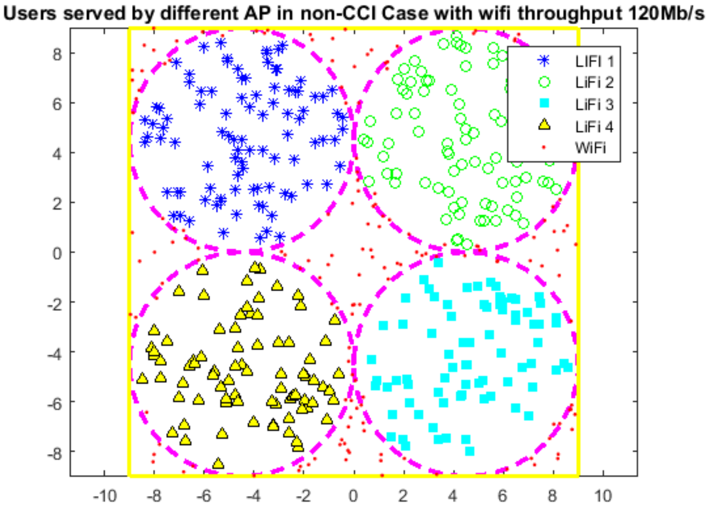


Fig. 4.8. Users dstribution in non-CCi case with WiFi throughput 120Mbps.

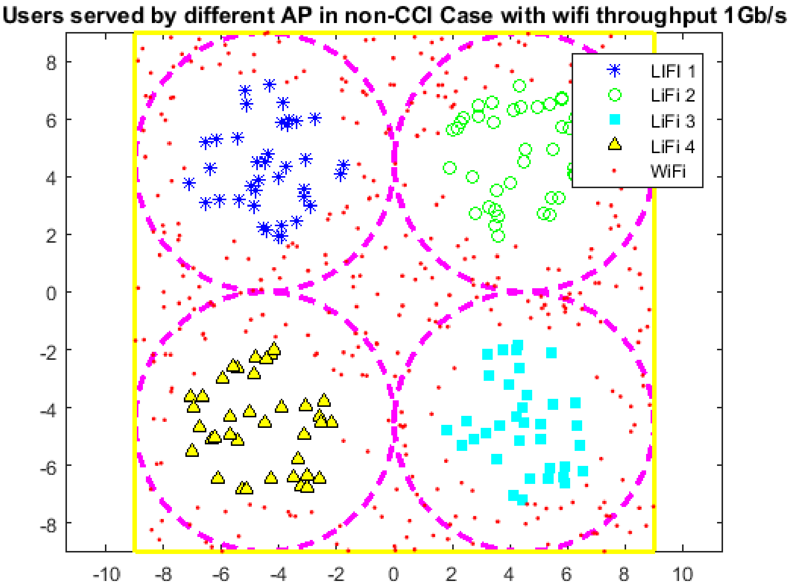


Fig. 4.9. Users dstribution in non-CCi case with WiFi throughput 120Mbps.

The obtained results in this section, study the effect of WiFi throughput in non-CCI case with four LiFi AP. The result obtained in Figs. 4.8 and 4.9 was as what we expected according to SNR distribution results in Fig. 4.6. Since SNR for each cell is zero at their edges, we got some users served by a WiFi signal. Moreover, as we increase WiFi throughput, more users located at circles edge will serve by a WiFi until it reachs to the same LiFi throughput. When we increase WiFi throughput as in Fig. 4.9, more WiFi users will serve in the LiFi cell edge and that's because LiFi SNR in the edge will be lower than WiFi signal which has a maximum throughput equal to 1Gbps.

3-Hybrid LiFi and WiFi System with Two LiFi Cells in CCI- Case

In this section, we show what happen in the case of CCI-channel (two intersect cells) considering three major variables:

1- Distribution of SNR in LiFi cells (discussed in section one).
2- WiFi throughput effect (explored in section two).
3- Signal to interference noise ratio.

These three parameters will control the number of users which will be served by each LiFi AP.

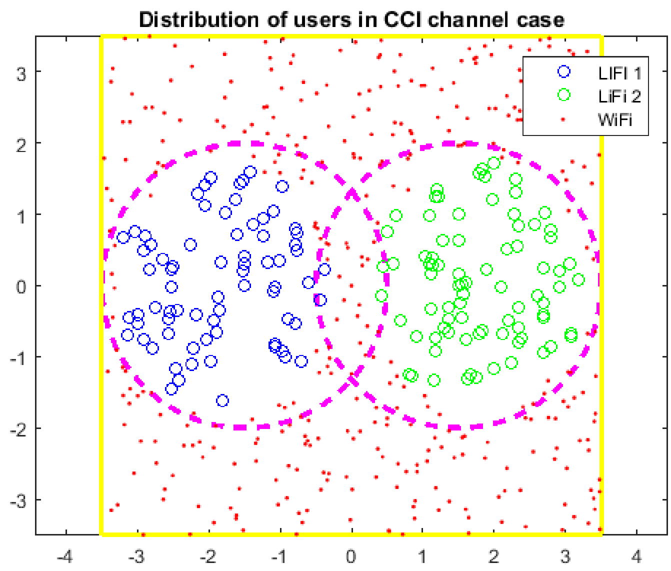


Fig. 4.10. Users distribution in CCI-case.

This section is focusing on the effect of intersecting area between the two cells in case of CCI- channel with new major variable called Signal to Interference Noise Ratio (SINR). Figure 4.10 illustrates the distribution of users inside and outside the two cells and how the intersecting will affect this distribution. In the result we found that users inside intersecting area will be served by WiFi because it has higher SNR and throughput.

4-Hybrid LiFi and WiFi system with four LiFi cells in CCI-channel case

In this part, we will summarize all situations and main points mentioned in the previous sections as areal LiFi scenario considering SNR, SINR, and WiFi throughput in CCI-channel.

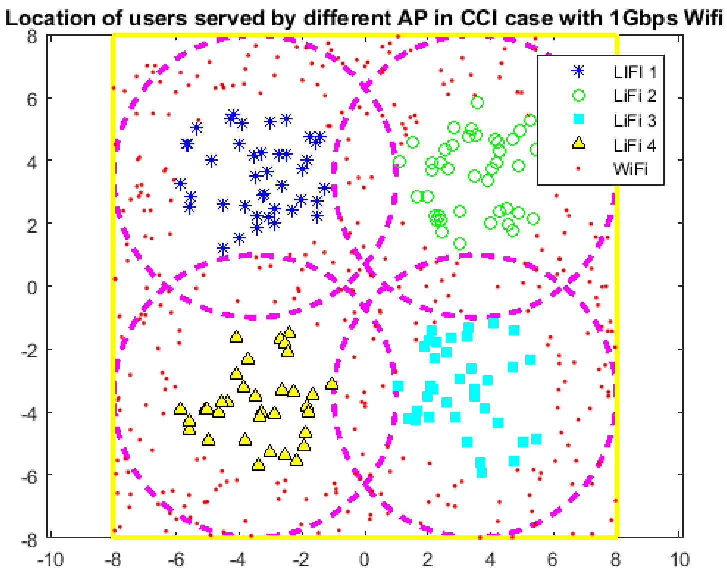


Fig. 4.11. Users distribution in CCI-case with WiFi throughput 1Gbps.

WiFi and LiFi throughput is set to be 1Gbps and the effect of SNR & SINR is demonstrated in Fig. 4.11. The results obtained as follows:

1-Users in the intersection area will be served by WiFi.

2- LiFi users will locate in which there is no intersection effect because of SINR.

3- Increasing WiFi throughput decrease LiFi users because of SNR effect.

5-Friquancy reuse techniques in hybrid LiFi and Wifi system

In previous simulations regarding hybrid LiFi/WiFi network, we considered WiFi standard which can almost guarantee a maximum throughput among 12m to simplify the simulations steps. Now we consider more practical situation when we had a poor WiFi signal with four LiFi cells in CCI- channel. In this scenario we want to increase number of users that will use LiFi inside the cells. So, we applied frequency plane techniques and avoid any interference between the cells.

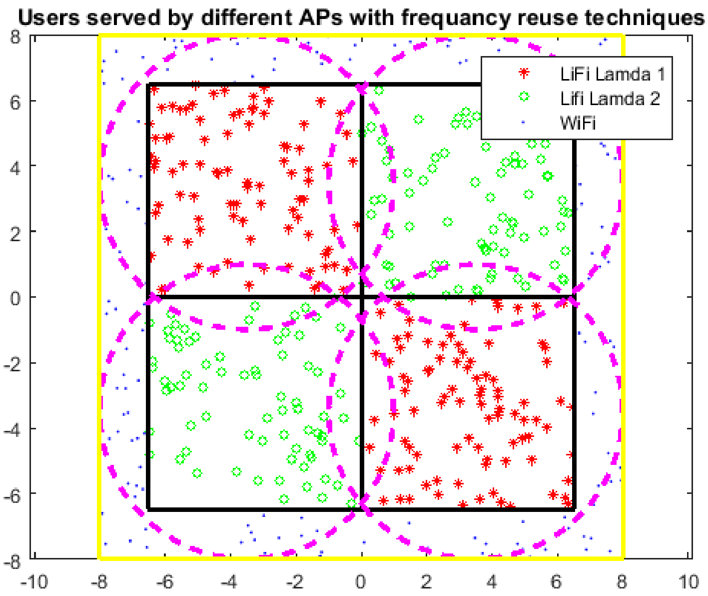


Fig. 4.12. Users distribution with frequancy reuse plan.

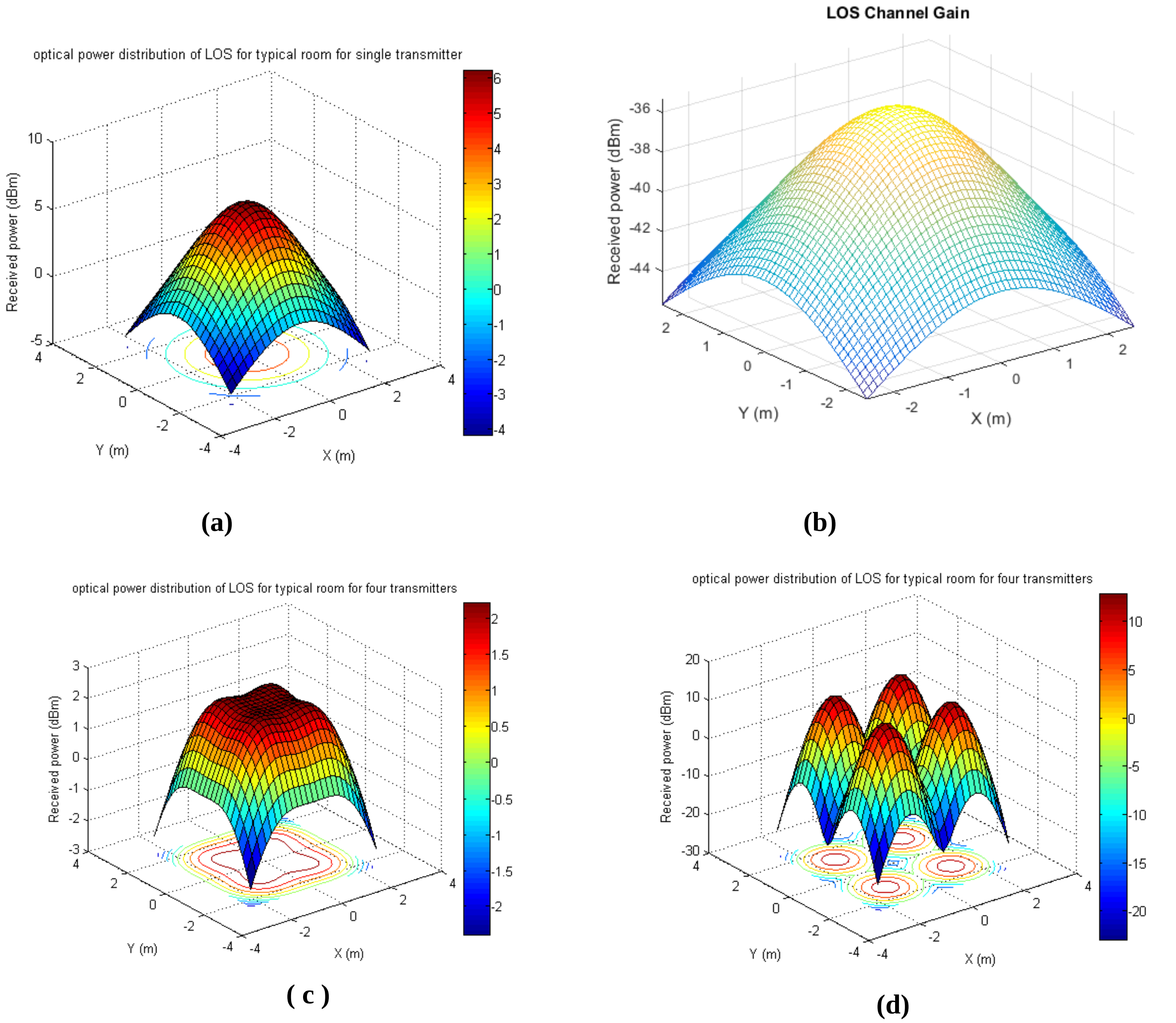
Figure 4.11 illustrates the application of frequency reuse techniques in a LiFi system. The bandwidth for a white led is 20 MHz and this bandwidth will be divided over two since we have four intersecting cells as shown in Fig. 4.11. The results state that number of LiFi users increase comparing with Fig. 4.10. However, LiFi throughput will decrease with the decreasing of its bandwidth but since we are using square cells, we will guarantee no WiFi users inside the LiFi coverage and no interference occurred.

4.4 Power Distribution

The optical power distribution for a receiver plane in a LOS path (ignoring the reflection of walls) is shown in Fig. 4.12a for one transmitter and Fig. 4.12 for the optical channel gain. Figures 4.12c and 4.12d presented four transmitter with different sensitive half angle.

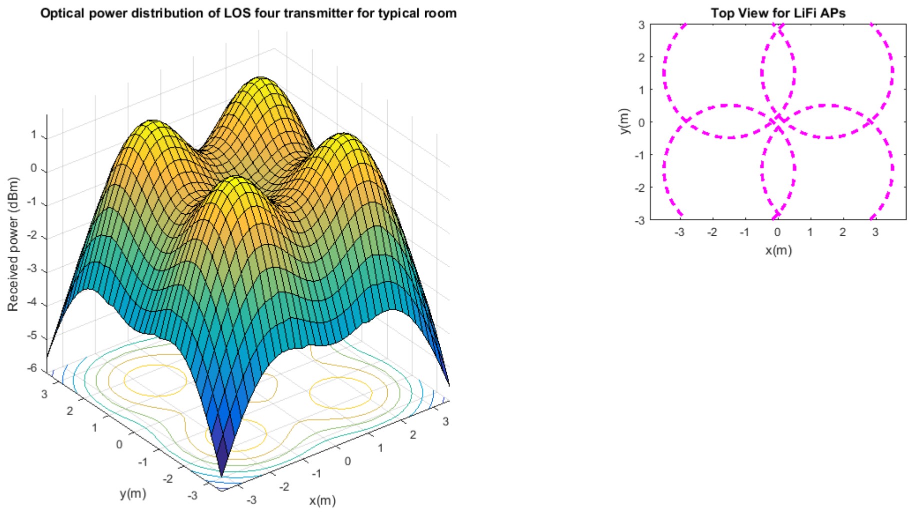
Figure 4.12 shows the total optical power distribution in a room with dimensions (5x5m) as the following:

Results obtained in this section is shown in Fig. 4.13 and we found that optical power received is distributed over the room with four transmitters better than using only one transmitter as illustrate in Figs. 4.13a and 4.13c. However, when the sensitive half angle equal to 12.5 degree as in Fig. 4.13d, we received greater power than when it was 70 degrees as in Fig. 4.13c.



Figs. 4.13. 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 transmitter with sensitive angle of 70 ; d) power distribution for four transmitter with sensitive angle of 12.5.

As a result, the advantage of these simulations is to build a good coverage plane for LiFi APs in typical area. Therefore, we have applied this results and techniques to a real example office with dimensions (7x7m) using standard LiFi AP specifications mentioned in [4]. Figures 4.14 introduces this coverage plane for an office with dimensions (7x7m).



(a) (b)

Figs. 4.14. LiFi coverage plane for an office (7x7m), a) Optical power Distribution in 3D view; b) Top view for LiFi Aps.

Summary:

In this chapter, we study four main topics in LiFi technology they still have being enhanced until now. First topic was BER theoretical and simulation calculations for OOK-NRZ modulation. Our results was almost the same as in [2] but we added more practical curve using same techniques in chapter five. There is also BER curve in [1] paper and they used OFDMA techniques with OOKand it differs from our curve.

Second section, we made an evaluation for the newest multiplexing techniques (NOMA) which has been used recently in 5G. Results we have obtained showed that NOMA is better from FDMA techniques when we compare total user throughput. In [1], they made same evaluation between TDMA and NOMA. They found that LiFi throughput can be efficiently enhanced with the application of NOMA. We also made same comparison between hybrid NOMA/SDMA with TDMA in a case of interference channels. Our results was exactly same as what was in [1], hybrid SDMA with NOMA can enhance and increase LiFi throughput in the network with interference exist. SIC in NOMA techniques is used to illuminate the interference by a TCP vector and SDMA.

Hybrid LiFi/WiFi network is showed in third section as the following:

We start by studying SNR with one cell then we add WiFi throughput effect in non-CCI channel. After that, we moved to SINR with two cells only and at the end we applied all what we got in four CCI-channel. Our final results is exactly the same as [1] & [4]. After achieving the results concerning load balancing algorithm, we want to apply frequency reuse tecgniques and present the differences, so we made a new simulation with square LiFi cells in a hybrid LiFi/WiFi system. The results illustrated that users served by LiFi can increase using frequency reuse factor and this is useful when we cannot guarantee maximum WiFi throughput.

Last simulations we made was focusing on how can we made a good plan for LiFi APs in typical room. The results we obtained is same as [6] except last one because we use our previous results and applied it to an office with specific dimension.

Finally, we achieved a good results and enhancement in the previous sections. Due to this point, we will continue this study among the proposed topics in this chapter because they will carry the future of LiFi, on other worlds, future for Internet of Things (IOT).

References of Chapter Four:

[1] Harald Hass, Liang Yin, Yunlu Wang, Cheng Chen, “What is LiFi?,” IEEE paper, 2015.

[2] Z. Ghassemloay, W. Popoola, S. Rajbhandari, “Optical Wireless Communication &Channel Modelling with Matlab”-chap. [4], 2013.

[3] L. Dai, B.Wang, Y. Yuan, S. Han, C.-L. I, and Z.Wang, “Non orthogonal multiple access for 5G: Solutions, challenges, opportunities, and future research trends,” IEEE Commun. Mag., 2015.

[4] Yunlu Wang, Harald Hass, “Dynamic Load Balancing With Handover in Hybrid LiFi and WiFi Network,” IEEE paper, 2016.

[5] Z. Ghassemloay, W. Popoola, S. Rajbhandari,“Optical Wireless Communication &Channel Modelling with Matlab,” book-chap. [8], 2013.

[6] H.Q. Nguyen, J.H. Choi, M. Kang, Z. Ghassemloay, D.H. Kim, “Matlab- Based Simulation Program for indoor VLC System,” IEEE paper, 2010.

Chapter Five:

Implementation of proposed method

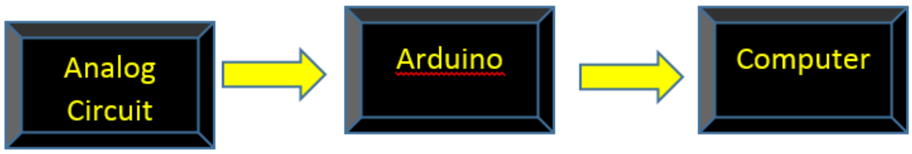
This chapter demonstrates:

Steps involved in implementation with some simulations; electronic parts and programs will be used for this project. Finally, it represents our result from this transceiver that can be integrated in a real LiFi scenario.

The objective of this chapter is to build a system with similar principles as LiFi technology that consists of:
Transceiver to send and receive text from both sides using Light.

5.1 Project Block Diagram

(Transmitter side Block Diagram)



(Receiver side Block Diagram)

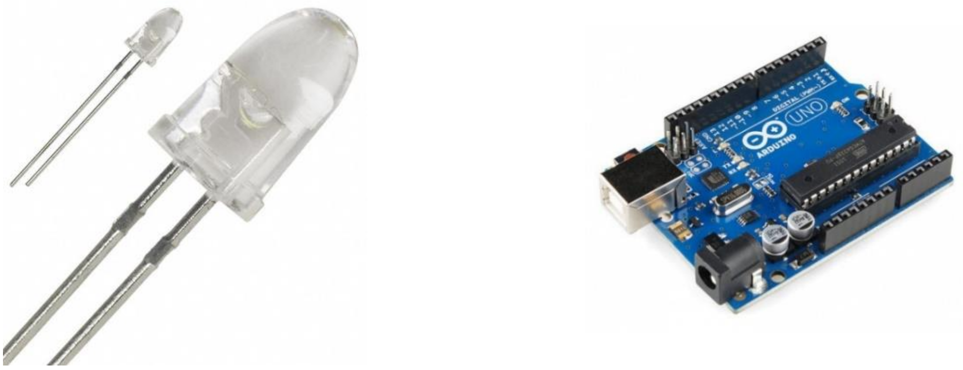
Fig. 5.1. Project block diagram

5.2 Transmitter Side
5.2.1 Components

1- Arduino: An open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing[4].

For our usage, we will program a microcontroller inside Arduino board to get binary information from matlab and do some tasks.

2-LED:
An LED is often small in area (less than 1 mm2) and integrated optical components may be used to shape its radiation pattern. Led characteristics for this Project:
1- Freq. speed 1MHz. 2- Color white.



Figs. 5.2. Transmitter components. a)white led. b) Arduino Uno board.

5.2.2 Circuit diagram

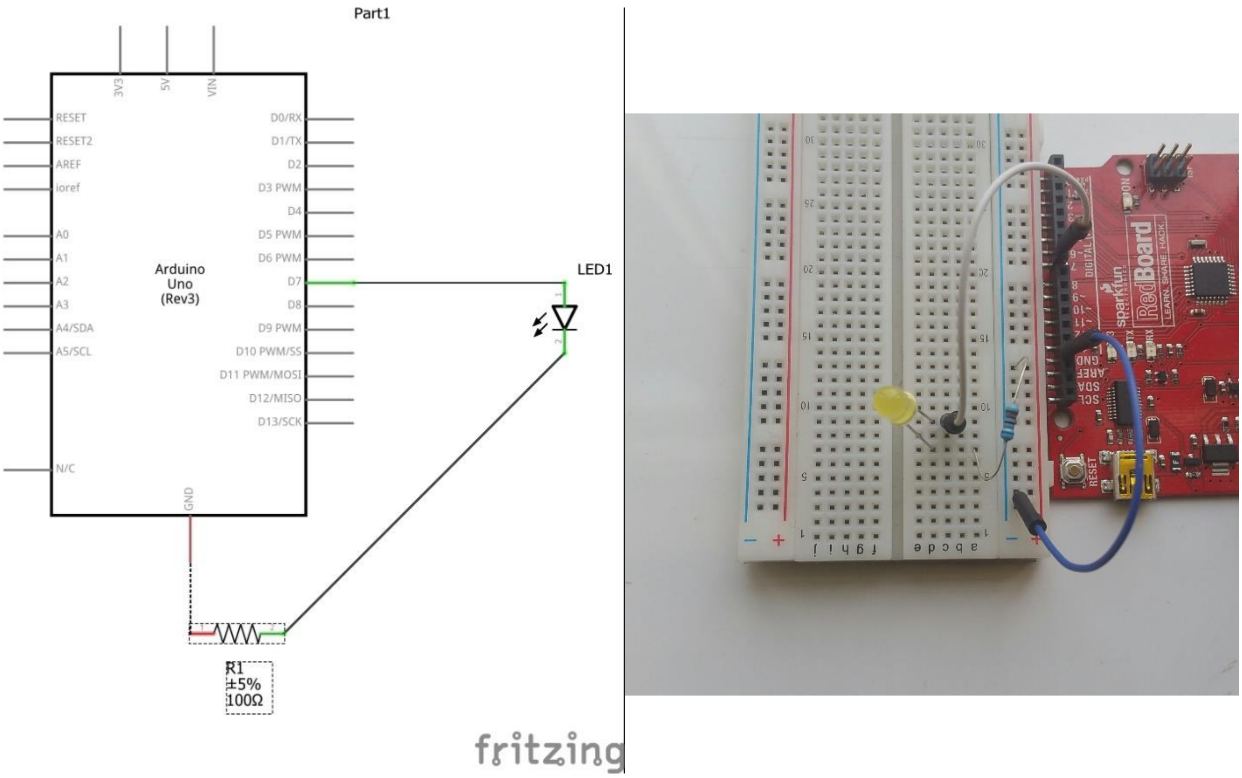


Fig. 5.3. Transmitter circuit diagram.

5.3 Receiver Side

5.2.1 Components

1- Arduino: we will use also another arduino to receive and import the data to the computer.

2- Photodiode: A semiconductor device converts light into current. The current is generated when photons are absorbed in the photodiode. Photodiodes may contain optical filters, built-in lenses, and may have large or small surface areas. Photodiodes usually have a slower response time as their surface area increases[5].
For our project we will use BPW20RF photodiode with the following specifications:
-Response time less than 10ns. Half angle 50 degree. We connect this photodiode with 470k ohm to adjust the current that will pass and to fix its sensitivity.

5.3.2 Circuit Diagram

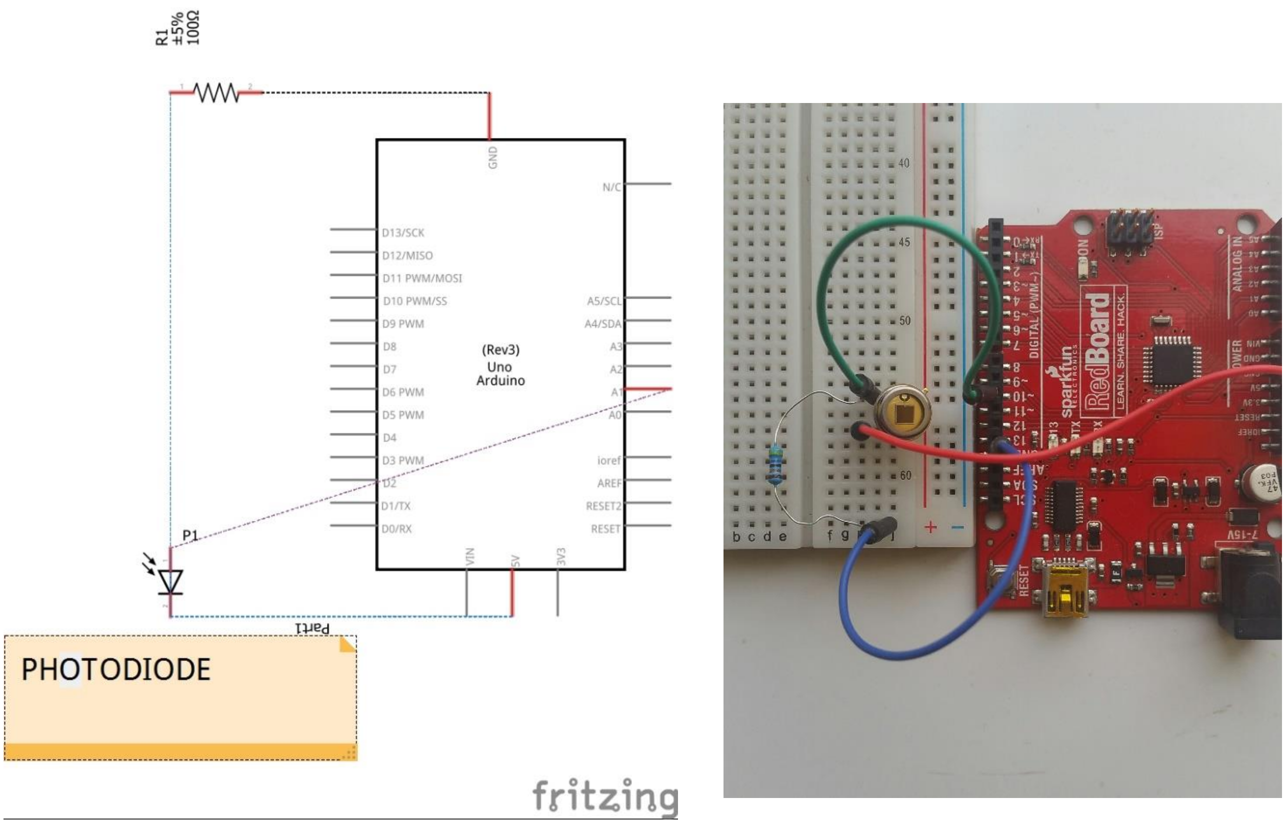


Fig. 5.4. Reciever circuit diagram.

5.4 Matlab & Arduino Program

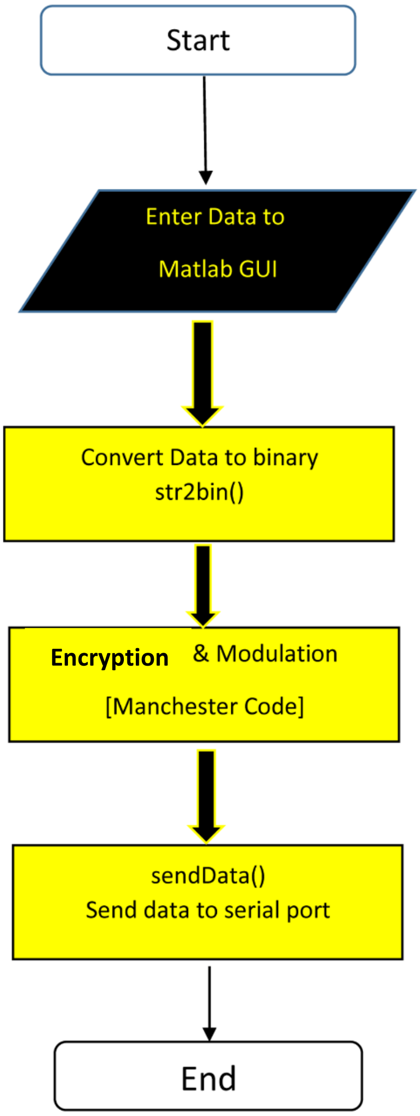


Fig. 5.5. Matlab transmitter flowchart.

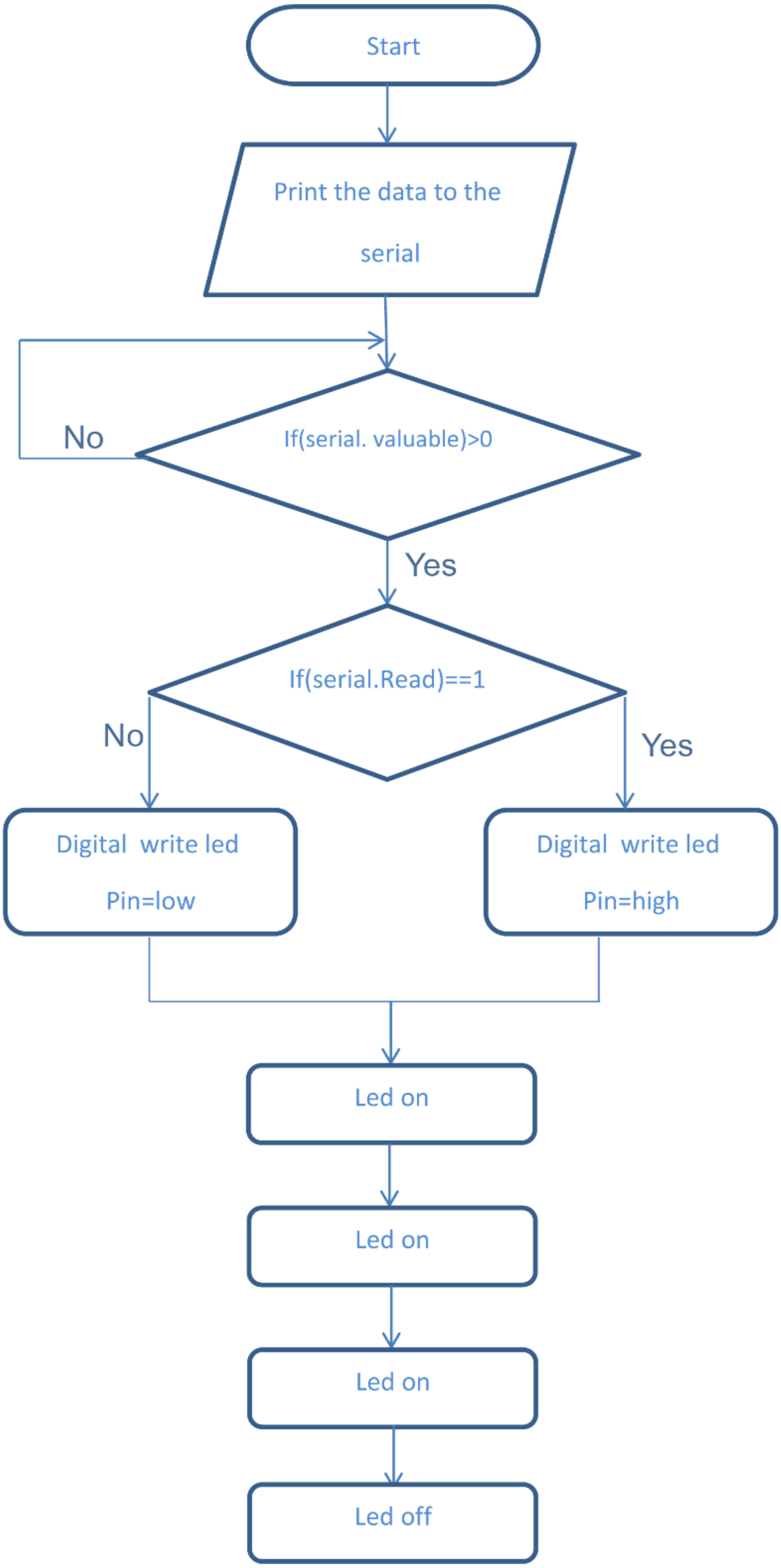


Fig. 5.6. Arduino flowchart for the transmitter code.

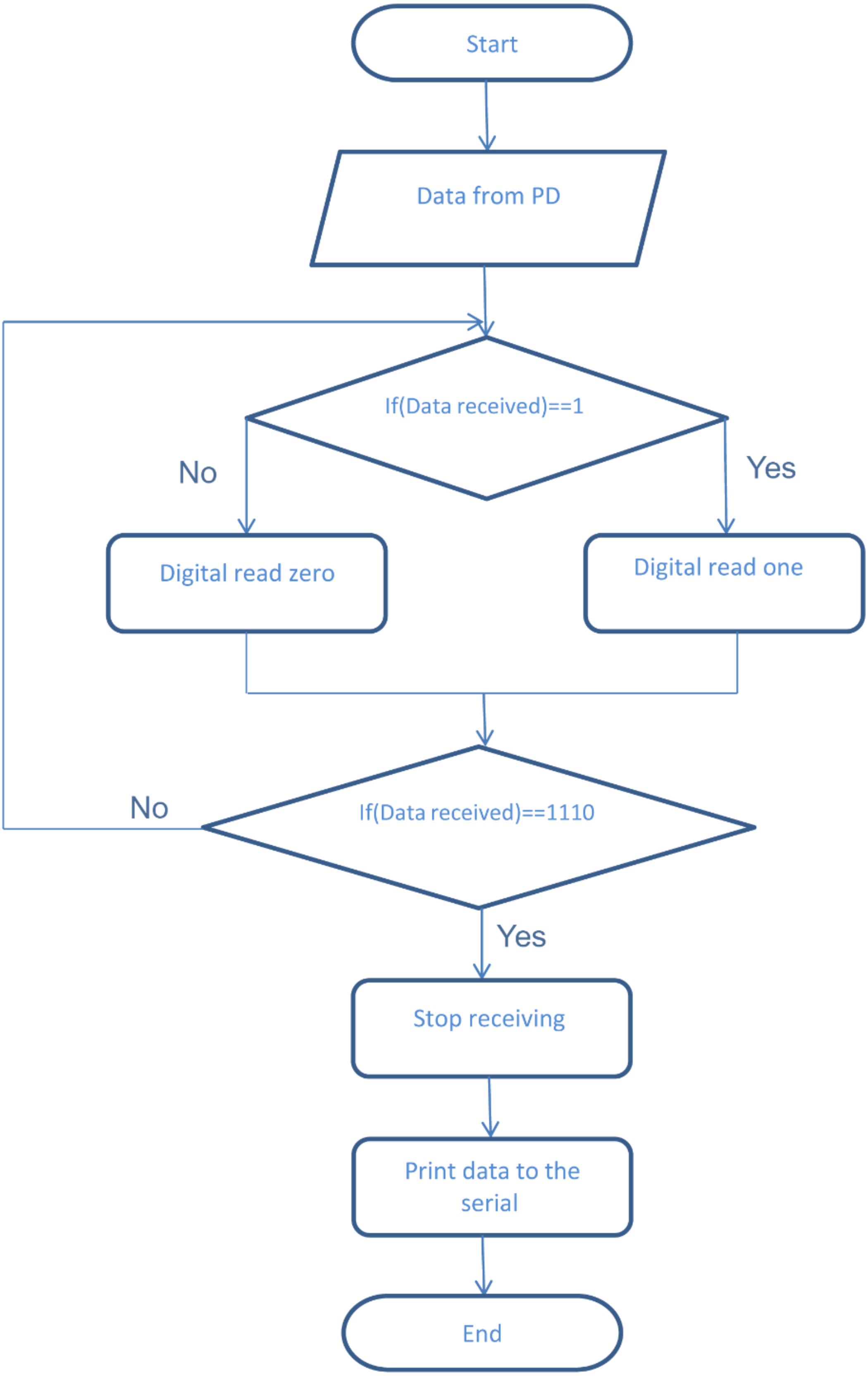


Fig. 5.7. Arduino flowchart for the reciever code.

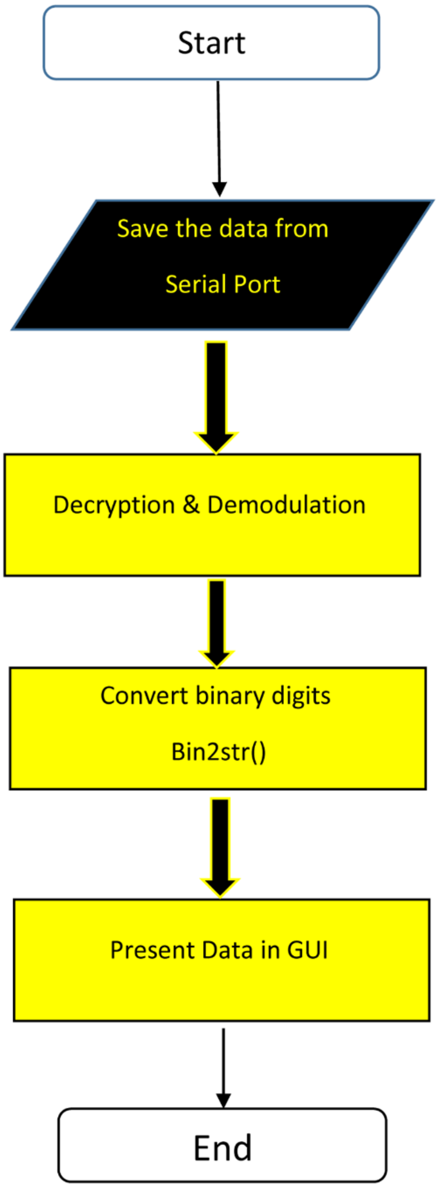
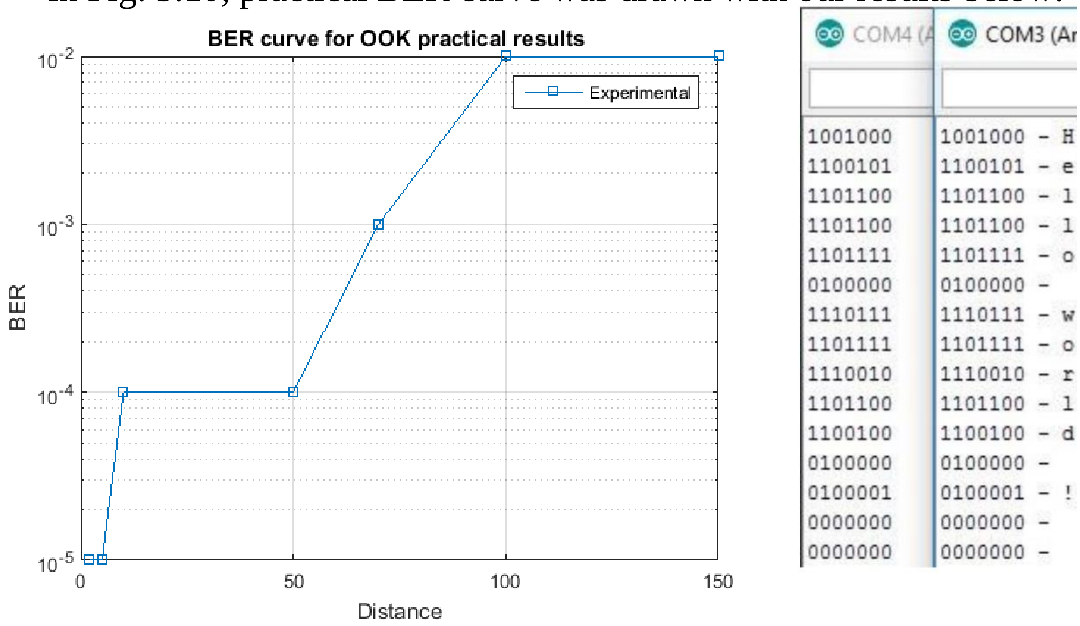


Fig. 5.8. Matlab flowchart for the reciever.

5.5 Summery

Figures 5.3 and 5.4 showed the circuit connection with Arduino Uno. We used digital pin to write data to the LED and digital pin for reading data from the photodiode. After implementing both circuits with their Arduino code as introduced in Figs. 5.6 and 5.7. We have made some tests by sending a stream of binary data and we fixed the difference time delay between TX and RX. Then we tried to increase the data rate until we reach to 0.67Kbps. We also tried to extend the distance by using Laser and we reach up to 3 m. at the end we integrate our system with a real light bulb and it gives maximum distance equal to 2m as seen in Fig. 5.10, practical BER curve was drawn with our results below:



(a) (b)

Fig. 5.9. BER calculation for practical results. a) BER curve for practical results; b) Transmitted and received bits.

After we had tested the circuits and fixed both [time delay & distance], we connected the circuit to the matlab codes which illustrated in Figs. 5.5 and 5.8. The most important tasks that will be done by matlab code are:

1- Processing user data and decreasing errors might occurred.

2- It connects GUI with the circuit so that we can understand the data being sent.

3- More reliable and easy to use for many applications.

At the end, we got a good result and we have achieved our goal from this prototype.

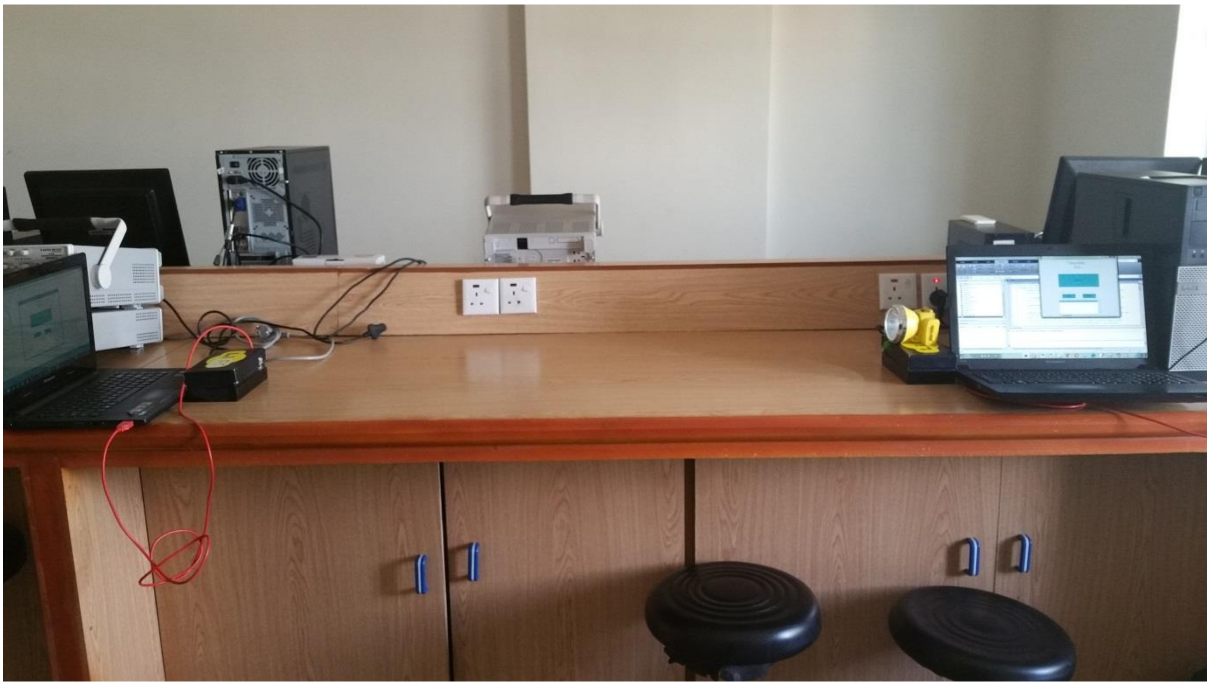


Fig. 5.10. Implementation final work.

References of Chapter Five:

[1] S. Kim and S.-Y. Jung, ―Novel FEC coding scheme for dimmable visible light communication based on the modified Reed- Muller codes, ‖ IEEE Photon. Technol. Lett., vol. 23, no. 20 pp. 1514– 1516, Oct. 2011.
[2] Zubin Thomas, Nikil Kumar and D. Jyothi Preshiya, “Automatic Billing System using Li-Fi Module,” IEEE paper, April 2016.
[3] R. Mahendran1, “Integrated Lifi(Light Fidelity) Communication Through Illuminatio”, 2016.
[4] https://www.arduino.cc_ [Why Arduino]
[5] Victor Monozon, Matilde Sanchez, Ana Garcia and Antonio Royo, “Testbed For LiFi in street Light,” IEEE paper, 2015.

Chapter Six:

General Conclusion

This chapter concludes this
work and study with brief explination
about what we got at the end. It also
demonstrated future work that can be handled
by other groups or teams depending
on this project.

Conclusion and Future Work:

In this study, a LiFi technology with several techniques and scenarios is discussed. All information about LiFi technology and its formulation was studied with brief explanation. Moving on, this thesis also showed and discussed the key research areas that are required to relies LiFi attocell. BER and multiusers access scheme was presented with our simulation results. Hybrid LiFi/WiFi networks with a load balancing techniques were proposed to mitigate the handover effects before and after frequency reuse factor. Finally, implementing for transmission using light was made and we got good results.

Due to steps we followed during our work, we explored many improvement and enhancement need to be done for the coming LiFi future, especially in simulation part. This work is the ending of our bachelor’s degree project and the beginning of master’s project with more enhancement for the simulation results. Hybrid WiFi or RF with LiFi systems, multiplexing techniques used in LiFi or uplink scenario will be our scope in the coming work. In the other side, many projects and researches can be done according to our results, which we got. Starting by simulation work, we improved our results but it also can be improved more. First, in hybrid LiFi/WiFi network simulation, we increased users throughput using load-balancing algorithm and we add frequency reuse plan in order to increase the users serve by LiFi APs. Future improvement can be done concerning hybrid LiFi/WiFi systems is increasing LiFi throughput inside a LiFi cells with frequency reuse plan. Second, in our multiusers access results we evaluated four types of multiplexing techniques. More work can be done to increase LiFi throughput by using new multiplexing techniques considering new scenarios. Last thing can be handled is hybrid LiFi/RF systems using same principles we followed in hybrid LiFi/WiFi network. This topic is the newest search has introduced recently at 2016.

As implementation work, there will be more enhancements like increasing the speed, reducing errors, sending other data types or using other computer, phone or Ipad software.

In closing, we had achieved all objectives we aimed to do and enhanced this new technology for the future use.