The Possibilities for Deployment Eco-Friendly Indoor Wireless Networks Based on LiFi Technology

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Abstract: Recently, traffic demand for wireless data has increased the need for extending the spectrum to transmit numerous signals. However, the bandwidth of radio waves has been scrunching in the last few years with tremendous development of technology such as 4G, 5G, Internet of Thing (IoT) and so on. Therefore, in a few recent years, LiFi technology which is considered a complement solution for radio frequency technology has attracted a lot of attention in scientific community. LiFi, which is a part of optical wireless communication (OWC), employs visible light from the green and eco-friendly light emitting diode (LED) to forward signals. In addition, LiFi is best-known for high-speed, bi-directional connection, save energy, security network, and safe for human. Because of the potential advantages that LiFi benefits in, we investigated to analyze the possibility to deploy indoor wireless networks based on LiFi technology with the existing infrastructure of LEDs and PoE cables. Moreover, in this study, we proposed the wireless network model in a typical office with nine LED luminaires positioned in the center of the room ceiling that support to intensify the illumination and communication in an entire room. Additionally, the received power of optical signals and signal-to-noise ratio (SNR) level in the proposed model were calculated and simulated with the MATLAB program. The study of these parameters advocates deploying the network system more effectively.

1 INTRODUCTION

According to an analysis in [1] that has pointed out the exponential increase of wireless data and significant growth of approximately 80 billion IoT devices which connect to the wireless network by 2020 and beyond. Due to the explosion of the amount of wireless data to be transmitted, the radio waves spectrum is quickly reaching its limit, as well as breeding some problems that are gaining more cause electromagnetic interference with high-frequency, not enough spectrum capacity to send out the enormous amount of data, and difficulty in security data [2]. Because of these limitations in wireless technologies which uses radio waves (RF) to carry signals, a number of researchers have drawn attention to other parts of the electromagnetic spectrum in order to find out the new approaches to deal with this issue. Therefore, LiFi, which had proposed since 2011 by professor Harald Haas, is considered as one of the robust trusted technologies, and widely known as a solution to complement wireless technology, especially WiFi.

In particular, the visible light that has a range of spectrum which is larger more than radio frequency approximately 10000 times, and unregulated that means LiFi no need to have a license to operate [3,4, 15-20]. Moreover, LiFi network system offers the dual functions of light used for lighting and communication purposes. Furthermore, LiFi could be compatible with PoE cables used for backbone networks, owing to simplify the network system and save energy [5-6]. Thanks to this, LiFi technology may have huge opportunities to develop and become more widespread in the future. Additionally, it should be noted that there have not been many pieces of research in evaluating the possibility of combining the benefits of both LEDs and PoE technology to use an indoor wireless network. For this reason, in this paper, LiFi's characteristics were studied, the possible prospect of deployment indoor wireless networks based on LiFi technology was explored, and we desire to investigate as much as possible in this issue, especially in typical office network systems. Simultaneously, parameters of physical elements in the network system which impact on process transmitting data were analyzed and simulated in MATLAB program to choose the suitable type of LEDs luminaires for setting up the position of LED luminaires array efficiently.

The rest of the study is constructed as follows: Section II assesses the possibility of deploying indoor wireless networks based on LiFi technology. Section III described the light of sight (LOS) propagation model in LiFi system. In section IV, the model of the wireless network in a typical office was proposed, and the received optical power and SNRlevel were calculated and simulated in MATLAB program. In section V, simulation results, which impact on the connectivity quality and the selecting different kind of LED luminaires for setting up a wireless network, were discussed. Finally, Section VI sums out the study and orientates future studies.

2 PROSPECTS OF DEPLOYING INDOOR WIRELESS NETWORKS BASED ON LIFI TECHNOLOGY

2.1 Structure of LiFi Network

Basically, LiFi network consists of two main components that are LED transmitter and LiFi dongle. Both of them have a built-in infrared uplink sensor. LiFi access point (AP) can be connected directly to the base network using PoE cables that contain data and power as one. In this case, LiFi technology has following merits:

- Environmentally safe wireless connection.
- Can be used in places that do not allow the use of WiFi (such as in aircraft, hospitals, etc).
- High bandwidth.
- High efficiency, energy saving, no required license, energy saving, and can be compatible with infrastructure based on lighting system using green and eco-friendly LEDs and PoE technology.
- Safe for humans (especially children and pregnant women).

The structure of the LiFi network was shown in Figure 1, in which the benefits listed above can be realized. First of all, LEDs are semiconductor devices, therefore, the impulse of light emitted by

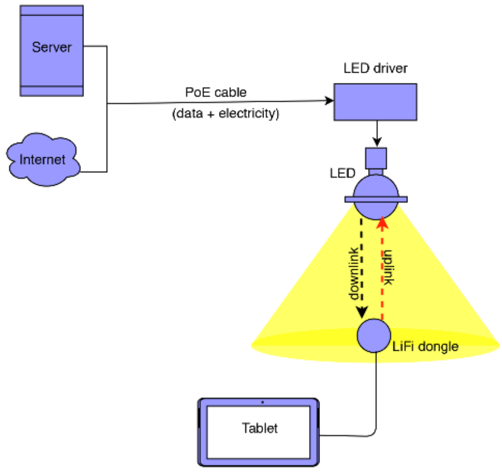


Figure 1: The structure of LiFi network system.

LEDs can be changed expeditiously. Recently, the time of switching LEDs from one state to another can reach nanoseconds. It allows transferring information in a wide variety of speeds. At the same time fluctuations in the light are not captured by the human eye. And in LiFi dongle, the signal is detected and light intensity changes are interpreted as data. In addition, it can integrate a built-in infrared detector for the uplink.

Then, the work process of the LiFi network system is as follows. Firstly, data from the Internet or Server of department store, office, hospital,…are sent to the LED driver which controls the process of converting electrical signals into optical ones using PoE cables. At the present time, almost LiFi luminaries are integrated LED drivers inside. Secondly, the modulated signals from LEDs are transmitted to the photodetector (PD) integrated into LiFi dongle. Finally, LiFi dongle which is plugged into end-user equipment like computers, laptops or smartphones to receive optical signals from LEDs and converts data from photon to electronic forms. The LiFi dongle integrated an infrared LED that modulates the transmission data from users to return to the LEDs and to the network.

2.2 Possibility for the Deployment of the Indoor Wireless Network System Base on Existing Infrastructure

Due to rising electricity prices, LEDs are now being implemented everywhere to decrease the cost. And there is a number of leading companies which deal with lighting business note that the use of LED lamps provides them with more than 50% of their income. In particular, Acuity Brands (67%), OSRAM (65%), Philips (61%), Hubbell (55%), and Zumtobel (73%). According to Strategies Unlimited at the end of 2016 LEDs accounted for 11% of the total number of installed lighting devices, and by 2022 this value would reach 20% as shown in Figure 2 [7,16].

In addition, the search for energy-efficient solutions attracted attention to the PoE technology which allows the transmission of electrical energy and data using the same cable. For example, there are already high-rise buildings in Amsterdam which have over 6500 PoE connections to LEDs, that help to reduce installation cost by 25% and system deployment time by more than 50%. Likewise, by 2024, the PoE market will be expected to reach $105.2 million, an increase of 13% on CAGR data as illustrated in Figure 3. So the growth rate of the LEDs and PoE market is a great prospect for the development wireless network based on LiFi technology, as it is ready for the basic wireless network infrastructure.

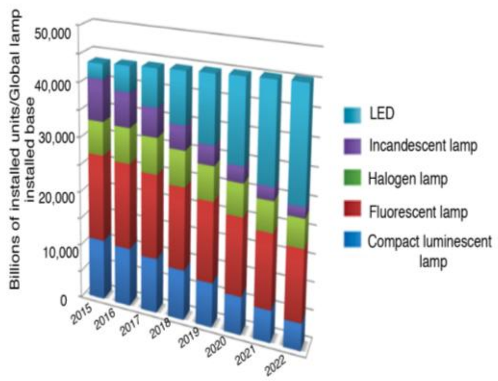


Figure 2: The trend growth some kind of lamps in the market from 2015 to 2022.

Currently, there are some pioneer companies (e.g. Oledcomm, Purelifi, Vlncomm, and others) that offer LiFi devices used to build optical wireless optical networks. On top of that, the world's first optical LiFi elements designed for mobile integration embedded into a standard HP laptop to facilitate high-speed LiFi with Gbps connectivity has published by pureLiFi company at the Mobile World Congress on February in 2019. The Gigabit LiFi system can transmit data up to 1 Gbit/s for downlink, and 377 Mbps for uplink [8]. However, this can be seen the LiFi components are still relatively high-priced. The cost is a range from $1000 to $2000 for a set of the transmitter. In addition, the LiFi network requires more transmitters than Wi-Fi due to standard illumination. According to experts, it is necessary to reduce the price of equipment up to $100 per piece, so that they were competitive compared to WiFi devices. On the other hand, it is necessary to scale down the size of the LiFi devices so that smartphones and laptops can accommodate signal receivers inside.

Additionally, in 2018 the IEEE 802.11 Working Group on LiFi Communications worked with manufacturers, operators, and end-users to develop a new standard [9]. The goal was to ensure that the new standard was completed in May 2021. However, it is possible to use the early version of the standard at this time. Therefore, the developing of the new LiFi equipment is in full swing.

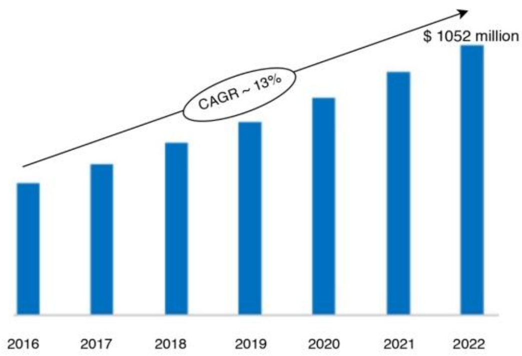


Figure 3: The trend of PoE market growth from 2016 to 2022.

3 LIGHT OF SIGHT PROPAGATION MODEL

In the indoor places, light reflects from the ceiling, walls or mirror surfaces but does not penetrate obstacles, while in external environment light is dissipated and absorbed in atmospheric conditions. There are several ways in which optical paths can be physically configured. They are usually grouped into two main system configurations: LOS (directed light) and non-LOS (undirected light). The LOS connection to the LiFi network offers lots of benefits including faster data transfer speeds over Gb/s, security, and low power consumption [10,11]. Therefore, in this study, we just dominated analyzing basic parameters which are relevant for the deployment network in the LOS path as shown in Figure 4.

The attenuation coefficient H_{LOS_i} of the optical signals from the LEDs to the receiver located at a distance d_i and the angle φ_i in LOS path can be simplified as [12]:

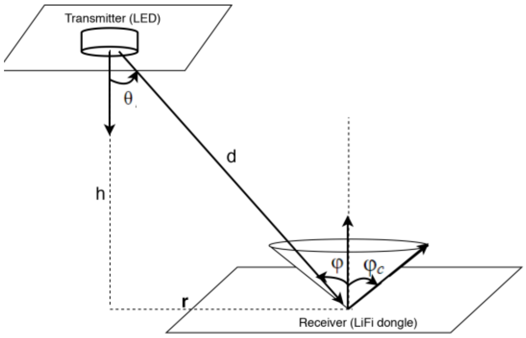


Figure 4: The LOS propagation model in optical channel.

$$H_{LOS\_i} = \begin{cases} \dfrac{m+1).A_{PD}.cos^m(\theta_i).T_s.g(\varphi_i).\cos\varphi_i}{2\pi d_i{}^2} \\ 0, \varphi_i > \varphi_c \end{cases} \quad (1)$$

where m is the Lambert order number representing the direction of the beam of the source, which is given as [12]:

$$m = \frac{-ln2}{ln(cos(\phi_{1/2}))}, \quad (2)$$

where $\phi_{1/2}$ is the angle at which the intensity of the source is half compared to the intensity when the source is viewed directly on the axis; A_{PD} is the physical area of the photodetector; θ_i is the incidence angle; φ_i is the angle at which the source is considered; T_s is the gain of optical filter; $g(\varphi_c)$ is the gain of optical concentrator, which is expressed as [12]:

$$g(\varphi_c) = \begin{cases} \dfrac{n^2}{sin^2(\varphi_i)}, \varphi_i \le \varphi_c \\ 0, \ \varphi_i > \varphi_c \end{cases}, \quad (3)$$

where $0 < \varphi_c < 90^{\circ}$ is the maximum angle at which the light that falls on the optics can be successfully sent to the detector.

For simplicity, we assumed that $\theta_i = \varphi_i$ and $cos(\theta_i) = \frac{h}{d_i}$.

Then H_{LOS_i} can be obtained as:

$$H_{LOS\_i} = \frac{m+1).A_E.T_s.h^{m+1}}{2\pi(d_i)^{m+3}}, \quad (4)$$

where A_E which is the light collection zone and is usually expressed as the area of the detector multiplied by the optical gain of any optics, can be written as [12]:

$$A_E = A_{PD} * g(\varphi_c). \quad (5)$$

4 CALCULATING THE RECEIVED OPTICAL POWER AND SNR LEVEL

4.1 Select quantity of LEDs

In LiFi technology, light from LEDs is used effectively with dual functions: lighting and data transmission. Therefore, when setting up the LiFi optical wireless network, we must consider the allowable illuminance of the LED to provide minimal illuminance for the network location. Especially for the indoor network, e.g. schools, hospitals, offices…

In this work, optical wireless network system LiFi in typical office is modeled. Thus, the illuminance requirement range is between 350 lux and 500 lux level satisfied the ISO standard [13]. General, the illuminance can be determined by the formula:

$$L_X = \frac{P_T .N_{LED} .\emptyset}{S}, \quad (6)$$

where L_X is the illumination; P_T is the power of LED; N_{LED} is the number of LEDs; $\emptyset$ is the energy efficiency of the system; and S = a × b, is the office size.

To guarantee the minimum illuminance for the network place, the number of LEDs should be accounted for. Consequently, from (6) the number of LEDs IN LED can be calculated as follow:

$$\frac{L_{Xmin} .S}{P_T .\emptyset} < N_{LED} < \frac{L_{Xmax} .S}{P_T .\emptyset}. \quad (7)$$

In this simulation, we selected each LED with a transmitted power P_T of each LED is equal to 35 W, an office size is 6m × 6 m, and $\emptyset$ is 50 lumen W. Hence, the quantity of LEDs is expressed as:

$$\frac{350.36}{35.50} < N_{LED} < \frac{500.36}{35.50}. \quad (8)$$

Equation (8) is equivalent to:

$$7.2 < N_{LED} < 10.3. \quad (9)$$

With the results from (9), we picked out 9 LEDs for our simulation.

4.2 Proposed indoor wireless network system configuration in the typical office

To calculate the parameters of the system, we used the following scenario. The fixed components of the

Li-Fi network consist of LEDs located around the center ceiling of the office as depicted in Figure 5. The distance between adjacent LED lamps is 2 m. The coordinates of each LED are given by (X_T, Y_T). The mobile component of the Li-Fi network consists of terminals moving at the office at very low speeds. The coordinates of a receiver is (X_R, Y_R). Therefore, the distance d_i can be calculated by:

$$d_i = \sqrt{(X_R - X_T)^2 + (Y_R - Y_T)^2 + h^2}. \quad (10)$$

And 100 × 100 points are selected in the room. These sample positions are uniformly allocated on the plane where the receiver is positioned. Other parameters of the LiFi system, presented here, are shown in Table I.

In this simulation, the selected LEDs have the same parameters, so if the receiving device is located under directly the LED at these positions (1,1), (1,2), (1,3), (2,1), (2,2), (2,3), (3,1), (3,2), (3,3), their received power is the same. The signal receiving signal is given by the formula :

$$P_R = P_T . H_{LOS\_i} = P_T . \frac{(m+1). A_E . T_s . h^{m+1}}{2\pi (d_i)^{m+3}}. \quad (11)$$

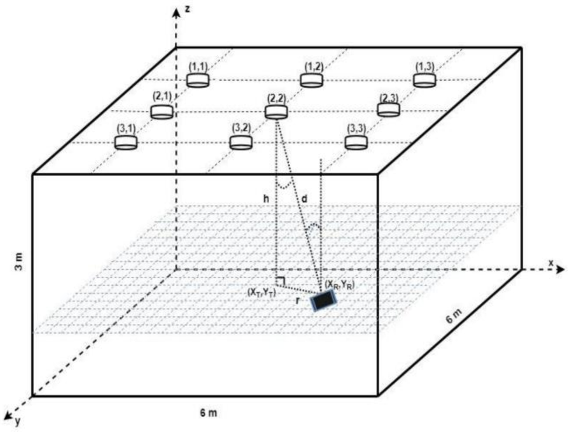


Figure 5: Proposed indoor wireless network system model with 9 LED luminaires.

4.3 Simulating in MATLAB program

Normally, LEDs have various radiation models that correspond to the value of $\varphi_{1/2}$. In this study, we simulated three scenarios with three different LED models selected, i.e. a planar lens, $\phi_{1/2} = 60^{\circ}$; a semispherical lens, $\phi_{1/2} = 40^{\circ}$; a parabolic lens,

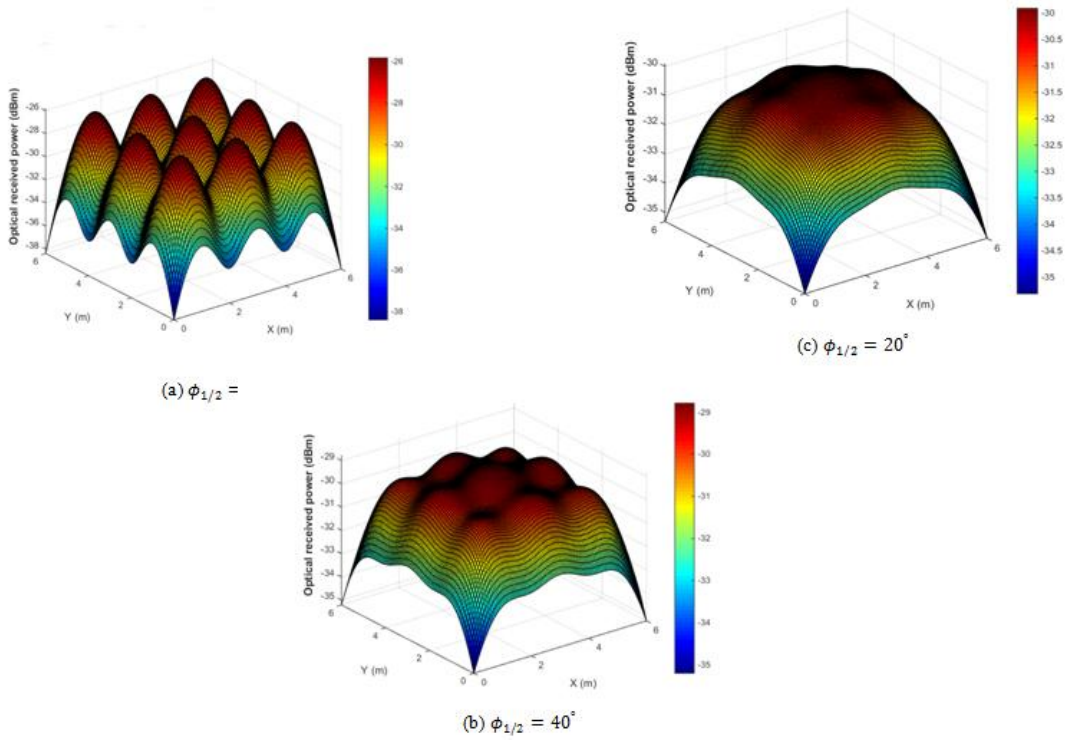


Figure 6: The optical received power distribution with diffirent LED model, (a) $\phi_{1/2} = 20^{\circ}$, (b) $\phi_{1/2} = 40^{\circ}$ and (c) $\phi_{1/2} = 60^{\circ}$.

$\phi_{1/2} = 20^0$. Note that the vertical stick on the right side of the picture indicates the relationship between P_R (or *SNR)* and color: blue represents the smallest value of P_R, and yellow is the highest P_R value.

Table 1: Simulated Parameters

Parameter	Value
Office size	6m×6m×3m
Vertical distance between transmitter and receiver plane, h	2 m
The half-intensity angle, $\phi_{1/2}$	20°, 40°, 60°
Transmitted optical power for an LED, PT	35 W
Number of LEDs, N_{LED}	9 LEDs
Field of view, φ_c	60°
Optical filter gain, TS	2
Refractive index of the lens in the photodetector, n	1,5
Physical area of the photodetector, APD	25.10-6, m2

4.4 Simulated results

4.4.1 Optical received power

4.4.1.1 Scenario I: $\boldsymbol{\phi_{1/2} = 20^0}$

The maximum received optical power, P_{R_max}, is -25.8360 dBm, when the receiver is located directly below the LED, and the minimum P_{R_min} is -38.3878 dBm, when the receiver is located in the corner of the room. Thus, the difference from peak to deflection is 12.5518 dBm.

4.4.1.2 Scenario II: $\boldsymbol{\phi_{1/2} = 400}$

P_{R_max} = -28.7871dBm
P_{R_min} = -35.2049 dBm
$\Delta P_R = P_{R\_max} - P_{R\_min}$ = 6.4178 dBm

4.4.1.3 Scenario III: $\boldsymbol{\phi_{1/2} = 600}$

P_{R_max} = -29.9097 dBm
P_{R_min} = -35.3150 dBm
$\Delta P_R = P_{R\_max} - P_{R\_min}$ = 5.4053 dBm

4.4.2 SNR level

4.4.2.1 Scenario I: $\boldsymbol{\phi_{1/2} = 200}$

The same as the received optical power, the maximum $SNR_{\_max}$ is 55.4376 dB when the receiver is positioned straight under the LED, while the minimum $SNR_{\_min}$ is 42.8738 dB when the receiver is positioned in the edge of the room. Thus, the variation SNR is 12.5638 dB.

4.4.2.2 Scenario III: $\boldsymbol{\phi_{1/2} = 400}$

SNR_{max} = 52.4859 dB
SNR_{min} = 46.0634 dB
$\Delta SNR = SNR_{max} - SNR_{min}$ = 6.4225 dB
SNR_{max} = 51.3629 dB
SNR_{min} = 45.9531 dB
$\Delta SNR = SNR_{max} - SNR_{min}$ = 5.4098 dB

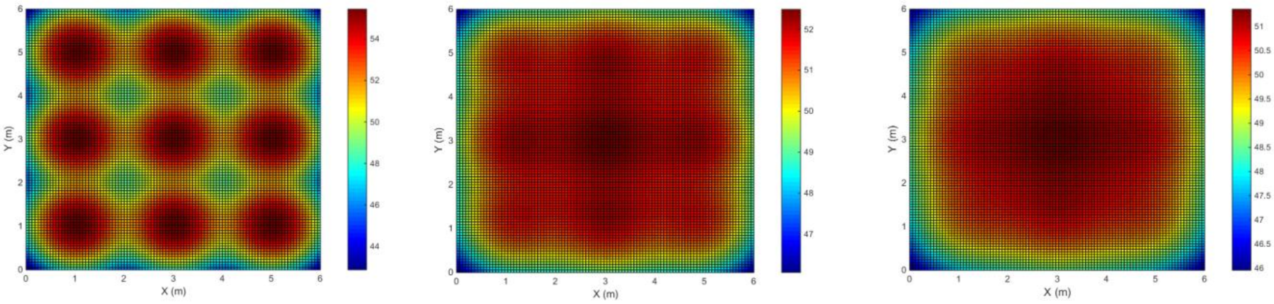
5 DISCUSSING SIMULATION RESULTS

As mention in the earlier studies [14], to stabilize the connection between transmitters and receivers the optical received power at the receivers requires higher than the receiver sensitivity (about - 36 dBm). As shown in Figure 4, the received power value is ranging from about -35 to -30 dBm in most of the places in a proposed model. Therefore, these results match the result mention before. Consequently, in these scenarios, all lighting configuration can get full connectivity.

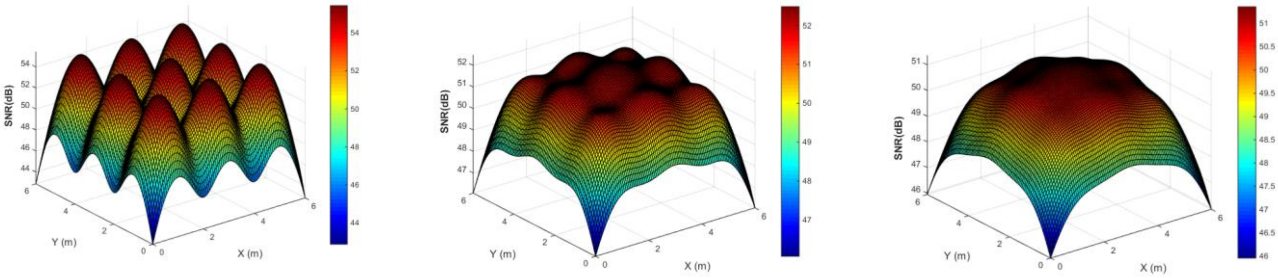
Furthermore, observing Figure 6 and Figure 7, it can be seen that SNR is proportional to P_R. When the value of P_R increases, SNR simultaneously raises. In addition, the optical signal power is strongest at the area under directly each LED and it becomes more weaker moving towards the corners.

In the first case when $\phi_{1/2} = 20^{\circ}$, the value of optical received power and the SNR level is the highest level at small areas (ΔSNR=12.5638 dBm) and appear blind spots on received plane including four corners and overlap areas. It means receiver maybe cannot get the light or receive a small amount of light from the LEDs in these areas.

In the second scenario when $\phi_{1/2} = 40^{\circ}$, the optical received power is distributed more uniformly on the receiving plane due to the difference between the highest and the lowest value is not too large about 6.4178 dBm, and the SNR level is at the medium level.



(a) $\phi_{1/2} = 20^{\circ}$ (b) $\phi_{1/2} = 40^{\circ}$ (c) $\phi_{1/2} = 60^{\circ}$



(d) $\phi_{1/2} = 20^{\circ}$ (e) $\phi_{1/2} = 40^{\circ}$ (f) $\phi_{1/2} = 60^{\circ}$

Figure 5: 2D plot for SNR distribution with diffirent LED model, (a) $\phi_{1/2} = 20^{\circ}$, (b) $\phi_{1/2} = 40^{\circ}$, and (c) $\phi_{1/2} = 60^{\circ}$. 3D plot for SNR distribution with diffirent LED model, (d) $\phi_{1/2} = 20^{\circ}$, (e) $\phi_{1/2} = 40^{\circ}$, and (f) $\phi_{1/2} = 60^{\circ}$.

5.1 Scenario III: $\phi_{1/2} = 600$

In the third case when $\phi_{1/2} = 60^{\circ}$, in the overlap areas, the value of the SNR level is declined gradually in spite of the fact that the receivers get more optical power from different LEDs. This is because, in the overlap area, the total received power is the sum of the desired signal power and noise power. And if the noise power increases that leads to the reducing of the channel quality and rising the BER level.

6 CONCLUSIONS

In this work, the possibility of deploying indoor wireless networks based on LiFi technology with the available infrastructure of LEDs and PoE cables is investigated. Additionally, we proposed the LiFi network model in the typical office with a size of 6m × 6 m × 3m and 9 LED luminaires. Furthermore, we were calculating the optical received power and SNR level in order to evaluate the quaility of the channel. Moreover, our simulation results have shown the relation between the optical received power and SNR level, i.e. when PR at the highest level, SNR also at the highest level. In order to reach the best connectivity, the half-intensity angle, in other words, it is the type of LEDs should be considered for setting the LiFi network system. Overall, with LEDs has the half-intensity angle that is equal to 40 or 60 will provide more uniform distribution of light more than the angle is 20. In conclusion, the result of this study provides wider support for researchers to investigate LiFi technology, and it could be used for companies to design effectively any practical LiFi network systems. Further studies with more focus on LiFi should be done to research the applicability of LiFi technology in hospitals and on airplanes.

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