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Novel Design for Li-Fi Healthcare Monitoring System

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Abstract: Patients who are in healthcare places need for continuous healthcare monitoring system for long periods to surveillance human body vital signs. This system should be secure, reliable, and guarantee not to interfere with available radio frequencies or sensitive electronic devises such MRI (magnetic resonance imaging) since it deals with human life. In this paper, we designed, implement and evaluate a prototype model for Li-Fi healthcare monitoring system over different propagation links as an integrated optical system. The key idea of the created system is to remove the optical background noise power and to ensure patient's mobility at distance up to 4 m and 2.5 m in Los (line of sight) and diffuser links respectively. The system is created to receive data from a fibre Bragg gratings sensor (FBG) that will be sent to the end receiver through different propagation links having 100 % accuracy. Also, it is particularized with low power consumption, low-cost components, and could be adapted to different other systems of sending or processing operation. The proposed system provides, much more accurate received data compared to previous related literature.

Keywords: Li-Fi, Wi-Fi, Healthcare, Optical wireless.

1. Introduction

Light fidelity (Li-Fi) is a new technology emerged as an alternative or solution to Wi-Fi (wireless fidelity) restrictions (capacity, efficiency, availability and security). Li-Fi is principally transmission of data via the illumination using LEDs and a photodetector to explore the signals. Li-Fi is the solution as it is inexpensive, much more impressive and it is considered as a healthy environment compare to the Wi-Fi. Li-Fi uses light spectrum with wavelengths from infrared (IR) to ultraviolet (UV) including the visible light (VL) spectrum alternatively of radio waves for relocating of data [1]. This technology is a short-range and secured communication presented by light through wireless, it is often coined to term as visible light communication VLC [2]. VLC and Li-Fi have shown to be the most promising of the candidate technologies [3]. Different literature has shown that VLC has the ability for providing a higher data rate, higher data density and transmission security in the physical layer [4, 5]. Comprehensive studies have led to the recent standardization [6]. Li-Fi extends the concept of VLC to achieve high speed, secure, bi-directional and fully networked wireless communications, and this is illustrated in Fig. 1. It is important to note that Li-Fi supports user mobility and multiuser access. The key advantages of a Li-Fi wireless networking layer are: i) three orders of magnitude enhanced data densities; ii) unique properties to enhance physical layer security; iii) three order of magnitude improvements in energy efficiency; iv) use in intrinsically safe environments such as petrochemical plants and oil platforms where RF is often banned; v) with the advent of power over Ethernet (PoE) and its use in lighting, there exists the opportunity to piggyback on existing data network infrastructures for the required backhaul connections between the light sources with its integrated Li-Fi modem and the Internet [7]. Li-Fi achieves high data rate transmission up to 10 Gbps, provides more privacy and security to the transmitted data since it covers just a small distance and not pierces the walls, 10000 times the frequency spectrum of radio and does not create interference in sensitive electronics, making it better for use in environments like hospitals and aircraft [8].The key design challenges to achieving high speed OW (optical wireless) transmission indoors stem from the ambient light noise and multipath dispersion causing inter symbol interference (ISI) [9].

The goal of this paper is to present a prototype remotely human body healthcare continuous monitoring system based on Li-Fi technology as healthy environment unlock Wi-Fi in hospitals to avoid electromagnetic interference especially in MRI test rooms or others. The contributions and key idea of this work could be described as shown in the following items: i- It accepts the desired signal and ignores the unwanted one. ii- Removing the optical background noise. iii- Guarantee a 100 % accuracy of the received signals. iv- Ensure the patient's mobility within distances up to 4 m at LOS and 2.5 m at non-LOS with high data rate. Also, this system is particularized with low power consumption, low-cost components, and could be adapted to different other systems of sending or processing operation. The rest of this paper is organized as follows: a literature survey related to this work is presented in section 2. Section 3 represents the problem formulation related to the li-fi system. In section 4, the proposed framework (Li-Fi algorithm) is presented. Section 4.1 presents the experimental activities implemented in this work. Section 5 offered result and discussion. Finally, a conclusion is presented in section 6.

2. Literature survey

In 2016, S. Sudha [10] presented an algorithm to help in the Patient monitoring in the hospitals and could be implemented utilizing the Li-Fi concept rather than the technology of Wi-Fi for preventing the interference of frequency with the human body. Sensors like temperature, glucose, heartbeat and respiration implemented in this model imply its particular functions. These sensors gather the data from the human body and are converted into the digital form utilizing the analog to digital converter and the outputs of the sensors are given to the microcontroller. The implemented microcontroller is PIC16F877A. The output from the microcontroller is fed to the transmitter unit that transmits the data in the light form and the receiver end gathers this data and then presents the graph for the various parameters utilizing the PC.

The authors of [11] present a secure network communications route (Li-Fi Technology) alternate to be used for radio frequency identification (RFID) algorithms and solutions. A communication channel that is resilient and reluctant to disruptions by mitigating advanced networks communication offensives like spoofing and TCP / IP attacks (Man-In-the middle attacks, Denial of Service attacks. This paper presents the implementation of Li-Fi network for a secure and safe cyberspace communication exchange path. The authors claimed the current radio spectrum could run out of capacity in the next five years as there is rising amounts of internet data are transmitted through mobile networks. This looming spectrum crunch would roughly bound the ability of people for information accesses costing the world's economy billions of dollars. Li-Fi is a non-RF alternate.

The authors of [12] in 2016 presented a prototype to examine the performance of the VLC system using Algorithms with MATLAB 8.1 (R2013a). In this experiment, two PCs with a 2.30 GHz Intel Core i3 CPU and 2 GB of memory are been used. The authors achieved a data transmission rate of 10 Kbps under normal daylight condition within a distance of more than 40 cm on a room with 3m × 3m × 3m.

The authors of [13] in 2017 used arduino in a Li-Fi transceiver to transmit digital data. Hardware was built utilizing the Eagle CAD tool (version 7.1.0) and the Proteus tool (version 8) also, Software code was written in Java (version 8). Textual and graphics data transmission and reception, as well as video signals, was carried out on speed of 115200 bps implementing VL and by a transceiver circuit. The obtained SNR is 2 to 12 dB at OOK (on-off keying) modulation.

The author of [14] presented an adaptive algorithm for multiple-input-multiple-output (MIMO) VLC for increasing energy efficiency. According to channel circumstances, the wanted spectral efficiency and a target error rate, the MIMO technique are selected from three possible options: repetition coding (RC), spatial multiplexing (SMP) and a spatial modulation (SM) modified version. In every possible place, the MIMO method with less input energy requirement is selected, and therefore the energy consumption is minimized. Such an adaptive method could be notably beneficial in different applications like Internet-of-things (IoT) where energy exhaustion is a serious factor. In this paper, the authors presented an adaptive method that chooses the minimum energy-consuming MIMO technique in varies locations of the room for a wanted spectral efficiency and a target bit error rate. It was proofed that energy consumption could be minimized if the correct MIMO technique is selected. The authors claimed that the presented technique is beneficial in IoT application due to the energy consumption could be minimized applying the most efficient MIMO technique wherever the user is placed.

In [15] 2018, the authors present an experimental explanation of an indoor uplink near-infrared LED camera communication that deploys near-infrared light as a communication medium and a camera as the receiver. The authors claim their Experiments illustrate that employing an even low-specification webcam and low-power LEDs is able to present precision of few centimetres for the user localization and a data rate of 6.72 Kbit/s with SNR 15.

The main drawbacks of the aforementioned literatures in this section are the optical background noise, low data transmission rate and 100 % accuracy for only a short distance of less 1 m. So, in this paper, we overcome the aforementioned drawbacks using the crated system.

3. Problem formulation

To obtain a signal that travels through different propagation channels using Li-Fi technology without losing the transmitted data is the main problem. The optical background noise is also another drawback of Li-Fi technology. The aim of this work is to present a remotely human body healthcare continuous monitoring system based on an optical wireless communication system (Li-Fi) that gathers data from the FBGs sensor needed to be sent with a minimum loss.

In this paper, we built a transmitter and receiver module prototype having an ability to eliminate the optical background noise and to receive the desired signal ignoring the undesired one. Also, ensuring the mobility in distance up to 4 m and 2.5 m at LOS and non-LOS respectively. The entire Li-Fi system in an ideal environment is designed and implemented in the laboratory of laser and optics in the ministry of science and technology.

4. Proposed framework

The main steps of the system model are presented in the algorithm I below. The Lab experiment has been performed within the dimensions of length, width, height (4 m x 4 m x 2.5 m) respectively. The Li-Fi transmitter module receives the signal from the FBG sensor (Sensing the human temperature, blood pressure, heartbeat and etc.) and modulates it over the light spectrum (IR wavelength 940 nm). Then, the Li-Fi transmitter module sends the modulated signal to an array of optical receivers created in the ceiling of the room. This array was divided into a number of cells with the same spaces and one optical receiver per cell. The received signal is travelled through different propagation links (direct LOS, non-direct LOS and diffuser) that provide full room coverage of the aforementioned dimensions. Then, received data are ready to be present to the end-user at the remote main monitoring station. The schematic diagram of the proposed Li-Fi system shown in Fig. 1.

<u>Algorithm 1 Precise health care monitoring system based on FBG sensor over Li-Fi technology.</u>

1: **procedure** FBG SENSOR.
2: Placing the FBG (Temperature and blood pressure) sensor on human body.
3: **end procedure**
4: **procedure** DATA MEASUREMENT
5: Measured and record the human temperature value.
6: Measured and record the human blood pressure value.
7: Measured and record the heart beat rate.
8: **end procedure**
9: **procedure** DATA TRANSMISION.
10: Fed FBG signal to Li-Fi transmitter module
11: convert the signal V/F.
12: Drive the signal through the IR-LED.
13: **end procedure**
14: **procedure** TRAVELED SIGNAL THROUGH DIFFERENT LINK
15: Signal transmitted over direct-LOS link.
16: Signal transmitted over non direct-LOS link.
17: Signal transmitted over diffuser link.
18: **end procedure**
19: **procedure** DATA RECEIVED
20: Receive the desired signal.
21: Ignore the unwanted signal.
22: Convert received data O/E by IR-Photodiode.
23: Convert signal F/V.
24: Data sent to main station.
25: **end procedure**.

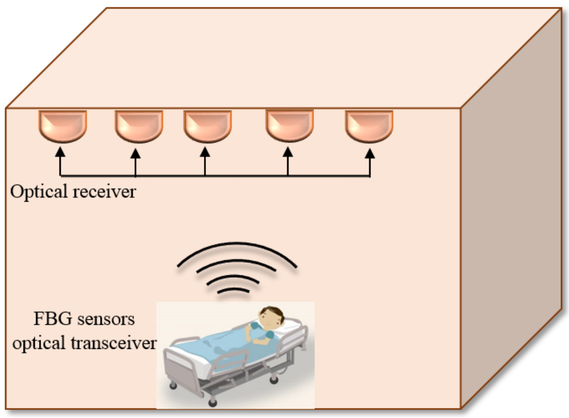

Figure.1 Schmetic diagram of the proposed LiFi system

4.1 System design

The entire proposed system consists of four-part; created, implemented, and tested as explained in the following subsections.

4.1.1. Li-Fi Transmitter module

One of the important stages in the implemented transmitter module shown in Fig. 2 is the conversion of the input voltage to frequency (V/F). V/F converter contains IC (N555), two-transistor type of BC107, five resistance, tow capacitance, and one signal diode. At the same time, the V/F converter acts as a high-quality transformer from analog to digital format. The drive circuit that modulates the signal over the IR-LED represents the final stage before the electrical to the optical conversion (E/O). E/O converter accomplished with the IR-LED (TSAL5100). Initially, to evaluate and validate the performance of the Li-Fi system designed, function/Arbitrary waveform generator DG-1022 (RIGOL) is the utilized generator. The generator controls the pulse width of the data transmitted bit stream (the generated electrical signal). The generator is utilized for creating a pure signal feeding the Li-Fi transmitter to be sent through different propagation links to the optical receivers placed on the room ceiling. Then, the real FBG sensor's signal is fed to a Li-Fi transmitter module after amplified using EDFA (20 dB).

4.1.2. Li-Fi receiver module

Fig. 3 illustrates the schematic diagram of the Li-Fi receiver module. The first stage in this circuit is the optical to electrical (O/E) conversion which consists of an IC (N555) and IR-photodetector SFH2030. In the next stage, the signal fed to the frequency to voltage converter (F/V). F/V converter consists of IC (LM331), seven resistors and three capacitors. At the same time, this circuit acts as a high-quality converter from digital to analog format. Output signal amplifier represents the final stage using (RN2222), capacitor and resistor.

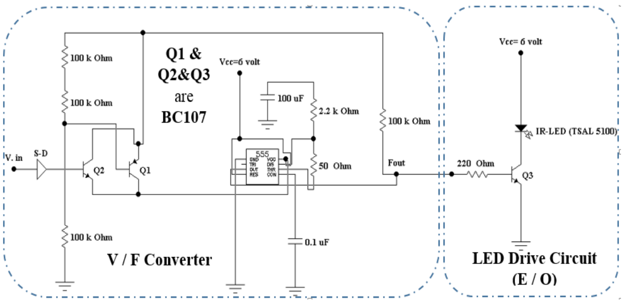

Figure.2 Schematic diagram of LiFi transmitter module

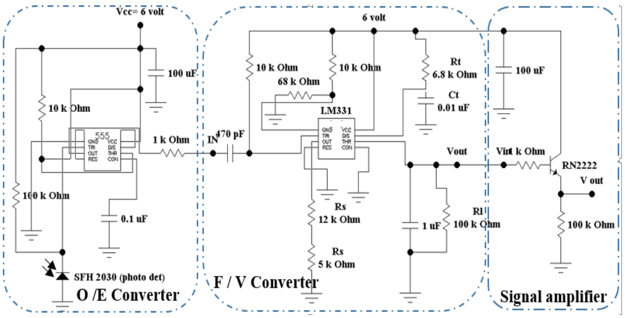

Figure.3 Schematic diagram of LiFi recievr module

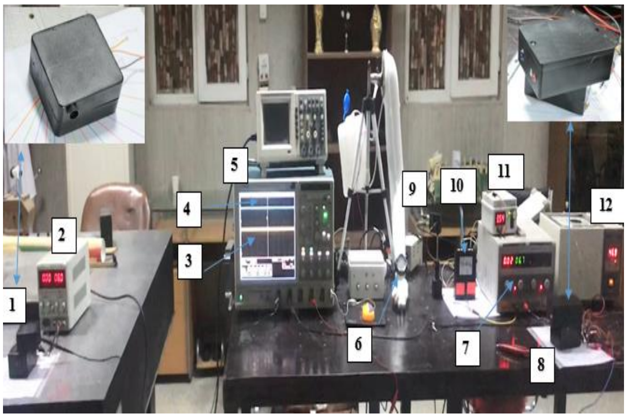

Figure.4 Experimental setup of Li-Fi prototype system: - (1) Li-Fi transmitter module, (2) power supply, (3) transmitted signal, (4) received signal, (5) oscilloscope, (6) FBG blood pressure sensor, (7) power supply, (8) Li-Fi receiver module, (9) fiber-coupled detector, (10) EDFA, (11) laser source for FBG, and (12) FBG temperature sensor

As the optical background noise and losing transmitted data is the main drawback of Li-Fi technology, an effective means has been constructed to remove the optical background noise by inserting the IR-photodiode receiver in a black tube inside packaged in a rugged dark housing.

As shown in Fig. 4, the entire experimental setup of Li-Fi system is based on a directly modulated LED of wavelength 940 nm with a constant optical power of 1.584 mw. Also, in this work, light power meter from mobiKen company (Model: LP-1) has been used at a receiver side to measure the received power at various links and for different distances. The function of the implemented electronic drive circuit part is to modulate the signal over the LED and it offers a higher signal speed.

4.1.3. Wireless channel

The indoor optical wireless channels are divided into three types:- i) direct LOS, ii) non-direct LOS, and iii) diffuser channel (non-LOS non-direct) under a fluorescent light in the LAB having 4 m x 4 m x 2.5 m dimensions.

4.1.4. Sensor

FBG is a fibre optic passive component that shows basic functional assigns of filtering and reflection. It is a kind of distributed Braggs which reflects a specific wavelength band and transmits the others. This concept is obtained by changing the refractive index as a periodic variation of the optical fibre core which creates a dielectric mirror for reflecting a specific wavelength [16]. The FBGs are categorized into three main classifications based on photosensitivity, structures, and refractive index [17]. FBGs can be effectively utilized in an extensive variety of biomedical applications such as blood pressure, temperature and tumour detection [18].

4.2 Li-Fi indoor propagation link

An indoor wireless optical link can be classified into different classes that could be identified by two characteristics. The first characteristic takes into consideration the degree of directionality of transmitter and receiver. The second characteristic classifies links according to whether or not there is an uninterrupted line-of-sight (LOS) path between transmitter and receiver. As shown in Fig. 5, we can conclude that non-directed-NLOS, named diffuse link, offers the greatest robustness and freedom of movement while maintaining connectivity [19].

4.2.1. Channel model

The general formula of the channel model shown in Fig. 6 can express in Eq. (1).

$$y(t) = x(t)\otimes h(t) + n(t) \tag{1}$$

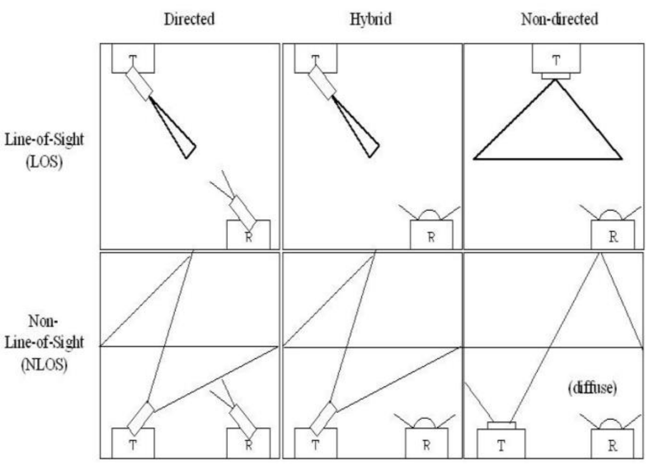

Figure.5 Classifications of simple indoor optical wireless links based on the degree of directionality of the transmitter and receiver and whether the link relies upon the existence of a LOS path between them [19]

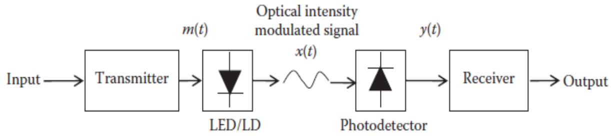

Figure.6 Blok diagram of an optical intencty, direct detection communication channel [22]

Where, $y\ (t), x\ (t), h\ (t)$, and $n\ (t)$ denote received signal, transmuted signal, channel impulse response, and total noise respectively. Normally, a LED scatter its light energy in all directions rather than generates a directional beam related to its own aperture design. LED is considered as lambert light sources because of its radiation energy intensity functions (angular distribution of radiant output power) $(R(\varphi))$ expressed in Eq. (2) follows the laws of Lambert [20, 21].

$$R(\varphi) = \frac{(m+1)}{2\pi} Pt\ COS^{m}(\varphi) \tag{2}$$

Where, φ, Pt denotes the angle between the light emission direction and the normal light source (irradiance angle), and the LED transmit power respectively. The total power emitted by a LEDs (P_{TX}) on a solid angle $d\Omega$ could be expressed by Eq. (3).

$$P_{TX} = \int_{Hemisphere} \frac{(m+1)}{2\pi} Pt\ COS^{m}(\varphi)\, d\Omega \tag{3}$$

When the $\varphi = 0$ is the angle of maximum radiated power, but the Lambert index is related to the LED semi angle at half power $\varphi_{0.5}$ which could be expressed in the Eq. (4).

$$m = \frac{-ln2}{\ln(cos(\varphi_{0.5})} \tag{4}$$

In general, the receiver implements a technique that suppresses the stray light noise and allows the optimum detection of the desirable optical signals and often comprises different components such as a light filter, an optical concentrator, an optical lens, and an amplifier connected to its rear end. The gain of an optical concentrator can be expressed in Eq. (5).

$$g(\theta) = \begin{cases} \frac{n^2}{sin^2\Psi c}, & 0 \le \theta \le \Psi c \\ 0, & \theta > \Psi c \end{cases} \tag{5}$$

Where $, n, \Psi c,\ \theta$ denote reflective index of an optical concentrator, the field of view (FOV) and incident angle. In this work as we aforementioned, the Li-Fi signal passes through different propagation links. These links are expressed mathematically as presented in the following paragraphs.

4.2.2. LOS propagation link model

The Li-Fi optical wireless communication transmitter is a Lambert source, so the DC gain for a receiver located at a distance of d and angle Ψ ; with respect to transmitter (please, see Fig. 7) can be measured as presented in [22].

Eq. (6) below expresses the path loss of the LOS link.

$$H.los(0) = \begin{cases} \frac{(m+1)\,Ar}{2\pi\, d^2}\; cos^m(\varphi)\, Ts(\theta) g(\theta) \cos(\theta), & 0 \le \theta \le \Psi c \\ 0\,, & \text{elsewhere} \end{cases} \tag{6}$$

Thus, the received optical power of the LOS path($Pr.los$) is given by Eq. (7).

$$Pr.los = H.los(0)\; Pt \tag{7}$$

4.2.3. Non LOS propagation link model

For NLOS link, the optical path loss is more complicated to be estimated because it depends on different factors such as room dimensions, the reflectivity of the ceiling, walls and objects within the room, and the position and orientation of the transmitter and receiver as shown in Fig. 8. The path loss of the first reflected signal (the channel DC gain of the first reflection in LOS link) is defined as shown in Eq. (8).

$$H.nlos(0) = \begin{cases} \frac{(m+1)A}{2\pi\;\, d1^2\, d2^2}\;\rho\, dAwall \\ cos^m(\varphi)\cos(\propto)\cos(\beta)\, Ts(\theta) g(\theta)\cos(\theta)\,, \\ \quad 0 \le \theta \le \Psi c \\ 0\,, \qquad \theta > \Psi c \end{cases} \tag{8}$$

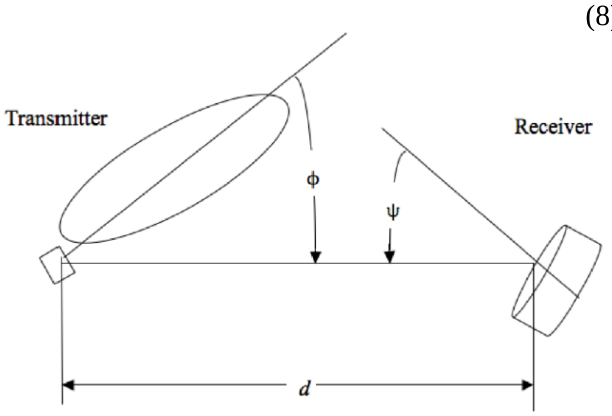

Figure.7 Los configuration [19]

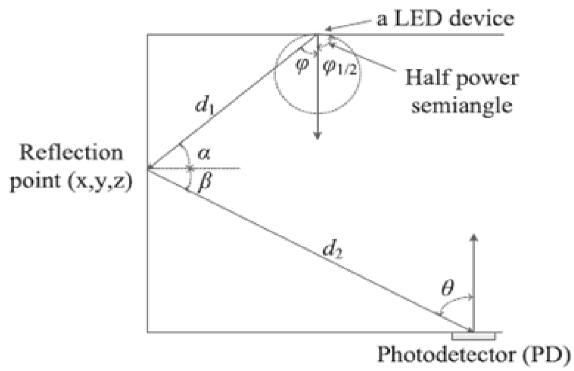

Figure.8 Diffuser propagation link [21]

The received power of the non LOS is associated with LOS channel DC gain $H.los(0)$, non LOS channel DC gain $H.nlos(0)$, and the optical transmission power Pt as shown in Eq. (9).

$$Pr.nlos = \big(H.los(0) + H.nlos\;(0)\big)Pt \tag{9}$$

5. Results and discussion

5.1 Results

To evaluate and validate the proposed system, firstly, a function generator is utilized to create a pure signal transmitted with a constant optical power of 1.584 mw from Li-Fi transmitter through different propagation links to optical receivers placed on the room ceiling. Then, we changed this generator with the FBG sensor to transmit a real signal. The obtained signals at direct-LOS, non-direct LOS and diffuser links are shown in Figs. 9, 10, 11, 12, and 13.

Different measurements are taken in this experiment to evaluate and validate the proposed system. These measurements are the received power (RP), optical signal to noise ratio (OSNR), electrical signal to noise ratio (ESNR), the transmitted half angle and the distance. As mentioned above, the proposed system is evaluated for different propagation links (direct Los, non-direct LOS, and diffuser) and distance. So, the measured signal is extracted from these links. The obtained results of experiments at the direct LOS link are shown in Figs. 14, 15, 16, and 17.

The outcomes of the non-direct LOS link, having the same distances and different half transmitted angles are depicted in Figs. 18, 19, and 20.

For the diffuser link, different distances (up to 2.5 m) are implemented in this experiment, as shown in Figs. 21, 22, and 23.

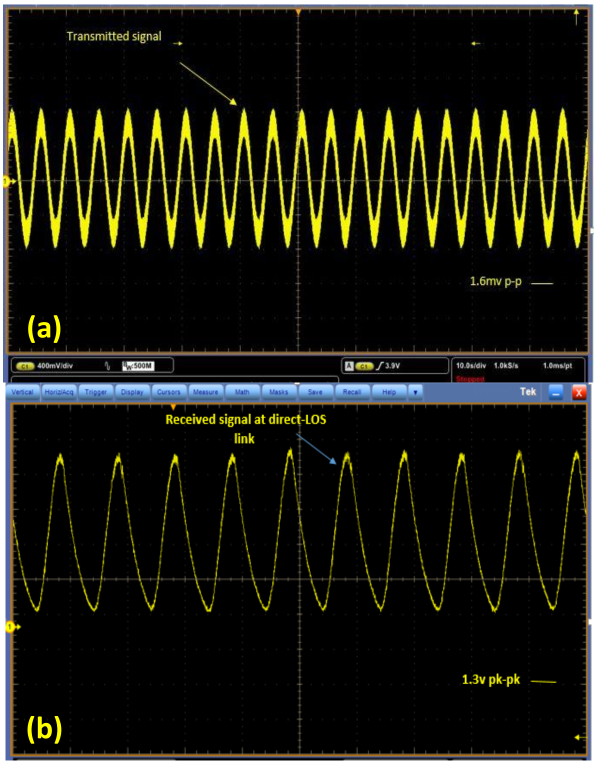

Figure.9 (a)The transmitted signal from function generator and (b)The received signal for direct-LOS at distances up to 3 m

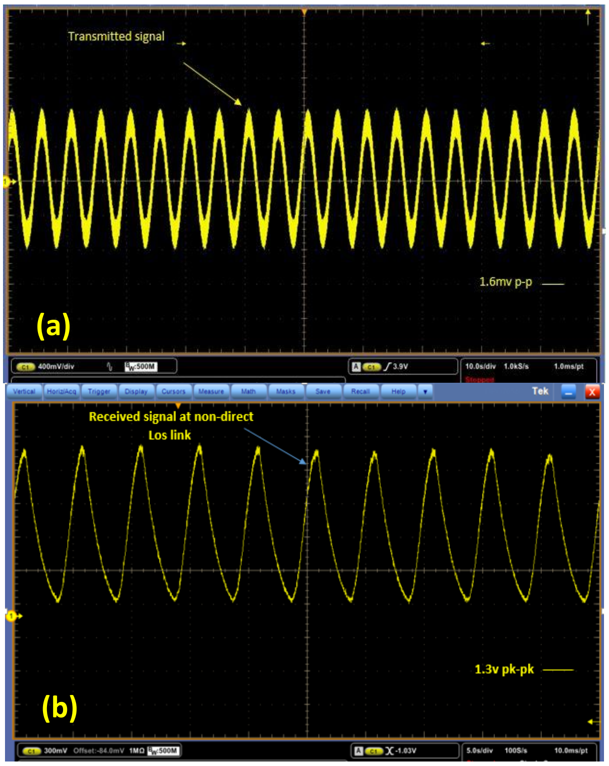

Figure.10 (a)The transmitted signal from function generator and (b) The received signal at non-direct LOS at different angles (10, 20, 30, and 40)

Figure.11 (a)The transmitted signal from function generator and (b) The recieved signal for diffuser link at distances up to 2 m

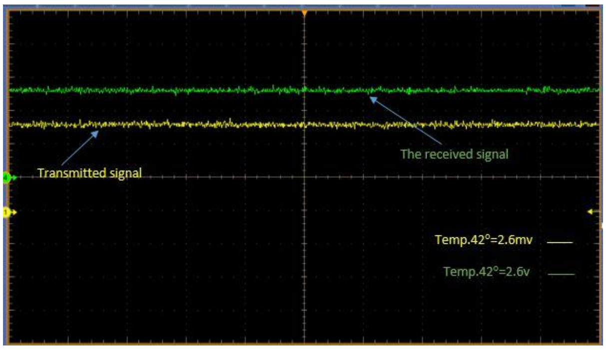

Figure.12 The recieved signal of FBG temperature sensor at different links (direct LOS, non-direct LOS and diffuser)

* Note: the voltage level 2.6mv represents the human temperature degree obtained from the FBG sensor which is 42°)

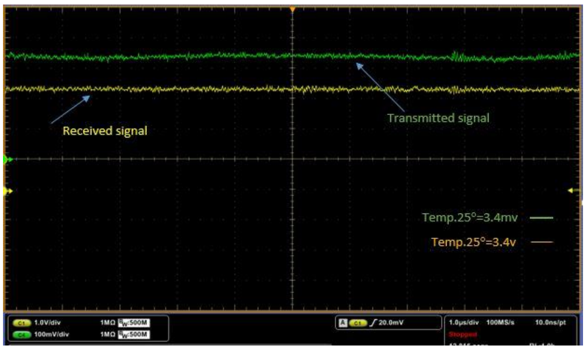

Figure.13 The received signal of FBG temperature sensor at different links (direct LOS, non-direct LOS and diffuser)

* Note: the voltage level 3.4mv represents the human temperature degree obtained from the FBG sensor which is 25°)

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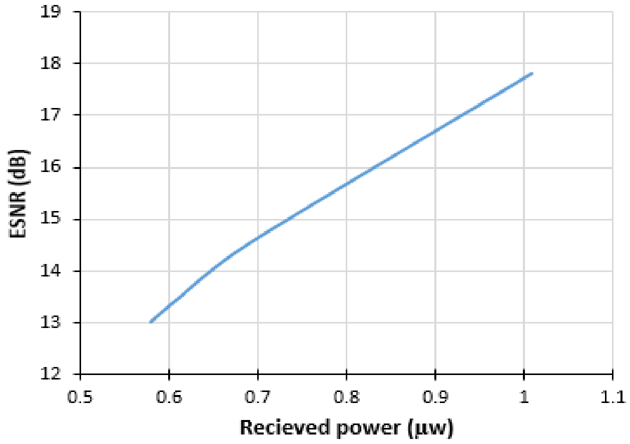

Figure.14 The relationship between the ESNR and PR at different distances (1m, 2m, 3m) at direct LOS link

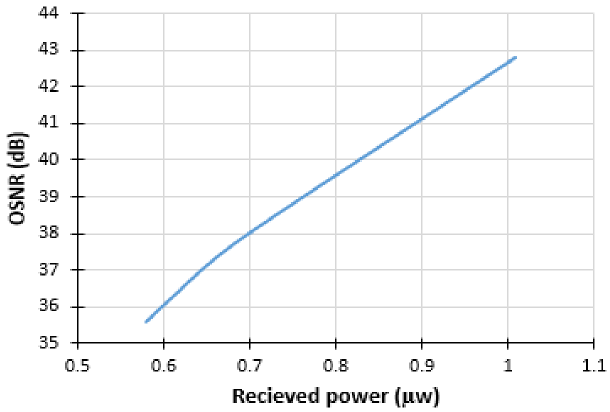

Figure.15 The relationship between the OSNR and PR at different distance (1m, 2m, 3m) at direct LOS link

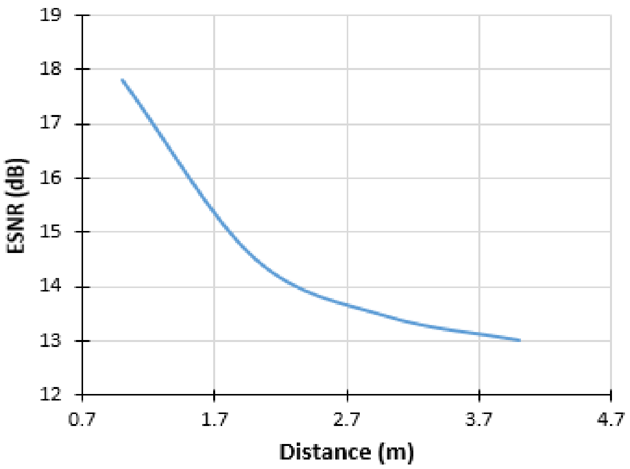

Figure.16 The relationship between the ESNR and distance change at direct LOS link

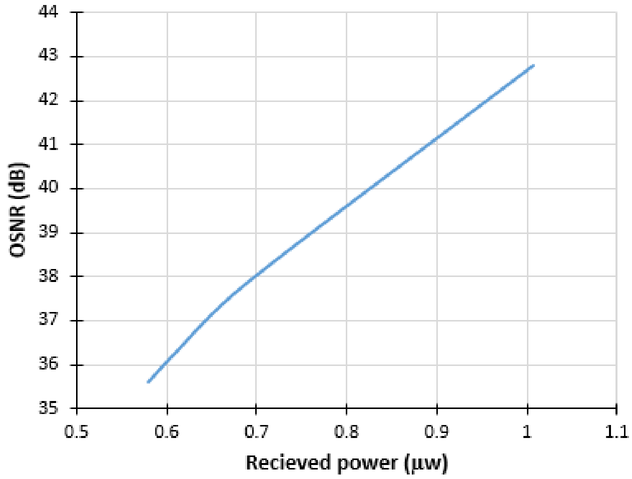

Figure.17 The relationship between the OSNR and distance change at direct LOS link

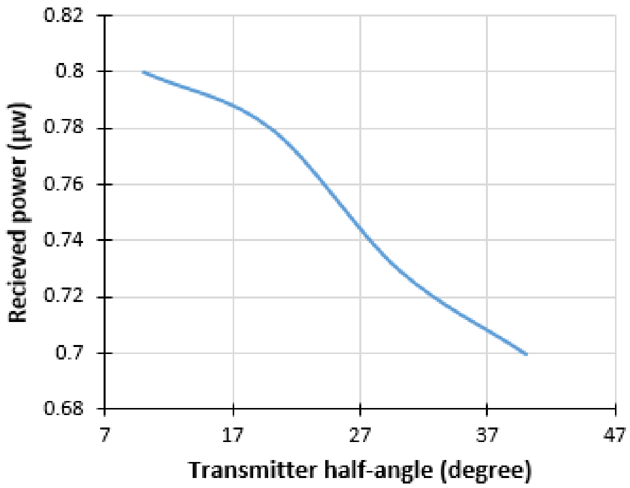

Figure.18 The relationship between PR and transmitted half-angle at distance 3m at non-direct LOS link

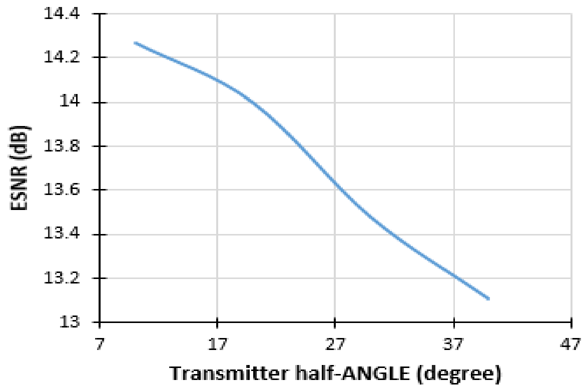

Figure.19 The relationship between ESNR and transmitted half-angle at distance 3m at non-direct LOS link

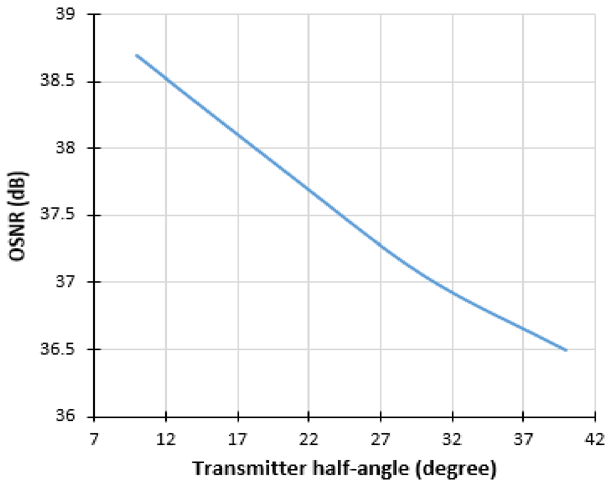

Figure.20 The relationship between the OSNR and transmitted half-angle at distance 3m

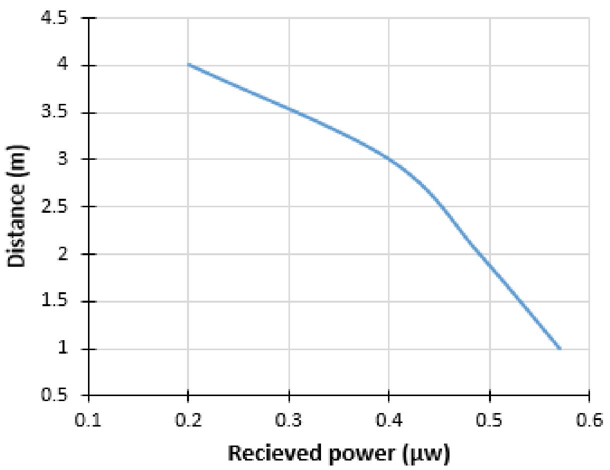

Figure.21 The relationship between the PR and change the distance at diffuser link

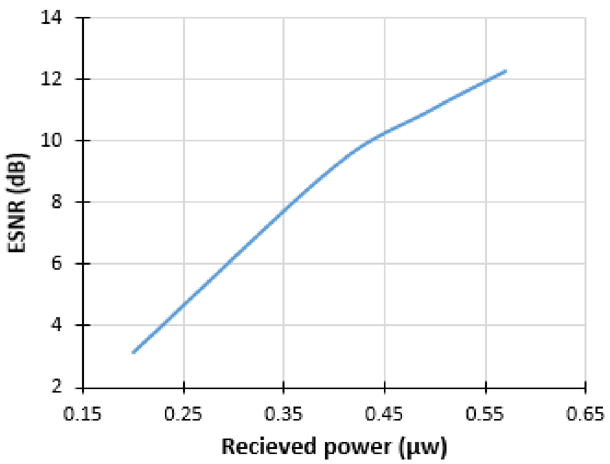

Figure.22 The relationship between the ESNR and PR at distance up to 2.5 m diffuser link

The results obtained from the performance evaluation of different propagation links are presented in Tables 1, 2, and 3.

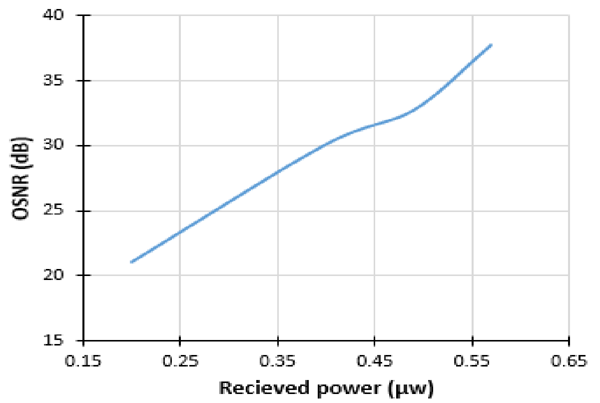

Figure.23 The relationship between the OSNR and PR at distance up to 2.5 m diffuser link

Table 1. Different measurments for direct LOS link

Received power (µw)	ESNR(dB)	OSNR(dB)	Distance (m)
1.008	17.82	42.8	1
0.69	14.53	37.86	2
0.61	13.46	36.26	3
0.58	13.02	35.6	4

Table 2. Different measurments parameter for non direct LOS link

Transmitted half-angle angle (degree)	ESNR (dB)	OSNR (dB)	Received power (µw)
10	14.27	38.69	0.8
20	14	37.86	0.78
30	13.48	37.06	0.73
40	13.11	36.5	0.7

Table 3. Different measurments parameter for diffuser link

Received power (µw)	ESNR (dB)	OSR (dB)	Distance (m)
0.57	12.26	37.76	1
0.49	10.9	32.75	1.5
0.4	9.18	30.14	2
0.2	3.16	21.11	2.5

5.2 Discussion

The proposed system is evaluated for different propagation links (direct Los, non-direct LOS, and diffuser) and distance, so the measured signal is extracted from these links. The optical background noise impacts the accuracy of the received signal and channel performance. Where it affects the distances that the signal could arrive, signal shape

Table 4. Comparison study of related previous works

Parameter	[12]	[13]	[15]	Our paper 2019
Data rate	10 Kbps	115.200 kbps	6.72 kbps	450 Mbps
SNR (dB)	-	Up to 12	about 15 dB	10 to 17dB
Transmitted power (mW)	-	0.5	600 to 5 LEDs	1.584
Received power (mW)	-	10	-	0.5 – 1.008 x10^{-3}
Distance (m)	0.4	-	1	4
Environment	- Room 3 m x 3 m x 3 m - Under Normal day light, No filtering mechanism	-	-Room 1.3 × 0.81 cm × 2 -under LED luminance.	- Room 3 m x 3 m x 3 m - Under Fluorescent light, eliminating the optical background noise
Data	graphics signals	text, graphics and video signals	video	- Sine wave from function generator - FBG sensor's signal
Wavelength (nm)	380 - 780	380 - 780	940	940
Modulation	OOK	OOK	OOK	OOK
Propagation link	LOS-direct	LOS-direct	LOS-direct	Los-direct, los-non direct and diffuser link

and level, and transmission data rate. Fluorescent Lamp, incandescent lamps, and Natural Light are the main sources of the optical background noise, which presents a periodic interference signal in Li-Fi receiver's module [23]. So, knowing ambient light power and the type of lamp an essential for developing effective techniques of eliminating the interference they produce. We calculated the ESNR and OSNR as indicators of signal accuracy. In the direct LOS link, the results of the experiment prove that a convenient $ESNR$ (13 dB to 17.82 dB) and $OSNR$ (35.6 dB to 24.8 dB) are obtained for a distance up to 4 meters as shown in Figs. 9, 12-17, and Table 1. In the non-direct LOS having the same distances and different half transmitted angles (10° to 40°), the results are as follows $ESNR$ (13.1 dB to 14.27 dB) and $OSNR$ (36.5 dB to 38.69 dB) at 3 m, which is still with an acceptable level as shown in Figs. 10, 12, 18-20 and Table 2. For the diffuser links, different distances (up to 2.5 m) are implemented in this experiment to evaluate and validate the proposed system. Figs. 11, 12, 13, 21-23 and Table 3 illustrate the obtained results of the received power corresponding to distance, $ESNR$ and$OSNR$. We observed that the SNR value remains within the accepted range up 2 m. Due to the aforementioned results, the increment in transmitted half angles leads to decreases the value of $ESNR$ and $OSNR$ causes waning in the received power. Increment in transmitted power leads to increment the distance that the signal can reach. Therefore, it increases the link performance (increase the$ESNR$ and $OSNR$). At the V/F and F/V part in the designed circuit, the frequency is linearly proportional to the input voltage and vice versa. This system is particularized with low power consumption 6-12 volts and low-cost components. The cost of the implemented Li-Fi system is around 7.5$. As we searched for another commercial devices that could be compared with this system, we couldn't find a device that may have same functionality of the proposed system. In general, when exploring the designed system and its components as shown in Figs. 2, and 3 (converter optical to an electrical, converter electrical to an optical, voltage to frequency converter, frequency to voltage converter, IR-LED, photodiode, microcontroller, resistors, capacitors, transistors, and ICs.), we conclude that the lowest cost to create a same functionality system is at least not less than 50$.

Also, it can adapt to different other systems of sending or processing operation. The created system accepts the desired signal and ignores the unwanted one, and removing the optical background noise power in range approximately up to 6 µW. Also, the experimental result shows a 100 % accuracy of the received signal since the implemented system having high stability by which the level and shape of the received signals are constant under all test experiments circumstances. The authors of the aforementioned related works present the SNR, data rate, and distance as parameters of the accuracy. After the evaluation and validation of the proposed system, it is compared with related works presented by [12, 13, 15] as shown in Table 4. We observed that the normal daylight extremely affects the link performance since the authors of [12] achieved only 10kbps at 0.4 m. The LED illumination has less impact on the received signal accuracy, where the signal arrives to distance up to 1 m and SNR of 15 dB but with low data rate 6.72 kbps as presented in [15]. Under artificial light, the authors of [13] obtained a data rate of 115.200 kbps and SNR 12 dB.

6. Conclusion

In this paper, a novel system of Li-Fi healthcare monitoring is created to transmit data through different propagation links from an FBG sensor carried by a patient to an optical receiver install in ceiling room using Li-Fi technology. This prototype is particularized with low power consumption and low-cost components. Also, it can adapt to different other systems of sending or processing operation. The created system accepts the desired signal and ignores the unwanted one. Also, the experimental result shows a 100 % accuracy of the received signal with removing the optical background noise power. We confidently claim that the proposed system provides much more accurate received data than the other literature.

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