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System Performance Evaluation of Indoor Visible Light Communication

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ABSTRACT- The objective of the paper is to exhibit the significance of the LiFi-based data transmission using light. LiFi is deployed in numerous applications such as security, augmented reality, intelligent transport system etc. as typical indoor localization is essential and is being done with mobile robots. This research article proposes a short range, indoor design, light fidelity model and discusses the simulations conducted for the LiFi model and the model is analyzed for various aspects that uses different LED light sources with Line of Sight (LOS) and without Non-Light of Sight (NLOS), different room sizes, different modulation formats, and simulation is also performed with and without noise models. The LiFi proposed model is designed to transfer data wirelessly with a data rate of 10 Gbps. The proposed results obtained is validated with other pervious LiFi works. Simulations results of our proposed model outperform the other previous LiFi works when operating under ideal circumstances with and without noise.

Keywords: LiFi, VLC, RZ, NRZ, BER, NRZ-OOK, FSO, LOS, NLOS.

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1. INTRODUCTION

It demonstrates that LiFi is still capable of utilizing only light-emitting diodes (LEDs) to route VLC to wireless networks, to improve wireless capabilities for fifth-generation cellular systems (5G) and beyond. It explains the LiFi components to hybrid LiFi, Wireless Fidelity (WiFi) networks, and explains why LiFi atto cells are applied [1, 2]. Investigation of indoor communications by measuring the channel characteristics of white LEDs using the Opti-system simulation tool [3]. VLCs performance is assessed using the graphing and logarithm of the appropriate BER value for various bit rates and connections [4]. Communication is done with white LEDs, and the modulation models RZ-OOK and NRZ-OOK are investigated in VLC.[5]. The demands of user as fast data rates, low power consumption, low latency, low trust, and a lot of equipment, new communication technologies as 5G wireless access technology were developed [6].

By converting every reading light into a passive access point (AP) with Light Source (LiFi), congested areas can have smooth connectivity free from radio frequency interference [7]. LiFi features two light-based wireless communication technologies and is networked. It connects mobile and fixed devices quickly by utilizing the visible and infrared spectrum [8]. The total amount of these spectrum sources exceeds the total radio frequency (RF) spectrum by a factor of 2,600 is explained with reference to sixth generation [9]. Integrating LiFi/Wi-Fi network topologies to diversify the RF and fiber spectrum, and how to strike a balance between the facts and the solutions [10]. Lifi transmission enhances the functionality of Wi-Fi networks [11].

However, there are still not many 5G-compliant radio frequency (RF)-based wireless networks. Due of potential interference and security concerns with air communications, deployment poses major challenges [12]. Every reading light may be turned into a passive access point (AP) using Light Source (LiFi) to provide radio frequency interference-free, seamless connectivity in crowded settings [13]. LiFi is networked and has two light-based wireless communication technologies. It uses the visible and infrared spectrums to instantly connect mobile and fixed devices [14]. This paper discuses positioning in a single channel or multiple input multiple output (MIMO) visible light communication (VLC) system using a minimum number of transmitters. It is based on the estimation of the user's velocity between the previous and current positions [15].

It discusses the LED modulation speed is limited by the remaining carriers that remain in the depletion capacitance. In this paper, we evaluate the increase in optical transmission rate for an LED driver for the first time by sweeping out the

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remaining carriers in a GaN-based LED for VLC system. The RF and fiber bands, how to strike a compromise between the available solutions and the realities, and how LiFi might be included into presently operational wireless networks [16]. This paper we investigate the line-of-sight Optical Wireless Channel characterization of Visible Light Communication by practically measuring a White LED's illuminance values. A comprehensive mathematical model is also derived and simulated in MATLAB® to investigate the power distribution, attenuation, and Beam Divergence of the White LED under study [17].

The article explains VLC with the impact of LED's parameters such as Electron carrier lifetime, RC time constant and receiver aperture diameter for various bitrates and link distances on VLC system are also studied with increase of receiver diameter and also extend link range [18]. The VLC deals with non-line of sight (NLOS) is a major challenge, so a new technique based on multichannel configuration is utilized to enhance the overall system performance. We also investigated the model under the influence of lighting noises in the ambient environment [19]. This paper presents new experimental results on a polymer light emitting diode based on visible light communications system. For the first time we demonstrate a 10 Mb/s link based on the on-off keying data format with real time equalization on a field programmable gate array with less bit error rate [20].

We propose a Monte Carlo ray tracing (MCRT) channel modelling, to capture the nuances of LiFi connections during flight by studying the effects on the optical channel of user terminals, exposure of box models, and operating wavelength [21]. It describes the use of indoor location as a visual light communication system that provides average and sub-meter precise indoor location [22].

White LED lights used to power an indoor communication system. This device not only lights the room but can also be used in the planning process for the optical wireless communication system [23]. In FSO optics, modulated light propagates with the OOK-NRZ modulator and demodulator [24]. The expansion of mobile devices is creating issues for radio frequency (RF) networks, including wireless fidelity (WiFi) networks. Our initial proposal for resource allocation (RA) in the LiFi system was multi-frequency division (OFDMA), which functions as a low-pass filter within the LiFi channel [25].

2. MATERIALS AND METHODS

In Visible Light Communication (VLC) or LiFi arrangements, data transfer occurs by altering the visible light output from the light source in a way that is not immediately visible to human observers. The two main parts of a typical LiFi network are the transmitter and the receiver. There are several ways to locate a VLC system in a one-way configuration. Trilateration-based location, RSS (Received Signal Strength)-based location, and time-of-flight-based position are a few of these techniques. This article analysis about the proximity-based localization, which is a powerful, fast, and effective approach suitable for low-cost end devices. It is also suitable for simple systems that require localization that is sensitive to the indoor performance. The project creates an affordable, effective, and simple indoor robot localization and data transfer system by utilizing proximity-based localization and NRZ-OOK modulation in VLC systems. In situations where performance is crucial, such as indoor settings, this technology offers a viable substitute for more expensive localization methods like GPS.

Every light source in a proximity-based VLC implementation is set up to show a certain set of special symbols. According to the article, NRZ-OOK (Non-Return-to-Zero On-Off Keying) modulation is utilized because it is simple and its available bandwidth. The sensor presents in receiver side sense the data send by the LED and extracts the transmitted special symbols, using this we can detect the precise local position in the room. Since NRZ has low BER for short distance and high SNR, it is highly suitable for LiFi indoor communication. RZ OOK modulation bandwidth requirement is higher with higher power efficiency and susceptibility to ISI is decreased. OOK modulation is hence a cost-effective option for VLC systems, particularly in proximity-based applications.

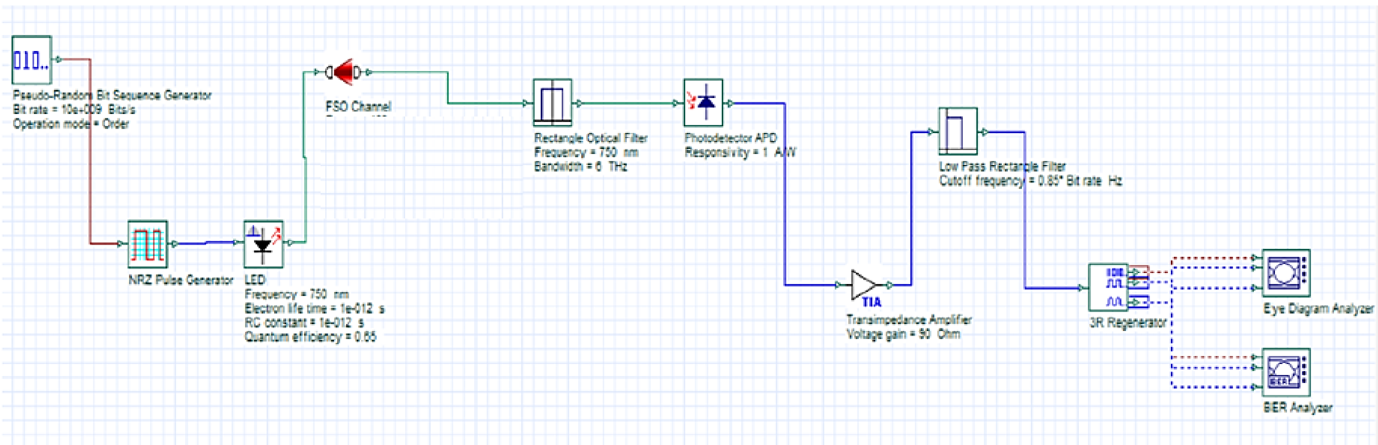

Figure 1. VLC schematic diagram without ambient noise

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The proposed design for proximity localization technique is demonstrated in a room of measurement size 5m x 5m x 3m with 4 LEDS placed on a roof ceiling. Avalanche photodiode of high sensitivity is used in receiver placed on the ground floor. The low power LEDs are made to transmit the special symbol using NRZ modulation. PRBS sequence of 8 bits of data is NRZ modulated using single LED. The received signal is always noise especially in indoor scenario, the noise is due to the ambient light from surrounding sources such as sunlight, tube light, incandescent lamp, fluorescent lamp around the room and the reflection of light from the surrounding walls. The noise that we considered is white Gaussian noise and it removed using the Butterworth low pass filter. The signal is then transmitted through the LiFi channel, it is sensed by APD photodetector and amplified by transimpedance amplifier which amplifies the voltage gain and the signal is filtered by LPF. The original signal is retrieved with reconstruction when passed through the 3R regenerator from the filter output. The retrieved signal output is measured by using BER analyser.

The *figure 1* shows the schematic diagram of visible light communication without ambient noise. Using a Pseudo random sequence generator of 10 Gbps is generated and fed to NRZ pulse generator. The output of NRZ pulse generator is given to LED of 550 nm. The modulated output signal of LED is transmitted to FSO channel of 5m with maximum attenuation of 1dB/km. The wirelessly transmitted optical signal is filtered using a rectangular filter to filter out the visible light from the infrared light and it is feed to APD photodetector where it is sensed and converted to electrical signal. The electrical signal is amplified using a high gain and high speed Transimpedance Amplifier. Then the electrical signal is electrically filtered using a low pass filter and the filtered signal is reconstructed using 3R regenerator. The resulted are tested and verified using BER analyzer and Eye diagram analyzer. In the *figure 2*, the proposed design is simulated for other modulation type such as RZ. In the place of NRZ the different modulation formats are replace and the analysis is carried out with the remaining proposed design components as constants. The process is also repeated for different LED wavelength of 750 nm and carried for different distances such as 1m, 2m, 3m, 4m and 5m.

The *figure 2* shows the schematic diagram of visible light communication with ambient noise. Using a Pseudo random sequence generator of 10 Gbps is generated and fed to NRZ pulse generator. The output of NRZ pulse generator is given to LED of 550 nm. Here the noise is introduced using a white light source. Both the output LED and white light noise source are combined using a power combiner and feed to a FSO channel of 5m with maximum attenuation of 1dB/km.

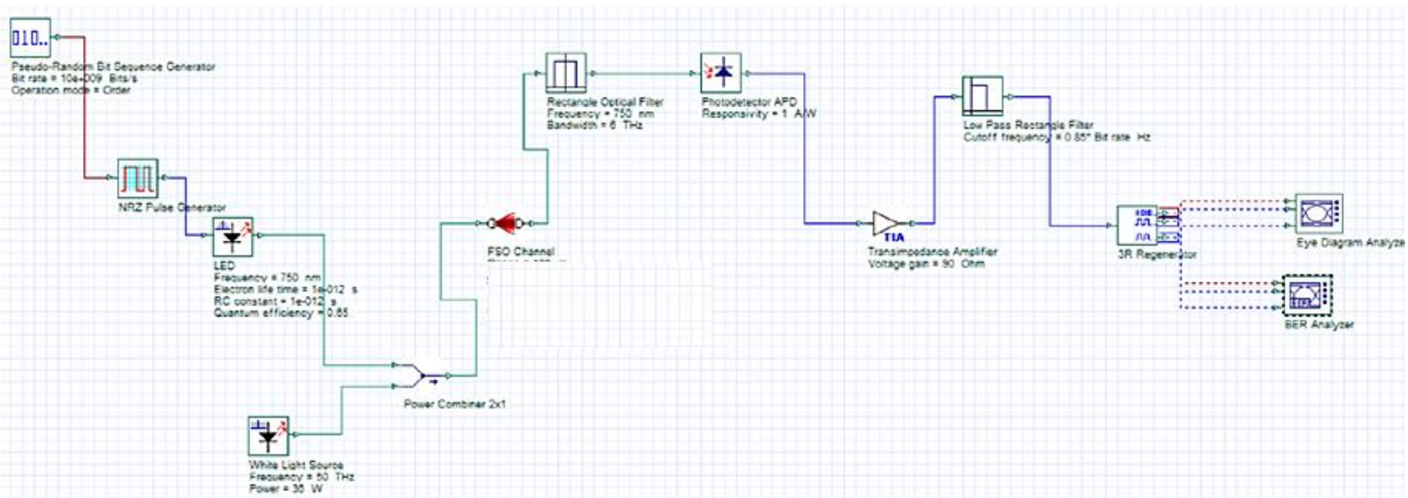

Figure 2. VLC Schematic diagram with ambient noise

The wirelessly transmitted optical signal is filtered using a rectangular filter to filter out the visible light from the infrared light and it is feed to APD photodetector where it is sensed and converted to electrical signal. The electrical signal is amplified using a high gain and high speed Transimpedance Amplifier. Then the electrical signal is electrically filtered using a low pass filter and the filtered signal is reconstructed using 3R regenerator. The resulted are tested and verified using BER analyzer and Eye diagram analyzer. In the *figure 2*, the proposed design is simulated for other modulation type such as RZ. In the place of NRZ the different modulation formats are replace and the analysis is carried out with the remaining proposed design components as constants. The process is also repeated for different LED wavelength of 750 nm and carried for different distances such as 1m, 2m, 3m, 4m and 5m.

3. RESULTS AND DISCUSSIONS

This section discusses the result obtained for the proposed design of VLC. Here the various analysis is carried out for the proposed design with LOS and with NLOS for different conditions such as

Condition1: Under different room sizes
Condition2: Under different LED sources
Condiiton3: Under different modulation formats

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Table 1. Summary of Components Used

Component used	Specification	Component used	Specification
Pseudo random Bit Sequence Generator	Bit Rate =10 Gbps PRBS bit sequence=100	RZ Pulse Generator	Rectangular Shape with min/max value=0 a.u/1 a.u Rise/Fall Time =0.05 bit
NRZ Pulse Generator	Rectangular Shape with min/max value Rise/Fall Time =0.05 bit	3R Regenerator	Delay compensation= 0 s Decision instant=0.5 Bit Absolute threshold=0.5 a.u
LED	Wavelength =550/ 750 nm Quantum efficiency=0.65 Gaussian Bandwidth =0.03 nm Slope efficiency 0.5 W/A RC time constant $100\text{x}10^{-12}$ s	Low Pass Bessel Filter	Cutoff frequency= 0.75 x symbol rate Insertion loss=0 dB Depth=100 dB Order=4
FSO Channel	Range =1 to 100 m Attenuation =1 dB/km Distance=1 m to 5 m	White Light Source	Frequency =50 THz Average power =36W Average noise power= e15W Noise PSD= -60dBm/Hz
PIN Photodiode	Responsivity =0.2A/W Dark current=10 nA Short noise bandwidth=35 MHz Thermal noise density=100e-024 Load resistance=50 ohms	Transimpedance Amplifier	1000 ohms Voltage gain =100 ohms Noise figure=3 dB Noise equivalent Bandwidth = 35 MHz Input capacitance=3 pF Absolute temperature=298K

The proposed design in the *figure 1* is simulated for various modulation types such as RZ and NRZ. NRZ modulation formats are replaced by RZ and the analysis is repeated with the remaining proposed design components as constants. Additionally, the simulation is also carried out further for different source LED with wavelength of 750nm. Along with that the analysis is performed for different distances. The simulation is also run and tested for white light source as noise model. In added to that the investigation is also accomplished for two distinct room sizes measuring 5m X 5m X 3m and 1mX 1m X 2m. For all the above analysis cases were simulated by considering all 4 LEDs in LOS and in NLOS all 4 LEDs are not in LOS. We have estimated the QoS parameters such the Q factor and the BER for all the above conditions. A measurement of communication quality called maximum Q factor is determined by considering both receiver sensitivity and signal-to-noise ratio. The input specifications and the simulation parameters used for the proposed model are summarized in the following *table 1*.

3. 1 Analysis of proposed VLC Model

3.1.1 Analysis for VLC design with LOS

The following results are obtained using the above proposed design by considering only the direct path and input specifications. The *table 2* shows the summary of results for VLC with noise and without noise for 5m. The results for the two different room sizes with LOS are implemented using the *figure1* and *figure2* with *table 1* specifications.

Table 2. Results for LOS VLC with and without noise for max distance of 5m

		Room size 5m X 5m X 3m Without noise		Room size 1m X 1m X 2m Without noise		Room size 5m X 5m X 3m with noise		Room size 1m X 1m X 2m with noise	
LED (nm)	**Modulation Scheme**	**Max. Q Factor**	**Min. BER**	**Max. Q Factor**	**Min. BER**	**Max. Q Factor**	**Min. BER**	**Max. Q Factor**	**Min. BER**
550	NRZ	4.73	3.93E-10	5.75	4.49E-11	3.87	3.87E-08	4.65	5.21E-09
	RZ	4.03	4.89E-09	4.84	6.79E-10	3.55	4.32E-07	4.35	6.79E-08
750	NRZ	4.49	1.52E-10	5.39	8.11E-11	3.62	5.36E-08	4.25	6.49E-09
	RZ	3.65	2.62E-09	4.95	4.39E-10	3.25	3.85E-07	3.85	5.41E-08

3.1.2 Analysis for VLC model with NLOS

The following results in *table 3* are obtained using the above proposed design with NLOS by considering the direct path and reflected path and input specifications. Here 4 LEDs are considered for direct and reflected pathways of light. This model is identical to the LOS propagation model except that it considers the reflection point. The equation provides the distance between one LED transmitter and receiver, the incidence angel and irradiance angle are $l1$ = 10m, 5m, 5m, 5m, $\theta 1i$ = 22, $\theta 1r$ = 25. The same specifications are assumed for all the four LED for NLOS. The *table 3* shows the summary of results for VLC with noise and without noise for a distance of 5m.

Table 3. Results for NLOS VLC with and without noise for max distance of 5m

		Room size 5m X 5m X 3m Without noise		Room size 1m X 1m X 2m Without noise		Room size 5m X 5m X 3m With noise		Room size 1m X 1m X 2m with noise	
LED (nm)	**Modulation Scheme**	**Max. Q Factor**	**Min. BER**	**Max. Q Factor**	**Min. BER**	**Max. Q Factor**	**Min. BER**	**Max. Q Factor**	**Min. BER**
550	NRZ	4.44	4.21E-07	4.67	5.52E-08	4.09	6.67E-05	3.67	2.87E-06
	RZ	3.47	6.45E-06	3.84	3.89E-07	3.05	4.45E-04	3.55	3.32E-05
750	NRZ	4.23	5.87E-07	4.63	2.67E-08	3.07	5.37E-05	3.62	6.66E-06
	RZ	3.13	6.31E-06	3.33	4.23E-07	2.57	5.31E-04	3.35	5.85E-05

The results for the two different room sizes with NLOS are implemented using the *figure 1* and *figure 2* with *table 1* specifications. The indirect path is considered as the reflection point with an attenuation of 2dB is applied. The simulation started with the same configuration in the LOS propagation model, and we used a power splitter/power combiner at the transmitting /receiver side before feeding it into the PIN photodiode. The NLOS simulation uses the same channel as in the case of LOS propagation model with the values specified in *table 1*.

3.1.3 Q factor for VLC model with LOS

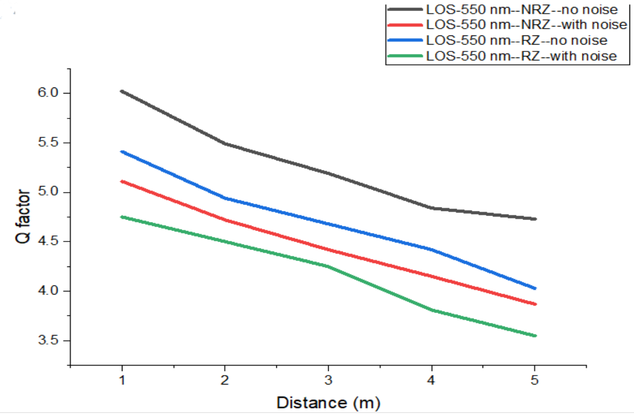

Figure 3. Distance Vs Q factor for room size 5mx5mx3m

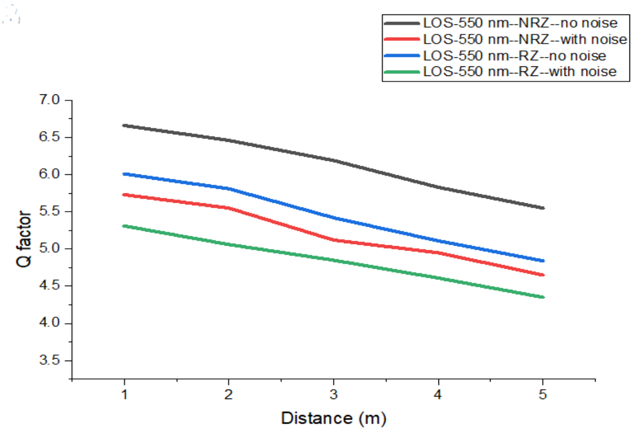

Figure 4. Distance Vs Q factor room size 1mx1mx2m

The *figure 3* shows the Q0factor for various distance measured for LOS VLC model two different room sizes. The results show as distance increase the Q-factor decreases. NRZ outperformance the Q-factor when compared to RZ for both cases without noise and with noise. But when comparing with room wise *figure4* Qfactor performance lesser room measurement surmounts the larger room measurement. When analyzing *wrt* the noise source aspect, without noise model surpasses the noise model in both cases of room sizes.

3.1.4 Q factor for VLC model with NLOS

The *figure 5* shows the Q factor for various distance measured for LOS NVLC model two different room sizes. The results show as distance increase the Q-factor decreases. NRZ outperformance the Q-factor when compared to RZ for both cases without noise and with noise. But when comparing with room wise *figure 6* performance lesser room measurement surpasses the QoS of larger room measurement. When analysing in the noise source aspect, without noise model surmounts the noise model in both cases of room sizes.

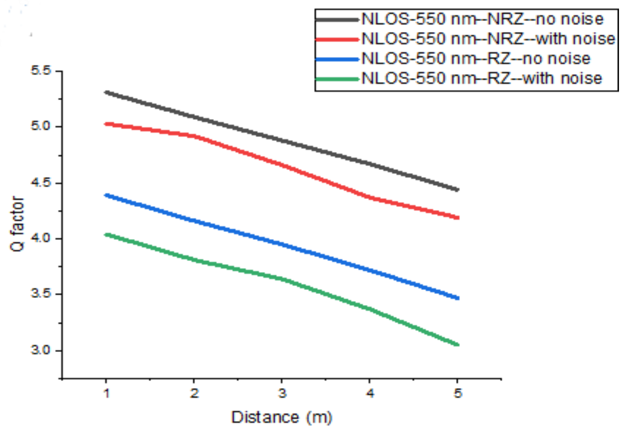

Figure 5. Distance Vs Q factor for room size 5mx5mx3m

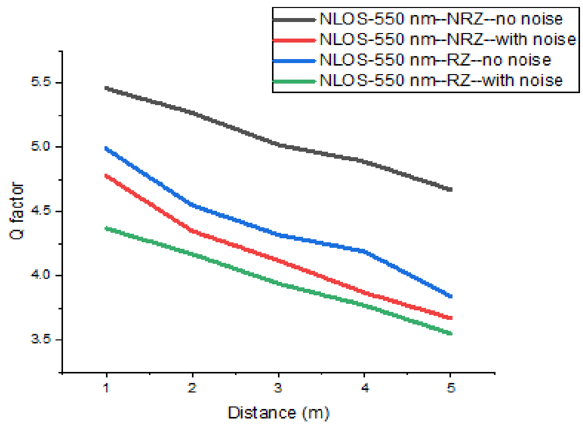

Figure 6. Distance Vs Q factor for room size 1mx1mx2m

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3.1.5 BER analysis for VLC model with LOS

Table 4. Summary of Results for 550 nm LOS VLC with and without noise for various distance

LOS	Room size 5m X 5m X 3m Without noise		Room size 5m X 5m X 3m with noise		Room size 1m X 1m X 2m Without noise		Room size 1m X 1m X 2m with noise	
Distance	Min. BER NRZ	Min. BER RZ	Min. BER NRZ	Min. BER RZ	Min. BER NRZ	Min. BER RZ	Min. BER NRZ	Min. BER RZ
1	8.95E-08	9.01E-07	7.52E-06	7.37E-06	7.83E-10	**9.45E-09**	**9.56E-07**	**8.52E-06**
2	7.53E-09	7.23E-08	6.02E-07	6.91E-06	5.68E-10	**8.55E-09**	**8.92E-08**	**7.77E-07**
3	6.35E-09	6.79E-08	5.77E-07	6.45E-07	5.22E-10	**8.13E-10**	**7.54E-08**	**7.55E-07**
4	4.52E-10	5.67E-09	4.32E-08	5.37E-07	4.87E-11	**7.32E-10**	**6.45E-09**	**7.32E-08**
5	3.93E-10	4.89E-09	3.87E-08	4.32E-07	4.49E-11	**6.79E-10**	**5.21E-09**	**6.79E-08**

The *table 4* shows the BER comparison for various distance measured for LOS VLC model two different room sizes. The results show as distance increase the BER increases. NRZ outperformance the BER when compared to RZ for both cases without noise and with noise. But when comparing with room wise performance lesser room measurement surpasses the BER of larger room measurement. When analyzing in the noise source aspect, without noise model surmounts the noise model in both cases of room sizes.

The *table 5* shows the BER comparison for various distance measured for NLOS VLC model two different room sizes. The results show as distance increase the BER increases. NRZ outperformance the BER when compared to RZ for both cases without noise and with noise. But when comparing with room wise performance lesser room measurement surpasses the BER of larger room measurement. When analyzing in the noise source aspect, without noise model surmounts the noise model in both cases of room sizes.

3.1.6 BER analysis for VLC with model with NLOS

Table 5. Summary of Results for 550 nm NLOS VLC with and without noise for various distance

NLOS	Room size 5m X 5m X 3m Without noise		Room size 5m X 5m X 3m with noise		Room size 1m X 1m X 2m Without noise		Room size 1m X 1m X 2m With noise	
Distance	Min. BER NRZ	Min. BER RZ	Min. BER NRZ	Min. BER RZ	Min. BER NRZ	Min. BER RZ	Min. BER NRZ	Min. BER RZ
1	3.87E-08	9.56E-07	4.65E-06	4.67E-05	7.45E-09	6.42E-09	9.67E-07	8.91E-06
2	7.76E-08	7.32E-07	3.69E-06	4.72E-05	5.63E-09	4.67E-09	5.45E-07	6.52E-06
3	9.38E-07	5.67E-07	2.56E-06	6.73E-05	9.24E-08	7.69E-08	7.12E-06	9.24E-05
4	6.57E-07	8.95E-06	9.24E-05	6.23E-04	7.89E-08	5.39E-08	5.91E-06	6.45E-05
5	4.21E-07	6.45E-06	6.67E-05	4.45E-04	5.52E-08	3.89E-07	2.87E-06	3.32E-05

3.1.7 Validation of Results

Table 6. Comparison Table of our results with other Literatures

Ref	Source	Data rate	Modulation format	BER	LOS/NLOS	Room Size
Reference [15]	LED	1Mbps	OOK	10^{-5}	LOS	5 x 5 x 2.5m
Reference [16]	LED	2Gbps	OOK	10^{-5}	LOS	5 x 5 x 3 m
Reference [17]	LED	1Mbps	OOK	10^{-4}	LOS	5 x 5 x 3 m
Reference [18]	LED	10 Gbps	NRZ	10^{-5}	LOS	5 x 5 x 3 m
Reference [19]	LED	2.5 Gbps	NRZ	10^{-5}	NLOS	5m
Reference [20]	LED	400 Mbps	OOK	10^{-5}	NLOS	5m
Our Proposed Model	LED	10 Gbps	OOK (Both NRZ and RZ)	10^{-11} 10^{-9}	LOS NLOS	5 m x 5 m x 3m and 1m x1m x 2m

Table 6 shows the comparison of results reported by authors in their previous investigations in VLC with our current research work. It clearly indicates that our proposed system could support up to 5m link distance with the bitrate of 10 Gb/s both in LOS and NLOS. The model also supports in presence of noise.

4. CONCLUSIONS

The Li-Fi system's performance under the impact of with and without an external noise source is propose and analyzed. The proposed design simulated for various modulation formats considering RZ, NRZ for various transmission distance from 1m to 5m. Performance and signal quality are both improved with increasing Q-factor. This investigation in the absence of background noise the suggested LiFi system had the max Q-factor of 6.5 and min BER of 10^{-11}. But when background noise was present, the maximum Q is decreased to 5.5. Background noise may influence the system's performance, as evidenced by a fall in the maximum Q-factor, which lowers overall quality a little. The proposed system has the lowest BER which represents the bit error rate of the system. Better performance is shown by a reduced bit error rate (BER), which denotes fewer issues with data transfer. The greatest Q-factor graphs and the min BER data show in table indicates that the suggested LiFi system performs just slightly better without light noise. The system's efficiency in presence of noise, however slightly decline the efficiency of the system with low Q-factor.

Author Contributions: This research articles were contributed by several author with their individual contributions as follows "Conceptualization by, S. Rajalkshmi and S.Balaji ; methodology by Karthigeyan.A.; software by Siddharth Gupta and R. Santha Kumar ; validation by S. Balaji and A.Karthikeyan; formal analysis by S.Rajalakshmi; investigation by S.Rajalakshmi; resources by Siddharth Gupta and R.Santhakumar.; data curation by A.karthigeyan.; writing—original draft preparation by Siddharth Gupta and R.Samthkumar.; writing—review and editing by S.Rajalakshmi.; visualization by A.Karthigeyan.; supervision by S.Balaji.; project administration by S.Balaji. All authors have read and agreed to the published version of the manuscript".

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