Design and Analysis of Light Fidelity Network for Indoor Wireless Connectivity

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ABSTRACT In the world of 20 billion connected devices, the data centers are just a drop in the ocean for the total energy consumption compared to the wireless access that is required for them. In the past years, it never became possible to obtain unprecedented bandwidth, to keep our data safe and repurpose the energy that we use for illumination to provide wireless communication, but now in the modern era, Light Fidelity (Li-Fi) can offer these things and much more. LiFi points towards high-speed, bi-directional, and networked wireless communications with the assistance of light. It offers users an almost similar experience as traditional wireless communications except using the light spectrum. With LiFi, a world connected by light has become an unbelievable reality. The design and functionality of the previous models are targeted to provide wireless communication but, to prove better quality results, an entire system is checked, and a new model is put forward. In this research study, the entire system is examined and tested on different values with various transmitting angles, data rates, distances, frequencies, the responsivity of PIN diodes to ensure the accuracy and best possible results are achieved. Testing of numerous ambient sources and modulation schemes aided in the success of this advanced technology. Different filters, transmitted pulses, modulation schemes, and angles are also changed and analyzed to study the behavior of LiFi thoroughly, which helped to attain a high-quality factor (Q-factor). The objectives of decline in Bit error rate (BER), increase in data rate, and quality signal are successfully achieved in the conclusion of this model. The research article is not only optimized but also has advanced features which mainly helped in gaining maximum results and goals behind this project.

INDEX TERMS Light fidelity (Li-Fi), quality factor (Q-factor), wireless fidelity (Wi-Fi), optical filters, modulation Schemes, pulse generators, transmission angles, PIN diode responsivity, bit error rate (BER), data rate.

I. INTRODUCTION
Internet rules our life without any dubiety, and according to a survey performed by optimum research online, WiFi is the first and foremost thing that the people are replying to their questionnaires and could not live without internet. Due to this heavy demand and rapid growth, the premodern Radio frequency (RF) networks face challenges. That being the case, there has been emerging interest in using Optical wireless communications (OWC) [1]. One of the most efficient technologies of OWC is LiFi because it is popular nowadays for indoor connectivity. This wireless optical communication technology uses a Light-emitting diode (LED) to send data and information. It is generally designed to use the light bulbs which are functioning as LED in homes and offices [2], [3]. The LEDs are working as transmitters in LiFi, whereas the receiver’s function is performed by photodiodes or solar cells [4]. LiFi was first set forth and demonstrated at TED GLOBAL Conference Edinburgh, in 2011, by Professor Harald Haas, co-founder of pure LiFi [5]–[8]. Li-Fi is ubiquitous and complementary to traditional wireless communications [9]. It has the ability to provide a more excellent spectral and spatial reuse. Data is transmitted wirelessly and then handed over from one light source to another to continue the exponential and technological growth. LiFi harnesses the Visible light communication (VLC) power for data transmission instead of RF waves used by WiFi [10]. The advantages of using LiFi for indoor connectivity include the ability of LiFi to work safely in aircraft, health sectors, power plants, and underwater as well. For the LiFi application, we require converting existing smartphones into LiFi enabled, and the LED bulbs used for this purpose shall also be enabled with
The researchers have proven that the speed of transmission is reasonably high as compared to the WiFi, and it moves in the range of 10-20 Gbps [12]. When data is transmitted in the form of bits there will be no interference issue in RF waves. The LEDs are switched on and off super quickly, and the binary code of 0 and 1 is integrated for data transfer. Binary 1 means switching on an LED, and switching an LED off is Binary 0 [13].

The research is performed with an in-depth analysis, and hence this article sheds light upon and support the realism. To test the accuracy of the entire model, a unique design is shaped to explain LiFi technology which helps to achieve successful objectives. Following procedures are performed to gain the maximum results:

- This model initially involves generating binary digits to get a rough idea about the characteristics of the numbers. The transition shows the production of electric pulses backed up by digital signals, then evaluated using an optical source. The analysis of signals goes side by side, and detailed images are recorded.
- The straight path of signals can be seen through the line-of-sight channel. An ambient noise source is fixed to detect all the sounds. After conversion into an electrical signal, the digital signal reaches the Transimpedance Amplifier (TIA), and hence the model is completed.
- By the end of the experimental, the proposed model helped achieve higher quality, an increase in distance and transmission rate, and a decrease in error rate, thus making it an efficient and advanced design for LiFi technology.

The remaining sections of the paper are discussed in the following manner. Section II discusses the previous research related to LiFi under the heading of related work, while Section III presents the numerical model and working boundaries. Section IV explains the entire scheme which is utilized to achieve efficiency in the design of LiFi. Section V subsequently presents the results and detailed analysis, which is followed by the conclusion presented in section VI.

II. RELATED WORK

The methodologies proposed in this paper aim towards improving the quality of the signals from a farther distance and decrease in the rate of error simultaneously. Previous researchers have utilized study of Sir Harald Haas in an effective manner and have made groundbreaking contributions in the development of LiFi and wireless networks.

Coordinated multipoint transmission and reception technique is proposed to provide an efficient data rate. Consequently, the model states that this method is highly beneficial in achieving the desired results for VLC in indoor areas [14]. In this paper, a cost-effective technique using a single wavelength is proposed, and the model is said to be close to real terms. The authors expect this model to be a foundation for further future developments in the respective area. Energy proficient and cost-effective vertical-cavity surface-emitting laser of 682 nm with a bandwidth of 1GHz modulation to create light, and transmission free of barriers with an 11.1 Gbps transmission rate is utilized in [15]. The researchers of this paper have put forward different rates of transmission using various techniques and have tested the results to find out the most acceptable rate at which high-speed connections can be made without using much energy along with a significant decrease in cost. Despite the progression in wireless networks, there is still a limitation for setting a goal to achieve a higher data rate without looking at certain significant factors. Using LEDs, the authors have set up a realistic VLC model and achieved an incline in the data rates [16]. The results of this model are based on the criteria of Internet of things and other biosensing software. The authors hold the claim that the highest data rates were achieved using organic LEDs.

Many similar techniques have been used in the past to produce profound benefits; however, some creative and novel ideas were introduced by several researchers to contribute in wireless network technology. An innovative methodology based on the measurement is proposed to enhance the reliability of optical and wireless communication methods in [17]. Different models are put in the light for mobile, and stationary users. Online surveys are also performed to ensure the usage of the best channel. This paper discusses the impact of the receiver’s movement on the LOS signals and emphasizes the better rates achieved for the uplink transmission. A fusion of wireless and LiFi is proposed in this paper, where an open-source model is utilized for an in-network stimulator 3 to emphasize the significance of critical features of LiFi [18]. Physical and other medium access-controlled layers are implemented to gain maximum output and dynamic results. Multiple users can access the data using the proposed system, and a source code is generated to modify the network parameters. A gradient projection technique is proposed using access points in [19]. The access points are placed in their utmost efficient position in the VLC network. Reynolds transport theorem is also applied to analyze the objective gradients mathematically. The results have shown that the applied algorithm can improve the positioning system in a more sophisticated way. With this being progressed, random positioning of users’ devices is modeled to analyze the effect on results of the LiFi network in [20]. Various datasets are collected in this paper to perform experiments and followed up the best possible outcome. The paper provides evidence that Gaussian distribution is adequate for mobile users, whereas it is better to use Laplace distribution for the static receivers. LOS signals are measured in this paper, and the accuracy of the method using the preferred distributions is checked using the KSD method. This paper also ends with the discussion that the random user positioning helps to better understand the model’s performance.

A variant kind of scheme inclusive of electro-optic, up-down link, and on-chip is proposed, where a plasmonic island node is inserted to obtain transferring signals through conversion of signals. It is concluded that a laser has enough power to be used as a foundation and a bridge for the LiFi
network. A sufficient amount of high power and a responsive is obtained and henceforth applied for better transmission with the quality signals [21]. A realistic indoor hybrid WiFi network-based model is utilized to study and to test random positioning and receiver motion. Various schemes such as OFDMA and EGT are applied and analyzed to improve the data transmission rate and to ensure fairness. The drawn conclusions emphasize the high frequency used to maintain the performance of the model. It provides an effective way to balance a load of users on WiFi and LiFi [6]. The accuracy of the performance of the model. It provides an effective way to balance a load of users on WiFi and LiFi [6]. The accuracy of the performance of the model. It provides an effective way to balance a load of users on WiFi and LiFi [6]. The accuracy of the performance of the model. It provides an effective way to balance a load of users on WiFi and LiFi [6].

Here \(d\) is the distance between transmitted source and the receiver [26]. So, the received power can be calculated by using the values of equation 3;

\[
P_r = I_s[d, \vartheta] \times A_{\text{eff}}(\psi)
\]

where \(A_{\text{eff}}\) is related to the structure of receiver and it consists of a filter, lens having gain and the area of detector which is calculated by:

\[
A_{\text{eff}}(\psi) = \begin{cases} 
A_{\text{det}} T_s(\psi) g(\psi) \cos(\psi) & 0 \leq \psi \leq \psi_c \\
0 & \psi > \psi_c
\end{cases}
\]

\(A_{\text{det}}\) is the area of detector, \(T_s\) is the transmission gain of filter, \(g\) is the lens gain, \(\psi_c\) is a FOV of the receiver and \(\psi\) is the incident angle with respect to receiver axis, the lens gain is calculated by the following formula in which \(n\) is the refractive index of the concentrator [27];

\[
g(\psi) = \begin{cases} 
\frac{n^2}{\sin^2 \psi_c} & 0 \leq \psi \leq \psi_c \\
0 & \text{otherwise}
\end{cases}
\]

Typically, the frequency response in VLC is flat near DC so the generalized Lambertian DC gain is given by:

\[
H(0)_{\text{Lamb,Gen}} = \begin{cases} 
\frac{(m+1)A}{2\pi d^2} \cos^m(\vartheta) T_s(\psi) g(\psi) \cos(\psi), & 0 \leq \psi \leq \psi_c \\
0, & \theta > \psi_c
\end{cases}
\]

So, the received power can be calculated by putting values in equation 4;,

\[
P_r = \begin{cases} 
\frac{P_t(m+1)A_{\text{det}}}{2\pi d^2 \sin^2 \psi_c} \cos^m(\vartheta) T_s(\psi) n^2 \cos(\psi), & 0 \leq \psi \leq \psi_c \\
0, & \theta > \psi_c
\end{cases}
\]

Here \(P_r\) is received power, \(P_t\) is transmitted power, \(m\) is Lambertian order \(A_{\text{det}}\) is an area of detector. \(T_s\) is transmission gain of filter, \(n\) is the refractive index of a lens, \(d\) is the distance between transmitter and receiver. \(\psi\) is an incident angle with respect to receiver axis and \(\psi_c\) is a FOV of the receiver, in the above equation, in the provided conditions if the incident angle of a receiver is greater than the FOV of the receiver then the received power will be zero [28].

### III. MATHEMATICAL MODEL

The features associated with indoor VLC comprise a dimension of the room, i.e., length and width, and secondly, visible or invisible light-emitting resources through which the information will be modulated and then utilized by the receiver source in that room. By considering the ray of geometry, the LED have Line of sight (LoS), and non-Line of sight (NLoS) communication with the receiver, which is named as PD having field of view (FOV), the angle associated to LED i.e., radiation angle \(\vartheta\); and the angle associated to PD is i.e., incident angle \(\psi\) [23]. The transmitting source is LED, which is emitting radiation, and it is assumed to be Lambertian radiation because it obeys the Lambertian cosine law, and the Lambertian radian intensity is the flux emitted or reflected, which is received by per unit solid angle, and it is different from irradiance, where flux emitted by per unit area so Lambertian flux intensity is written as [24];

\[
R_o = \frac{m + 1}{2 \times \pi} \cos^m \vartheta
\]

where \(\vartheta\) is radiation angle and \(m\) is Lambertian order given by

\[
m = -\left\{ \frac{\ln 2}{\ln(\cos(\vartheta_1/2))} \right\}
\]

where \(\vartheta_1\) is the transmitter semi-angle at half power [25]. If it is assumed that transmitter is emitting symmetrical radiation pattern then it is \(P_t \times R_o\), where \(P_t\) is average power transmitted by optical transmitter. So, at receiver side the irradiance \(\frac{W_{\text{cm}^2}}{\text{cm}^2}\) is given by the following equation by equating values of equation 1;

\[
I_s[d, \vartheta] = \frac{P_t \times R_o(\vartheta)}{d^2}
\]
TABLE 1. Stimulation parameters.

| Parameters                  | Symbol | Value   |
|-----------------------------|--------|---------|
| Transmitted Power of LED    | \( P_t \) | 50 mW   |
| Lambertian Order            | \( m \)  | 1       |
| Surface Area of detector    | \( A_{det} \) | 1.5 cm\(^2\) |
| Transmission Gain of Fiber  | \( T_s \) | 0.5 dB  |
| Refractive Index of Lens    | \( n \)  | 1.5     |
| Incident Angle of receiver axis | \( \psi \) | 20°     |
| FOV of receiver             | \( \psi_c \) | 15°     |
| Distance between Tx and Rx  | \( d \)  | 6 m     |

our goals in designing and developing a successful approach to evaluate and perform a better analysis of the LiFi network for indoor connectivity. Mainly, we have three main goals behind our research and proposed scheme. The first one is to ensure a quality signal and a good internet speed regardless of the distance between the device and the user in indoor environment. The second goal is to achieve a decline in BER, which means the imperfections in the components responsible for connectivity shall be eliminated to the possible extent so, to improve the overall bandwidth, and achieve the lower levels of noises at receiver. The third objective is to increase the range of LiFi, data rates and to transmit the signals at higher speed and with better results.

In the proposed model, we have tested and amended the existing design, and after detailed analysis, the results of numerous improved parameters are combined to put together as one model. The most important thing about this model is the effectiveness of the components utilized to achieve the stated objectives. The function of each element involved as a building block of the proposed model is highlighted in the next section. These components were previously utilized in one of the presented models in literature [10] however, we have optimized the different blocks for much better quality. For system optimization, our focus is to increase the distance while maintaining good quality signal, secondly to improve the data transmission rate for the upgraded model. For this purpose, different system parameters are tuned and set to find out the finest points in coverage area. For example, while performing optimization, we have changed and tested the values of transmitting angles, data rates, distance, the responsivity of the PIN diode, frequency, modulation formats and added various ambient sources of photodiodes to improve the design of the indoor LiFi connectivity source.

A pseudo-random bit generator, as shown in Fig. 1 is a first basic component of the model to generate a series of binary digits whose characteristics provide a vague estimation of the properties of the random numbers. It is directly connected to the Non-Return to Zero (NRZ) pulse generator whose function is to produce electrical pulses in NRZ modulation format, and these pulses are backed up and coded by a digital input signal. This NRZ pulse generator is also linked with BER analyzer for BER estimation at output side.

NRZ pulse generator is then connected with the LED because the pulse generated is typically a variant of the digital electrical signal, and a light source would be required to visualize in the frequency and time domain. Here the frequency, bandwidth, and modulation of the transmitted pulses are recorded. The signal at this point is analyzed using Optical spectrum analyzer (OSA). OSA analyzer displays modulated optical signals in the frequency domain and provide detailed image regarding the signal intensity, power spectral density (PSD), group delays and dispersion. Optical time domain visualizer (OTDV) and Optical power meter (OPM) are also attached to study further details about signal. The OTDV displays modulated optical digital signals in the time domain, whereas the OPM is utilized to measure power of transmitted optical signal. It helps in the valuation of average power in optical communication systems. In these systems, 0 dBm is taken as high-power, while \(-50 \text{ dBm}\) is considered as a low power signal.

A LOS channel based on the Lambertian source model is placed next to the LED, where the optical wireless signals are transmitted applied with NRZ modulation format. In LOS channel direct and indirect transmission of waves from transmitter to receiver is possible. In case of indirect path, multiple paths exist between source and destination. Here the angles, distance, and area are detected and noted for further analysis. A significant point in the proposed simulation is the difference between the link distance of the existing model and our proposed model. We have tested our model on a distance 6-10m which is greater than one already determined in the existing model to prove the efficiency of our research. After passing through LOS channel, the signal passes through optical filter, which is an automated tool with a rectangular frequency transfer function. The insertion loss and maximum alternation are set to 0 dB and 100 dB, respectively. Function of the filter is to eliminate added noises from the signal. OSA and post OPM are used there to record details of the filtered signals after passing through filter. OSA performs post-analysis of the signal before its conversion from optical to electrical form. This signal is then received on a PIN photodiode whose function is to receive filtered optical signal and to convert back into electrical domain i.e., NRZ electrical pulses. The details of the signal are again analyzed and recorded at this point. Here, the electrical signal is combined with Ambient noise sources of the room by using electrical adder. These noise sources can be considered as the induced noises during the transmission of signal. The mean, variance, and standard deviation of the received signal are thus recorded after the combination with electrical noises in electrical adder. The electrical signal then reaches the TIA (Transimpedance amplifier). The input and output signals of TIA are both in the same electronic form, unlike PIN photodiode. TIA acts as a battery as it has thermal noise and frequency transfer functionality which helps in the conversion of
current to voltage. The DC block preset in between TIA and BER Analyzer, subsequently blocks the direct current voltage from the input electric signal by eliminating the mean value. The LP Chebyshev filter is used in our model to filter out any undesirable noise which is included in it. The order of filter is kept as 1 with ripple factor 0.5 dB. The oscilloscope visualizer is also placed there which helps to display electrical signal in a time domain and shows the signal amplitude subsequently, the signal reaches the point of the BER analyzer. We tested numerous signals on these components and determined the most efficient way to increase the distance and transmission rate and to decrease error rate.

V. RESULT AND DISCUSSION
After thorough testing of various parameters values on the components and implementation of the above-mentioned model, we extracted and combined the outcomes to propose a model which is proved to be effective and accurate, because a better and efficient outcome is achieved using this model at a distance (i.e., 6m) which is higher than the one reported in an existing model (i.e., 4m). Error is also lessened significantly, and the data transmission rate is also successfully elevated.

For better understanding, the effects and results of various components used in the existing LiFi model and reapplied in our proposed model are given in Table 2. In this table, clear differences can be seen in the results of two models which are using the same filters, modulation scheme, and pulse generator. The detailed results after the testing of entire proposed model are also covered step by step in this section.

The result and discussion section is mainly divided into four parts based on the working of different parts of the proposed model. These include,

- Filter type
- Shape of the pulses
- Transmission angles,
- Modulations schemes

The effectiveness of proposed model and the achievement of stated goals are described through plotted graphs and formulated figures (eye-diagrams).

A. FILTERS ANALYSIS
Different filters are designed to allow a certain amount of frequency signal to pass through them such as high-pass filters are designed to allow high-frequency components to pass through it, similarly band-pass filters are designed to pass components with specific frequency band through it, but in the proposed model we used low-pass filters to have all data components at the receiver end. Since, we transmit data in the form of bits so for successful communication and recovery of signal, it is necessary to have all transmitted bits at the receiving end. So, we allow even low-frequency components to pass through it; moreover, we modulate it with a high-frequency carrier signal to travel for more distance than a broadband signal. To recover the original low-frequency signal, we use low pass filters and analyze which filter gives better results for the above-proposed model.

1) BIT RATE VS QUALITY FACTOR
The effect of different filters (such as Chebyshev, Inverse Gaussian, Bessel, Butterworth, Cosine Roll Off) on the Q-factor of the signal with change in bit rate is shown in the bar chart in Fig. 2. Both components are inversely related to each other as the Q-factor decreases with the increase in the number of bits in transmitting signal. The bit rate is shown along the x-axis, whereas the Q-factor is presented along the y-axis. Using inverse Gaussian filters, the effect on the Q-factor of the change in the number of bits conveyed per unit of time is less than the other filters. The Cosine Roll off displays the overall highest peaks of Q-factor whereas LP ChebyShev performs good when used for large data or file sizes.

2) BIT RATE VS BIT ERROR RATE
BER is comprehended as the percentage of the bits that have errors in relation to the total number of bits conveyed per transmission, while the bit rate is the term used for the number of units transferred from one point to another in a defined time. The effect on BER using different filters with the change in bit rate is displayed in the line chart shown in Fig. 3. Bit rate
TABLE 2. Comparison of existing model with proposed model.

| Components in Proposed Model | LP Chebyshev Filter | NRZ Scheme | Modulation | Gaussian pulse |
|------------------------------|---------------------|------------|-------------|----------------|
| Existing Model               |                     |            |             |                |
| Q-factor                     | 11.0013              | 7.5595     |             | 6.72405        |
| BER                          | $1.85 \times 10^{-28}$ | $1.99 \times 10^{-14}$ |             | $8.76 \times 10^{-28}$ |
| Eye Height                   | 0.000240152         | 0.000199743 |             | 0.000164215    |
| Proposed Model               |                     |            |             |                |
| Q-factor                     | 14.4608              | 13.8046    |             | 10.9512        |
| BER                          | $1.10 \times 10^{-47}$ | $1.15 \times 10^{-43}$ |             | $3.22 \times 10^{-28}$ |
| Eye Height                   | 0.000398627         | 0.000398627 |             | 0.000303566    |

is plotted on the x-axis, whereas BER is shown on the y-axis. These two correlated factors show direct relation with each other as the graphic representation proves that the BER keeps on increasing with the increase in data transmission rate or bit rate. LP Cosine Roll-Off filter shows the sharpest incline in its curve with an increased bit rate whereas LP ChebyShev shows low error rate while maintaining steady state.

3) DISTANCE VS QUALITY FACTOR
The bar chart in Fig. 4 shows the graphical representation of the effect on Q-factor by varying distance and using different type of filters. The general rule is that with increasing bandwidth, the Q-factor of the signal is reduced. The functionality and quality directly depend on the distance between the source of connectivity and the receiver of connection. With increasing distance, most filters display harmonious results, i.e., decrease in Q-factor, but the Butterworth filter shows different results as the quality of the signal using the Butterworth filter has increased at larger distances comparable to 2m.

4) DISTANCE VS BIT ERROR RATE
BER is the crucial parameter for determining the performance of wireless signals. Distance directly affects the BER as we tested various filters on the signals and recorded their effect (given in Fig. 5) by varying distance. The BER graph gets an incline with the increase in distance however, in different ways for different type of filters. It is observed that the value of error is increased significantly with the increase in distance for LP Chebyshev and LP Cosine Roll off filter.

B. PULSE SHAPE ANALYSIS
Pulses are required to make our data suitable for transmission over a medium. This method helps in transmission by overcoming the factors like inter-symbol interference (ISI) or aliasing effect by filtering the pulses at adequate bandwidth to transmit signal. Pulse shaping is done through filters by evaluating the Nyquist-ISI criterion. To evaluate the better-quality signal Gaussian, Triangular, Hyperbolic, and Raised Cosine
FIGURE 4. Effect on Q-factor using different filters by varying distance.

FIGURE 5. Effect on BER using different filters by varying distance.

pulses are tested and compared by varying data rate and distance.

1) BIT RATE VS QUALITY FACTOR
The bar chart in Fig. 6 illustrates the behavior and impact of different kinds of pulses on Q-factor and data rate (Mbps). The pulses are generated by using Gaussian pulse generator, Hyperbolic pulse generator, Triangular pulse generator, and Raised Cosine pulse generators. Simulations are carried out to check the Q-factor with the increase/decrease in data rates. The graph shows the significant continuous upward trend in the Q-factor with the decrease in the data transmission rate, and interestingly all the pulses showed similar behavior of high Q-factor, whether slight or significant, with the decline in data rate. Raised Cosine pulse displayed the highest Q-factor, 16.72, on a lower data rate, but it shows a sharp decline in quality with a slight increase in data rate. Thus, we have used Gaussian pulse in the model as the results indicate that Gaussian pulse maintains a good quality on varying data rates compared to the other pulses, and the quality decreases gradually.

2) BIT RATE VS BIT ERROR RATE
The line chart in Fig. 7 represents the behavior and impact of different kinds of pulses on BER by varying data rates (Mbps). The data rate is presented along the x-axis, whereas the BER factor along the y-axis. Gaussian pulse, Hyperbolic pulse, Triangular pulse, and Raised Cosine pulse displays incline in BER with the increase in data rate, which means if the data is transmitted at higher rate, the chances of BER increases. Hyperbolic pulse shows the steadiest behavior but overall, very high BER. Raised Cosine pulse shows minimum BER at low data rates, but it increases sharply as the data rate increases.

3) DISTANCE VS QUALITY FACTOR
The horizontal bar chart presented in Fig. 8 is elaborating the performance of different pulses by observing the quality of signal obtained at receiver end by varying distance. The distance is shown along the y-axis, while the Q-factor is plotted along the x-axis. Four kinds of pulses involved show almost similar results as the quality is diminished with the increase in the distance.
Raised Cosine pulse, as portrayed in the graph, evidently provides almost similar results no matter the distance between the source and the receiver from 2m to 8m. The use of Gaussian pulse is justified here because its quality is not showing a sudden decline with the increase in distance, and at the farthest of the distances selected, 10m, the quality of the signal using the Gaussian pulse is better compared to other pulses.

4) DISTANCE VS BIT ERROR RATE
The impact on BER by varying distance is presented in the line chart given in Fig. 9. The different pulses show variant results because after passing through the entire range of components, BER Analyzer provides the precise outcome regarding the functionality of the signal. Triangle pulse and Gaussian pulse show an incline in the BER with the increase in distance to some extent (from 2m to 6m), but after that, it decreases, and the trend varies.

Hyperbolic pulse and Raised Cosine pulse displayed same BER results irrespective of the distance between the LiFi source and the user. However, the error rate of Raised Cosine pulse remained little higher than the hyperbolic pulse throughout the distance.

C. TRANSMISSION ANGLES ANALYSIS
Angle plays a vital role in providing the quality of transmission. LiFi model performance directly varies with the transmission angle. The goal of this research is to increase the area of coverage of the transmitter and provide a better-quality signal.

1) BIT RATE VS QUALITY FACTOR
The effect on the Q-factor of the signal with the change in transmission angles at different data rates is presented in the bar chart shown in Fig. 10. Q-factor is plotted along the x-axis, whereas the data rate is shown along the y-axis. Both the parameters show an inverse relation between them because the Q-factor is decreased due to an increase in bit rate. At an angle of 15°, the highest Q-factor is recorded at a low data rate (10Mbps).

2) BIT RATE VS BIT ERROR RATE
The impact on number of error bits of the signal with the change in transmission angles at different data rates is shown in Fig. 11. The data rate is given along the x-axis, while BER is presented along the y-axis. As evident from the graph, both these factors are directly proportional to each other as the BER increases with the increase in data rate. The highest BER is recorded at an angle of 90°. At 15°, lower BER found
at lower data rates however, BER increases sharply with the increase in data rates.

D. MODULATION SCHEMES ANALYSIS

Modulation is an important step in LiFi communication and can play an important role in efficient data transfer. Our proposed model is tested by using different modulation schemes including Non-Return-to-Zero (NRZ), Return-to-Zero (RZ), Alternate Mark Inversion (AMI) and Duobinary (DB).

1) NON-RETURN-TO-ZERO

The eye diagram represented in Fig. 12 shows the modulation scheme of NRZ; in this eye diagram, the blue line represents the height of the eye, which is directly related to the eye’s opening, and its value is found as $0.0003986$. It is good enough to recover the modulated information which is transmitted. The other factors associated with the eye are the BER and Q-factor of the transmitted information, and these are calculated as $1 \times 10^{-43}$ and $13.8046$ respectively, for the distance of 6m.

2) DUOBINARY

Fig. 13 represents the Duobinary scheme, which is simple and also not very complex to implement; its eye height for the distance of 6m is found as $7.44 \times 10^{-7}$. The Q-factor of this modulation scheme is found as $6.98536$ whereas BER is calculated as $1.40 \times 10^{-12}$. The BER of Duobinary scheme which is a 3-level scheme, is higher than simple NRZ which is of 2-levels. Also, the eye-opening is much lower than the NRZ scheme as evident from Fig. 12 and Fig. 13.

3) ALTERNATE MARK INVERSION

In Fig. 14, the result of AMI modulation scheme is shown, where the eye-opening is much narrower. It means that it is prone to noise and the received modulated information has...
the chances of error. The height of the eye is found as $5.01 \times 10^{-7}$, which is least in all the tested schemes. For the AMI scheme, the Q-factor and BER are calculated as $4.9172$ and $3.43 \times 10^{-7}$ respectively.

4) **RETURN-TO-ZERO**

Fig. 15 is the eye-diagram representation after using RZ modulation scheme in LiFi model for the same distance i.e., 6m. It can be observed that in this modulation scheme, in comparison to NRZ, there is a slight difference in eye-opening, and the height of the eye is found as $0.00031563$. Thus, again it is easy to recover the information in case of RZ scheme when the eye-opening is greater. The Q-factor and BER of the RZ scheme are calculated as $13.1683$ and $6.49 \times 10^{-40}$ respectively.

Overall, the response of using RZ scheme in LiFi model found better than Duobinary and AMI but less than NRZ scheme.

**VI. CONCLUSION**

An optimized and smooth wireless connectivity model is put forward, based on improved Q-factors at different distances (2m to 10m) between the source of connectivity and the user, for ameliorated indoor network connections. We propounded firm connectivity model to achieve new targets successfully. The model brought forth is studied in detail, and we tested myriad ambient sources on different levels to make sure the model is duly optimized and efficiently analyzed. As Li-Fi is ubiquitous and complementary to traditional wireless communications, and it is way better than Wi-Fi in terms of quality, connectivity, and security, we have provided thorough numerical and graphical analysis supported with evidence to prove that the suggested model helped to achieve higher Q-factors from 6 meters, whereas the existing model was able to get signals up to 4m distance only.

The proposed model is tested in different ways. By choosing different type of filters in our model we concluded that Chebyshev filter is the best choice amongst others because it resulted in high quality and low BER. For data transfer different shapes of optical pulses are used including Gaussian, Hyperbolic, Triangular and Raised cosine. Gaussian pulse shows preferably sophisticated results compared to the other pulses. Gaussian pulse provides better results at greater distance with the lowest BER. We also analyzed various angles to improve the Q-factor in transmission. Although $15^\circ$ angle shows variation in BER with change in data rate, it is contemplated to be given the priority for better results instead of the other angles. Finally, the proposed model is tested by using different modulation schemes for data transfer. NRZ modulation scheme found best in terms of better quality and low BER. The efficiency and reliability of this research study by using the most efficient factors, assisted in getting increased data rate, decreased BER, and improved quality from a farther distance. The result of this suggested successful model proves that our research outperforms the existing models, and it is a highly sophisticated and effective design for improved wireless indoor connectivity.

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