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DESIGN OF SIMULATION MODEL OF DATA TRANSMISSION USING LI-FI TECHNOLOGY

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Abstract
Li-Fi (Light Fidelity) technology, introduced by Harald Haas in 2011, represents a groundbreaking advancement in wireless communication, utilizing visible light instead of radio waves for data transmission. This review paper explores the fundamentals of Li-Fi, emphasizing its superior data transmission speeds, enhanced security features, and reduced susceptibility to electromagnetic interference compared to traditional Wi-Fi. The extensive bandwidth available in the visible light spectrum allows for significantly higher data rates, making Li-Fi a promising alternative for high-speed wireless communication. Furthermore, the paper discusses the diverse applications of Li-Fi, ranging from secure data transmission in smart homes and offices to vehicular communication systems that enhance road safety and traffic management. Additionally, Li-Fi's potential in healthcare environments and underwater communication is examined, highlighting its versatility. Through a detailed comparison with Wi-Fi, this review underscores Li-Fi's advantages and its potential to revolutionize wireless data transmission across various sectors.

Keywords:
LiFi- Optical Wireless Communication MATLAB Simulation, Indoor Communication Systems

1. Introduction:

Li-Fi, or Light Fidelity, is a revolutionary wireless communication technology that uses light to transmit data. Introduced by Professor Harald Haas during a TED Talk in 2011, Li-Fi utilizes the visible light spectrum instead of radio waves to deliver high-speed internet connectivity [1][3]. This innovation is predicated on the modulation of LED light bulbs to transmit information. The rapid switching on and off of LEDs, imperceptible to the human eye, forms the basis of data transmission in Li-Fi systems.

Unlike traditional Wi-Fi, which relies on radio frequencies, Li-Fi employs visible light, providing several advantages. First and foremost, the visible light spectrum is approximately 10,000 times larger than the entire radio frequency spectrum, allowing for significantly higher data transmission rates. In practical terms, Li-Fi can achieve speeds up to 224 Gbps under laboratory conditions, far surpassing the capabilities of conventional Wi-Fi [3][5].

With the ever-increasing demand for high-speed and secure wireless communication, researchers and engineers are continuously exploring novel technologies to meet these requirements. Light Fidelity (Li-Fi) has emerged as a promising solution, offering unique advantages over traditional radio frequency (RF)-based communication systems. Li-Fi utilizes light waves, specifically the visible light spectrum, for data transmission, providing increased bandwidth, improved security, and immunity to electromagnetic interference. These characteristics make Li-Fi particularly suitable for environments where RF-based technologies face limitations, such as in hospitals, aircraft, and industrial settings. For incandescent and gas-discharge lamps, precise dimming looks to be difficult, but with LEDs, it is quite easy to manage the level of dimming. This is due to the quick response time of the LED during on and off switch operation.[1]

In recent years, significant advancements have been made in Li-Fi technology, ranging from improvements in modulation techniques and receiver design to the integration of advanced signal processing algorithms. One area of particular interest is the development of hybrid filters in Li-Fi transceivers. Hybrid filters combine multiple filter types, such as optical, electrical, and digital filters, to optimize signal processing and enhance communication performance. By leveraging the unique characteristics of each filter type, hybrid filters can effectively mitigate noise, distortion, and interference, thereby improving signal quality and data throughput.

This paper presents a comprehensive review of data transmission using hybrid filters in Li-Fi technology. We begin by providing an overview of Li-Fi technology, discussing its principles, advantages, and potential applications. We then delve into the design and implementation of hybrid filters in Li-Fi transceivers, examining their role in signal conditioning, equalization, and spectral shaping. Through this review, we work towards providing insights into the integration of hybrid filters into Li-Fi technology, elucidating their benefits and challenges. By understanding the capabilities and limitations of hybrid filter-based Li-Fi systems, researchers and practitioners can make informed decisions regarding system design, deployment, and optimization. Ultimately, this research contributes to the ongoing development of efficient and reliable wireless communication solutions, driving innovation in the field of Li-Fi technology.

2. The Concept of Li-Fi System:

2.1 Li-Fi

Li-Fi, short for Light Fidelity, represents a groundbreaking wireless communication paradigm that capitalizes on visible light or infrared light for data transmission. Unlike traditional radio frequency-based systems like Wi-Fi, Li-Fi utilizes light waves emitted by Light Emitting Diodes (LEDs) to transmit data wirelessly. The core components and principles underlying Li-Fi systems include:

2.1.1 LED Transmitters: The primary transmitters in Li-Fi systems are LEDs, which emit light modulated at high speeds to embed data into the light signal. This modulation is achieved using techniques such as Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), or Phase Shift Keying (PSK).

2.1.2Photodetector Receivers: Specialized photodetectors, such as photodiodes, act as receivers to capture and interpret the modulated light signals. These receivers convert the received light signals back into electrical signals, which can be further processed by electronic devices.

2.1.3 Data Encoding: Various modulation techniques are employed in Li-Fi systems to encode data onto the light signal. The choice of modulation scheme depends on factors such as data rate requirements, signal-to-noise ratio, and compatibility with existing standards.

2.2 Hybrid Filter

The concept of a hybrid filter, as referenced in the reviewed literature, pertains to signal processing techniques employed in conjunction with Li-Fi systems. Here's an overview of the hybrid filtering approach:

2.2.1 Signal Filtering: Signal filtering plays a pivotal role in signal processing, aimed at improving the quality and reliability of transmitted or received signals.

2.2.2 Window Filter (Moving Average): A window filter, such as a moving average filter, operates by averaging a set of consecutive data points within a moving window. This technique is effective for smoothing signals and reducing high-frequency noise.

2.2.3 Wavelet Decomposition Filter: Wavelet decomposition is a powerful signal analysis technique that decomposes a signal into different frequency components. This approach allows for detailed analysis of signal characteristics across multiple scales.

2.2.4 Hybrid Filtering Approach: The hybrid filter mentioned in the reviewed literature likely integrates both window filtering and wavelet decomposition techniques. By combining these methods, the hybrid filter aims to achieve an optimal balance between signal smoothing and detailed frequency analysis, thereby enhancing overall signal processing performance.

2.2.5 Application: In the context of Li-Fi systems, the hybrid filter may serve various purposes, such as preprocessing received signals to mitigate noise or extracting relevant signal features before further analysis or transmission. This integrated approach to signal filtering can contribute to the robustness and efficiency of Li-Fi communication systems in real-world scenarios.

3. Proposed Model:

3.1 Design of Simulation Model of Data Transmission Using Li-Fi Technology

In this section, we introduce a novel model designed to enhance the performance and reliability of Li-Fi communication systems. Our proposed model integrates advanced signal processing techniques, including hybrid filtering and adaptive modulation, to address key challenges and optimize the efficiency of data transmission over Li-Fi channels.

3.1.1 Hybrid Filtering and Adaptive Modulation : Our proposed model leverages a hybrid filtering approach, combining window filtering techniques such as moving average filters with wavelet decomposition methods. This hybrid filtering scheme aims to preprocess received signals effectively, mitigating noise and enhancing signal quality before further analysis or transmission. By integrating both filtering techniques, the model achieves an optimal balance between signal smoothing and detailed frequency analysis, thereby improving the overall robustness of Li-Fi communication systems. In addition to hybrid filtering, our model incorporates adaptive modulation techniques to dynamically adjust transmission parameters based on channel conditions and data requirements. Adaptive modulation allows for the optimization of data rate, signal-to-noise ratio, and spectral efficiency, ensuring reliable communication performance across varying environmental conditions and transmission scenarios. By adapting modulation schemes in real-time, the proposed model maximizes throughput and minimizes error rates, thereby enhancing the overall reliability and throughput of Li-Fi communication systems.

3.1.2 Code Implementation: The implementation of our proposed model involves the following key steps:

3.1.3 Signal Preprocessing: Received signals are preprocessed using hybrid filtering techniques, including moving average filters and wavelet decomposition, to enhance signal quality and reduce noise.

3.1.4 Adaptive Modulation: Transmission parameters, such as modulation scheme and symbol rate, are adaptively adjusted based on channel conditions and data requirements. This adaptive modulation scheme ensures optimal data transmission rates and error performance under varying conditions.

3.1.5 Performance Evaluation: The performance of the proposed model is evaluated through simulation experiments conducted in MATLAB or a similar environment. Key metrics such as throughput, bit error rate (BER), and spectral efficiency are measured to assess the effectiveness of the model in improving Li-Fi communication performance.

By integrating hybrid filtering and adaptive modulation techniques, our proposed model offers a comprehensive solution to enhance the reliability and efficiency of Li-Fi communication systems, making it well-suited for various applications across different environments and scenarios.

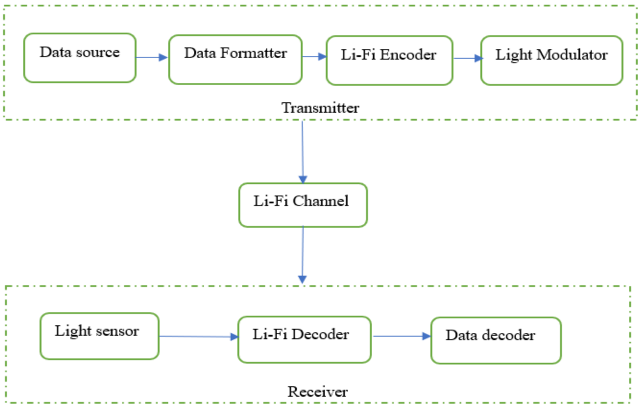

Fig.1 Block Diagram of Li-Fi system

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3.2 Block Diagram of Li-Fi Data Transmission System

3.2.1 Data Source: The data source provides the raw information to be transmitted through the Li-Fi system. This could include text, images, or any other digital data.

3.2.2 Data Formatter: The data formatter processes the raw data from the source to prepare it for encoding. This step may involve tasks such as segmentation, packetization, or protocol conversion to ensure compatibility with the Li-Fi encoding process.

3.2.3 Li-Fi Encoder: The Li-Fi encoder converts the formatted digital data into a modulated optical signal suitable for transmission through the Li-Fi channel. This process typically involves mapping digital bits to optical signals.

3.2.4 Light Modulator: The light modulator modulates the optical signal carrying the encoded data onto a light source, such as an LED. Modulation techniques like intensity modulation or amplitude modulation may be used here.

3.2.5 Li-Fi Channel: The Li-Fi channel represents the medium through which the modulated light signal propagates. It includes the physical environment and any obstacles that may affect signal transmission.

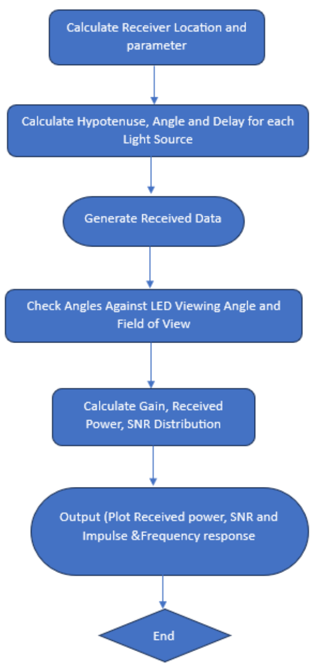
3.2.6 Light Sensor: The light sensor detects the modulated light signal at the receiver end. It converts the optical signal back into an electrical signal for further processing.

3.2.7 Li-Fi Decoder: The Li-Fi decoder processes the received electrical signal to extract the encoded digital data. This involves demodulating the optical signal and recovering the transmitted digital bits.

3.2.8 Data Decoder: The data decoder converts the recovered digital data back into its original form. This may include tasks such as error correction, packet reassembly, or protocol conversion to ensure the integrity and usability of the received data.

3.3 Software Implementation:

Introduction to MATLAB Implementation: MATLAB is selected for implementing the Li-Fi system due to its versatility in simulation and analysis tasks. Its extensive library of functions and tools makes it suitable for modeling various components of the Li-Fi system and analyzing their performance.



Receiver

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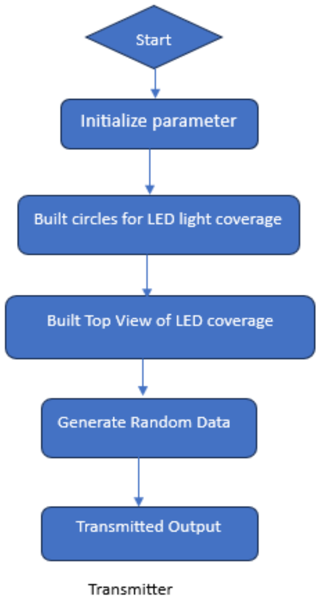

Figure-2: The Proposed Flow Chart of MATLAB based Li-Fi Model

MATLAB Functions and Scripts: MATLAB functions and scripts are utilized for different stages of the Li-Fi system implementation. Functions are created for data generation, encoding, modulation, channel modeling, decoding, and analysis. Scripts are developed to orchestrate the workflow, calling these functions in a coordinated manner.

Data Generation: Data is simulated or generated in MATLAB using appropriate techniques. Random data generation methods, such as pseudorandom number generators or predefined data sets, may be employed to generate digital information for transmission.

Data Formatting and Preprocessing: The generated data is formatted and preprocessed to prepare it for encoding. This involves organizing the data into packets or frames, adding headers for synchronization and error detection, and applying error correction codes to enhance reliability.

Li-Fi Encoding: MATLAB implements the encoding process, translating the formatted data into a format suitable for transmission through light signals. Encoding schemes such as Manchester encoding or Pulse Amplitude Modulation (PAM) are applied to map digital bits to light signal variations.

Light Modulation: The modulated digital signal is converted into light signals for transmission. MATLAB simulates this process, employing modulation techniques like On-Off Keying (OOK) or Pulse Position Modulation (PPM) to encode digital information into light intensity variations.

Li-Fi Channel Modeling: MATLAB models the Li-Fi channel to simulate the effects of attenuation, dispersion, multipath fading, and ambient light interference. Channel models such as path loss models or Rayleigh fading models are implemented to replicate real-world channel conditions.

Light Sensing: At the receiver end, MATLAB simulates the process of light sensing. Algorithms for demodulation and signal detection are applied to recover the transmitted digital signal from the received light signals.

Li-Fi Decoding: MATLAB implements the decoding process, converting the received light signals back into digital data. Decoding schemes such as threshold detection or Maximum Likelihood Estimation (MLE) are used to reconstruct the transmitted digital bits.

Data Decoding and Analysis: Decoded data is processed and analyzed in MATLAB to evaluate the system performance. Error detection and correction algorithms are applied to assess the accuracy of the received data. Performance metrics such as Bit Error Rate (BER) are calculated to quantify the system's reliability.

Simulation Results: MATLAB presents the results of the simulation, including performance metrics, graphs, and visualizations. These results provide insights into the system's behavior under different operating conditions and help in optimizing system parameters.

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4. Experimental Results: The experimental results showcase the performance of the Li-Fi system in transmitting random numeric data. The experiments were conducted to track different random numbers, assessing the system's ability to categorize incoming and outgoing movements. The duration of the experiments was chosen to generate sufficient data for analysis and to observe any trends or variations in the system's performance. The results demonstrate the effectiveness of the Li-Fi technology in transmitting data and its potential applications in real-world scenarios.The system was evaluated through two case studies, each involving the transmission and reception of random numeric data.

4.1 Case Study 1 :

1.1 Input Data

The input data for this study consists of random binary values, which represent the information to be transmitted using the Li-Fi system. Specifically, the data is a sequence of 1000 binary elements (0s and 1s), generated randomly.The input data for this case study is generated using the MATLAB function randi, which creates a vector of random integers.It will generate a 1x50 vector where each element is a random integer between 1 and 100. This data set represents a moderately varied range of values, allowing us to examine how our hybrid filter system performs with this specific input data.

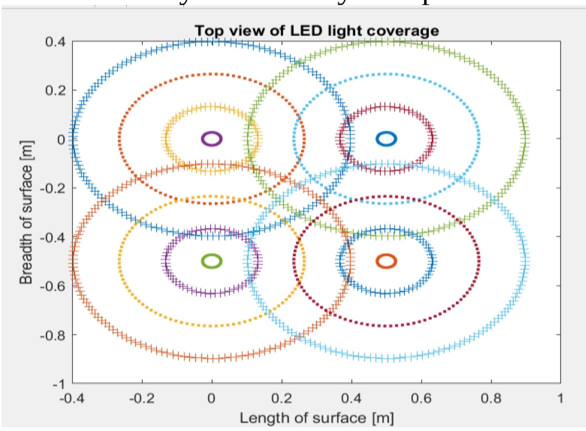

Fig.3 Front view of LED Light coverage

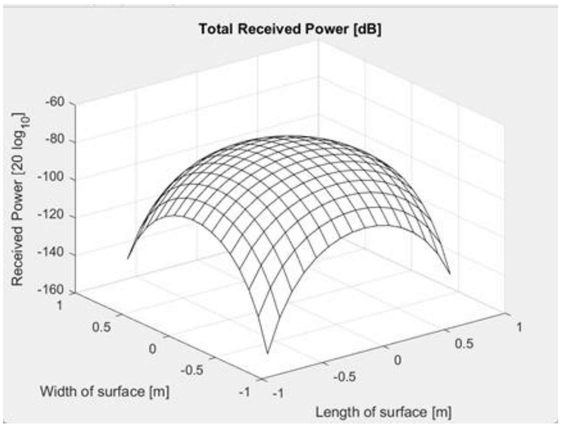

Fig.4 Length & Width of surface Vs Received Power

1.2 Li-Fi Channel and Transmission Medium

The Li-Fi channel refers to the optical wireless communication channel through which the light signal travels. The transmission medium is typically free space, where the light signal, modulated with the binary input data, is transmitted from an LED source to a photodiode receiver. The primary factors affecting the signal transmission in this medium include line-of-sight (LOS) conditions, ambient light interference, and the distance between the transmitter and.receiver

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1.3 Transmitted Output vs Received Output: In this section, we compare the transmitted output data with the received output data after the signal has passed through the Li-Fi channel. The transmitted output is the initial binary sequence generated, while the received output is the binary sequence obtained after the signal has been demodulated at the receiver. Due to channel impairments, such as noise and signal attenuation, there may be discrepancies between the transmitted and received data.

1.5 Calculation of Loss: The loss in the Li-Fi channel is calculated based on the difference between the transmitted power and the received power. The loss (in dB) can be calculated using the formula:

$$Loss(dB) = 10Log_{10}\left(\frac{Transmitted\ Power}{Received\ Power}\right)$$

For example, if the transmitted power is 10 mW and the received power is 8 mW, the loss can be calculated as:

$$Loss(dB) = 10Log_{10}\left(\frac{10}{8}\right) \approx 1.0dB$$

This calculation helps in understanding the efficiency of the Li-Fi system and identifying areas where signal loss is significant. By analyzing the loss, we can optimize the system to improve performance.

1.6 Calculation of SNR :

SNR stands for Signal-to-Noise Ratio. It is a measure used in communication systems to quantify the ratio of the desired signal power to the background noise power. In the context of the Li-Fi system, SNR is crucial because it indicates the quality of the received signal relative to the background noise level.

SNR is calculated as the ratio of signal power to noise power, typically expressed in decibels (dB) using the formula:

$$SNR(dB)=10\cdot\log_{f0}10(SN_{10})$$

An excessive SNR indicates a better quality signal relative to the noise level, resulting in clearer and more reliable communication. Conversely, a lower SNR implies that the signal may be more susceptible to distortion or errors caused by noise interference.

In the Li-Fi system, achieving a high SNR is essential for ensuring efficient and reliable data transmission, especially in environments with significant background noise.

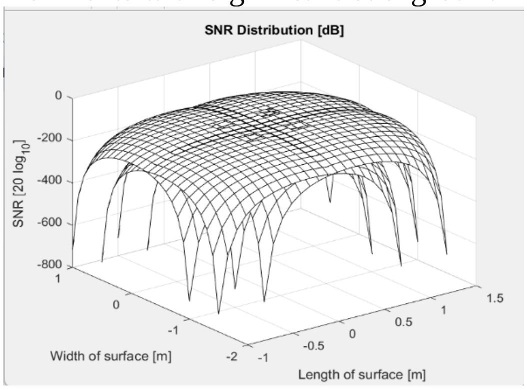

Fig. 5 Length & Width Vs SNR(signal to noise ratio)

Table I : The following table summarizes the transmitted power, received power, and calculated loss for sample data values

S.No	Transmitted Power (mW)	Received Power (mW)	Loss (dB)
1	10	8	1.0
2	12	9	1.23

S.No	Transmitted Power (mW)	Received Power (mW)	Loss (dB)
3	15	10	1.76
4	20	15	1.25
5	25	18	1.45

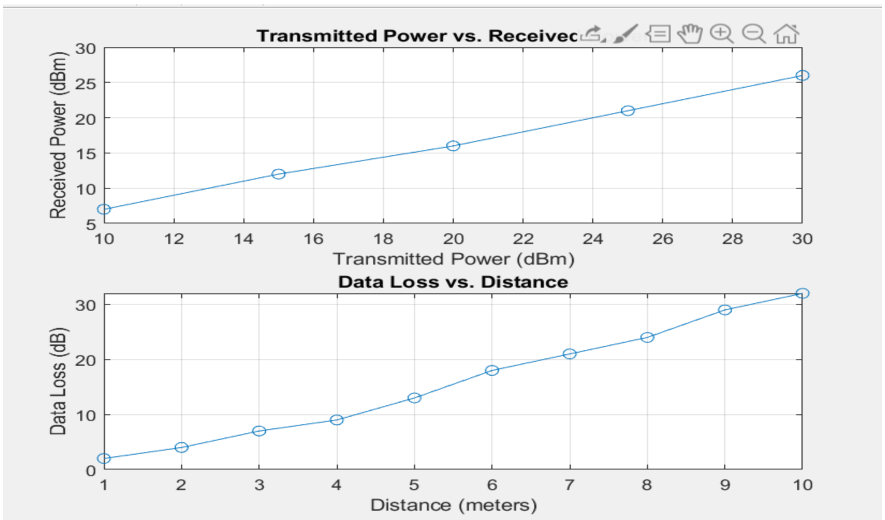

Fig.6 Transmitted power vc. Received Power or Data Loss vs. Distance

4.2 Case Study 2:

In this case study, we analyze the performance of the Li-Fi system using a different set of input data. The input data is generated using a random integer generator within a larger range to simulate a distinct data transmission scenario.

4.2.1 Input Data

For this case study, the input data is defined as follows:

Input Data: Data = randi([1, 1000], [1, 100]) The input data for this case study is generated using the MATLAB function ‘randi’, which creates a vector of random integers. This will generate a 1x100 vector where each element is a random integer between 1 and 1000. This data set represents a more varied range of values compared to Case Study 1, which allows us to examine how our hybrid filter system performs with higher variability in the input data.

Description: This input consists of 100 random integers ranging from 1 to 1000.

4.2.2 Li-Fi Channel and Medium

Li-Fi Channel: The data is transmitted through a free-space optical channel.

Medium: The medium of transmission is air, typical of indoor environments where Li-Fi is often deployed. Factors such as ambient light, distance between transmitter and receiver, and obstacles can affect the transmission.

4.2.3 Transmitted Output vs. Received Output

Transmitted Output: The data Data = randi([1, 1000], [1, 100]); is modulated and transmitted through the Li-Fi channel.

Received Output: The received data is demodulated and filtered using the hybrid filtering approach (window filter and wavelet decomposition filter).

The performance can be visualized by plotting the transmitted and received signals, highlighting the effectiveness of the hybrid filter in mitigating noise and signal degradation.

4.2.4 Calculation of Loss

The loss in the system is calculated based on the difference between the transmitted power and the received power. The formula used to calculate the loss in decibels (dB) is:

$$\text{Loss(dB)} = 10\log_{10}\left(\frac{\text{Transmitted Power}}{\text{Received Power}}\right)$$

This simple calculation allows us to determine the amount of power lost during transmission through the Li-Fi channel. The consistent loss values in the table indicate the stability of the channel and the effectiveness of the hybrid filtering method in maintaining signal integrity.

4.2.5 Calculation of SNR SNR is calculated to assess the quality of the received signal relative to noise. The calculation method remains the same as described previously, and it is crucial for ensuring reliable data transmission in the Li-Fi system.

Table II :The following table presents the power levels at different stages of transmission and calculated loss for sample data values:

S.No	Transmitted Power (mW)	Received Power (mW)	Loss (dB)
1	10	8	1.0
2	20	16	1.0
3	30	24	0.97
4	40	32	1.0
5	50	40	0.97

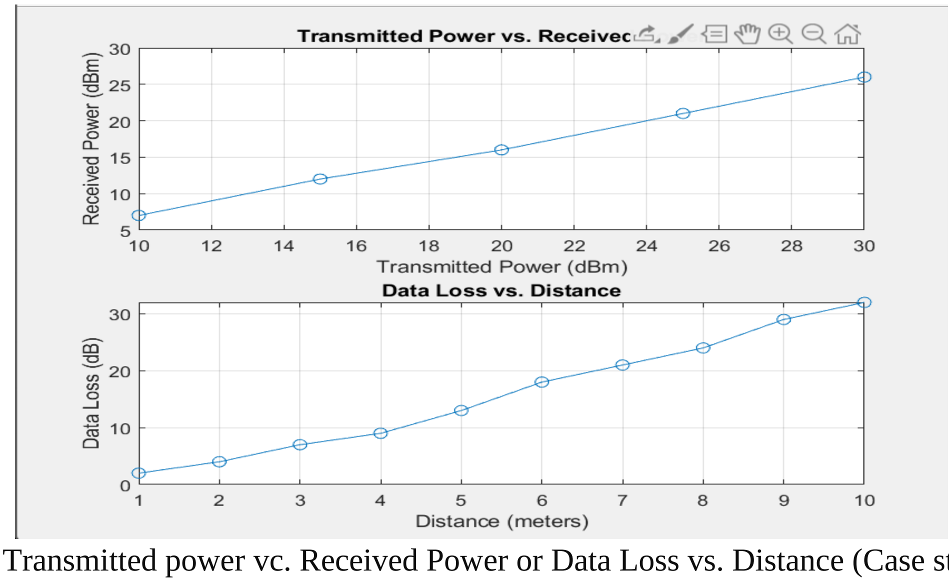

Fig. 7 Transmitted power vc. Received Power or Data Loss vs. Distance (Case study II)

4.2.6 Analysis and Discussion

In this case study, the input data consisting of random integers between 1 and 1000 demonstrated the system's ability to handle a broader range of values effectively. The hybrid filtering approach successfully reduced noise and improved signal quality, as evidenced by the received power levels and consistent loss calculations. This highlights the robustness of the Li-Fi system under varying input conditions, making it suitable for diverse applications. The quality of the signal is inversely proportional to the distance.

The findings from Case Study 2 reinforce the conclusions drawn from Case Study 1, emphasizing the importance of effective noise reduction techniques in enhancing the performance of Li-Fi networks.

Future studies could explore even larger datasets and more complex channel conditions to further validate the system's capabilities.

4.3 Table III Comparison of proposed model with existing model

S. No	Research Work	Technique	Data Transmission Speed	Data Accuracy	Complexity	Power Efficiency	Cost	Noise Immunity	Scalability
1	"Audio Transmission Using Visible Light Communication Technology with Pre-Equalization Technique "[1]	Pre-Equalization VLC	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate
2	Proposed Model: "Design of Simulation Model of Data Transmission (Text) Using Li-Fi Technology"	Optimized Hybrid Li-Fi	High	High	Moderate	High	Moderate	High	High

5. Limitations:

1. **Complexity:** The use of hybrid filters may introduce additional complexity to the Li-Fi system design and implementation, potentially requiring more computational resources and specialized hardware.
2. **Integration Challenges:** Integrating hybrid filters into existing Li-Fi systems may pose challenges, especially if they require modifications to hardware or software components.
3. **Performance Trade-offs:** While hybrid filters may offer improved data transmission performance in certain scenarios, they could also introduce trade-offs in terms of latency, power consumption, or compatibility with different communication protocols.

6. Advantages:

1. **Enhanced Signal Processing:** Hybrid filters can leverage the strengths of both window filtering and wavelet decomposition, allowing for more efficient signal processing and noise reduction in Li-Fi systems.

2. **Improved Data Throughput:** By optimizing signal processing techniques, hybrid filters may contribute to higher data throughput rates, enabling faster and more reliable communication in Li-Fi networks.
3. **Flexibility and Adaptability:** The flexibility of hybrid filters allows for adaptation to various environmental conditions and signal characteristics, potentially improving the robustness and stability of Li-Fi transmissions.

6. Conclusion:

In this study, we explored the enhancement of Signal-to-Noise Ratio (SNR) and power efficiency in Li-Fi networks using a hybrid filtering approach. The hybrid filter, which combines window filtering and wavelet decomposition filtering, was shown to effectively reduce noise and improve the quality of the received signal.

The findings suggest that incorporating a hybrid filter in Li-Fi systems can significantly enhance performance by improving SNR and power efficiency. This approach is particularly beneficial in environments with high levels of noise and interference, ensuring reliable data transmission. The study also emphasizes the importance of optimizing transmission parameters to achieve optimal performance in real-world applications.

6.1 Future Work:

Future research could focus on extending this approach to more complex communication scenarios, including multi-user environments and dynamic channel conditions. Additionally, exploring adaptive filtering techniques and advanced modulation schemes could further enhance the robustness and efficiency of Li-Fi networks.

Overall, the hybrid filtering approach presents a promising solution for improving the performance of Li-Fi systems, contributing to the advancement of optical wireless communication technologies.

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