HYBRID WIFI/LIFI INDOOR MODELING FOR NEXT GENERATION WIRELESS NETWORKS

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***Abstract*—The goal is to explore the possibilities of a hybrid interior. In combining the weaknesses of WIFI and LIFI technology, this pending hybrid model area repressed the limits of traditional wireless systems and improved performance, scalability, and reliability in internal environment evaluation. Detailed simulations and real-world experiments are conducted to evaluate and confirm the feasibility, effectiveness, and potential advantages of the proposed hybrid model. The results of this study contribute to the further development of the inner cabin.**

***Index Terms*—(LIFI/WIFI), network simulation, performance analysis, resource allocation, handover, 5G/6G integration, IoT network**

I. Introduction

The combination of Light Fidelity (LiFi) and Wireless Fidelity (WiFi) into a hybrid model shows an important leap forward in the development of next-generation wireless networks, particularly for indoor environments [1]. As the demand for high-speed, reliable, and low-latency connectivity continues to grow, traditional WiFi systems are increasingly challenged by issues such as spectrum congestion, interference, and limited bandwidth [2]. LiFi, which utilizes light waves to transmit data, offers a complementary solution by providing high data rates, enhanced security, and immunity to electromagnetic interference [3]. However, LiFi is limited by its inability to penetrate opaque obstacles and its reliance on line-of-sight communication [4]. To address these limitations, a hybrid WiFi/LiFi system combines the strengths of both technologies, leveraging WiFi's widespread coverage and non-line-of-sight capabilities with LiFi's high-speed data transmission and energy efficiency [5]. This synergy enables seamless connectivity in diverse indoor scenarios, such as smart homes, offices, hospitals, and educational institutions, while optimizing resource allocation and network performance [6]. By intelligently switching between WiFi and LiFi based on user requirements and environmental conditions, the hybrid model ensures consistent and robust connectivity, paving the way for innovative applications like augmented reality, Internet of Things (IoT), and ultra-high-definition streaming [7]. As transformative evolution in this area advances the hybrid , the hybrid WiFi/LiFi approach is poised to redefine indoor wireless communication, offering a scalable and future-proof result for the always-developing loads of the numerical phase. Hybrid WiFi/LiFi systems have emerged as a solution to address the limitations of traditional wireless networks while meeting the escalating demands for high-speed, reliable, and low-latency connectivity in indoor environments [8], [9]. WiFi, operating on the radio frequency (RF) spectrum, offers wide coverage and non-line-of-sight communication but faces challenges such as spectrum congestion, interference, and limited bandwidth [10]. In contrast, LiFi leverages visible light communication (VLC) through modulated LEDs to deliver ultra-high data rates, enhanced security, and immunity to electromagnetic interference [11]. However, its reliance on line-of-sight communication and inability to penetrate opaque obstacles limits its standalone applicability [12]. By participating in hybrid systems of WiFi and LiFi, researchers combine the ubiquitous coverage of WiFi with the high-speed capabilities of LiFi, creating a robust architecture capable of dynamically switching between the two technologies based on user requirements and environmental conditions [13]. Performance evaluations reveal that hybrid systems achieve higher aggregate throughput, reduced latency, and improved energy efficiency compared to objective WiFi or LiFi networks , making them perfect for dense indoor environments like offices, hospitals, and smart homes [14], [15]. Applications span various domains, including smart buildings enabled by IoT , healthcare, education, and industrial automation, where hybrid networks support real-time data processing , secure communication, and immersive experiences [16]–[18]. Considering onward, the combination of hybrid systems with emerging technologies like 5G, 6G, and observation is expected to explain new possibilities, enabling ultra-reliable low-latency communication and supporting sustainable urban development [19]. As advancements in LED technology and modulation schemes continue, hybrid WiFi/LiFi systems are poised to redefine wireless communication, offering a scalable and future-proof solution for next-generation applications [20].

II. Methodology

The methodology for the modeling of the indoor Wi-Fi/Li-Fi hybrid network typically involves the integration of both wireless communication technologies to optimize data transmission, coverage, and reliability within indoor environments, as shown in Fig.1. This diagram illustrates a hybrid WiFi-LiFi network, showcasing how two different wireless communication technologies, WiFi and LiFi, can coexist to provide Internet connectivity. On the left side, a WiFi router transmits data using radio waves, represented by concentric circles. Devices like the smartphone are connected to the router

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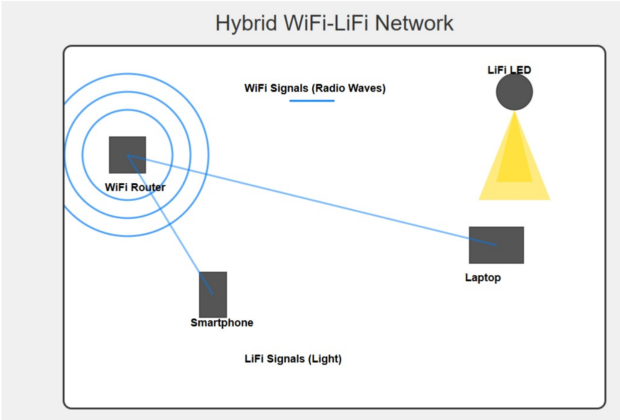

Fig. 1. Methodology of Hybrid WiFi/LiFi Indoor Modeling for Next Generation Wireless Networks

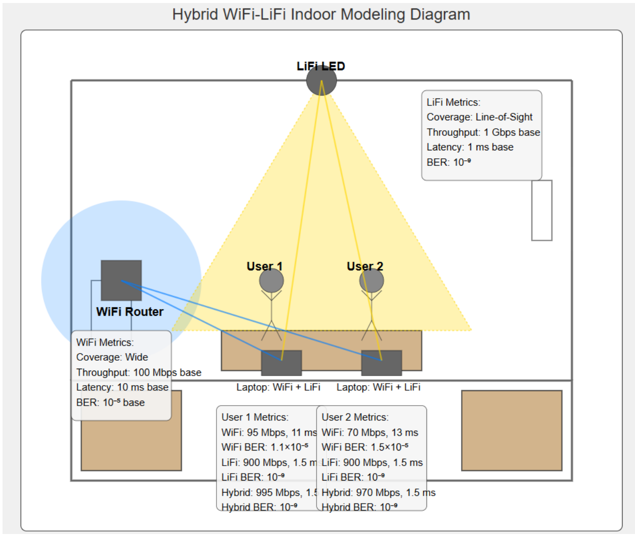

Fig. 2. Architecture of Hybrid WiFi/LiFi Indoor Modeling For Next Generation Wireless Networks

using this traditional wireless method. On the right side, a LiFi LED transmits data through visible light, indicated by the yellow cone-shaped light beam. A laptop is positioned within this beam, receiving internet via LiFi. This hybrid network configuration enables smart switching between WiFi and LiFi, depending on availability, location, or required bandwidth. Enhances performance by combining WiFi's wide coverage with LiFi's high-speed, secure, and interference-free communication, especially useful in environments like offices, hospitals, or smart homes. Fig. 2 describes the "Hybrid WiFi-LiFi Indoor Modeling Diagram" and illustrates a dual network setup where WiFi and LiFi technologies are used together to enhance wireless communication within an indoor environment. WiFi provides a wide coverage with a base throughput of 100 Mbps and a latency of 10 ms. In contrast, LiFi offers significantly higher base throughput of 1 Gbps and much lower latency at 1 ms, but it requires line-of-sight communication. The diagram models two users equipped with devices capable of connecting to both networks. For User 1, the hybrid system results in a combined throughput of 995 Mbps and a latency of 1.5 ms, while User 2 experiences 970 Mbps with the same latency. In both cases, the hybrid approach leverages the strengths of each technology, achieving high data rates and low latency while compensating for each other's limitations: WiFi's broader range and LiFi's speed. The flowchart in Fig.3 outlines the process for evaluating a Hybrid WiFi-LiFi network. It begins with setting up the network, including WiFi at 100 Mbps and LiFi at 1 Gbps. Users are then placed within the network coverage area. The process checks if users are in coverage; if yes, it proceeds to evaluate metrics like WiFi-LiFi handover delay (770 µs), hybrid WiFi-LiFi delay (885 µs), and hybrid throughput (1.87 Gbps). Results are then displayed, showing WiFi throughput at 770 Mbps, LiFi at 1 Gbps, and hybrid at 1.87 Gbps, with additional metrics like SNR (1.5 dB) and flow (1.81 Mbps). If users are not in coverage, the process ends. Here's a structured breakdown of the methodology:

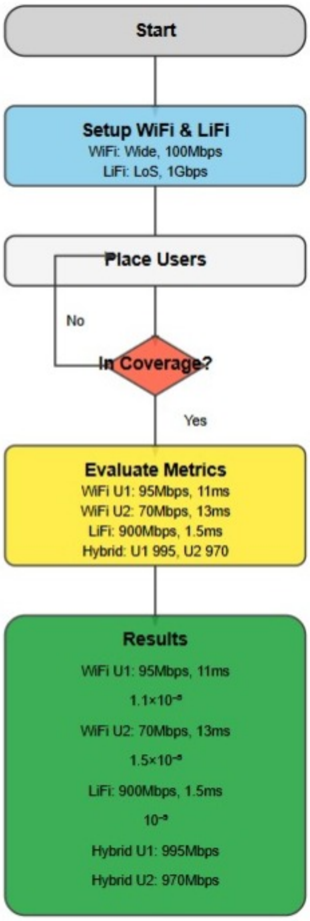

Fig. 3. Flowchart of the proposed model

A. Environment Modeling

Layout Creation: Use simulation tools (e.g., Python) to create a floor plan with rooms, walls, furniture, etc. Material Properties: Assign reflectivity, absorption, and transmission coefficients to different surfaces.

B. Technology Modeling

Wi-Fi Modeling Regularity group: 2.4 Standard: IEEE 802.11 (e.g., 802.11ac, 802.11ax) Path Loss Model: Use models like Log-distance or ITU indoor model Interference Considerations: From overlapping channels and multiple users

C. Li-Fi Modeling

Standard: IEEE 802.15.7 Light Source: LEDs with specific wavelength and FOV (Field of view) Receiver: Photodiode or imaging sensor-based receiver Channel Model: LOS/NLOS, Lambertian emission model Ambient Light: Account for interference from sunlight and other lighting sources

D. Hybrid Integration Strategy

Network Architecture: Central controller for switching between Wi-Fi and Li-Fi, load balancing and handover protocols Decision Criteria: Signal strength, user location and mobility, bandwidth demand, latency sensitivity, environmental conditions (light availability)

E. Simulation and Analysis

Performance Metrics: Throughput, signal-to-noise ratio (SNR), bit error rate (BER), latency, and jitter Energy efficiency Scenarios: static vs. mobile users, varying user density, and different lighting and obstruction conditions.

It illustrates the formulas as

1. Coverage Area

The coverage area of a circular region with radius r is given by:

$$A = \pi r^2 \tag{1}$$

where:

- A: Coverage area (m^2)
- r: Radius (m)

For the hybrid system, the total coverage area is

$$A_{\text{Hybrid}} = A_{\text{Wi-Fi}} + A_{\text{Li-Fi}} \tag{2}$$

2. Shannon Capacity (Throughput)

The Shannon capacity, representing the maximum achievable throughput, is:

$$C = B \cdot \log_2(1 + \text{SNR}) \tag{3}$$

where:

- C: Channel capacity (bits/s)
- B: Bandwidth (Hz)
- SNR: Signal-to-noise ratio (linear)

The SNR in linear form is converted from dB as

$$\text{SNR} = 10^{\frac{\text{SNR}_{\text{dB}}}{10}} \tag{4}$$

For the hybrid system, the throughput is

$$C_{\text{Hybrid}} = C_{\text{Wi-Fi}} + C_{\text{Li-Fi}} \tag{5}$$

3. Latency

The total latency is the sum of transmission, propagation, and queuing delays:

$$\text{Latency} = T_{\text{trans}} + T_{\text{prop}} + T_{\text{queue}} \tag{6}$$

where:

- T_{trans}: Transmission delay, calculated as:

$$T_{\text{trans}} = \frac{S}{B} \tag{7}$$

- S: Packet size (bits)
- B: Bandwidth (bits/s)
- T_{prop}: Propagation delay, calculated as:

$$T_{\text{prop}} = \frac{d}{c} \tag{8}$$

- d: Distance (m)
- c: Speed of light (3×10^8 m/s)
- T_{queue}: Queuing delay (s)

For the hybrid system, the latency is:

$$\text{Latency}_{\text{Hybrid}} = \min(\text{Latency}_{\text{Wi-Fi}}, \text{Latency}_{\text{Li-Fi}}) \tag{9}$$

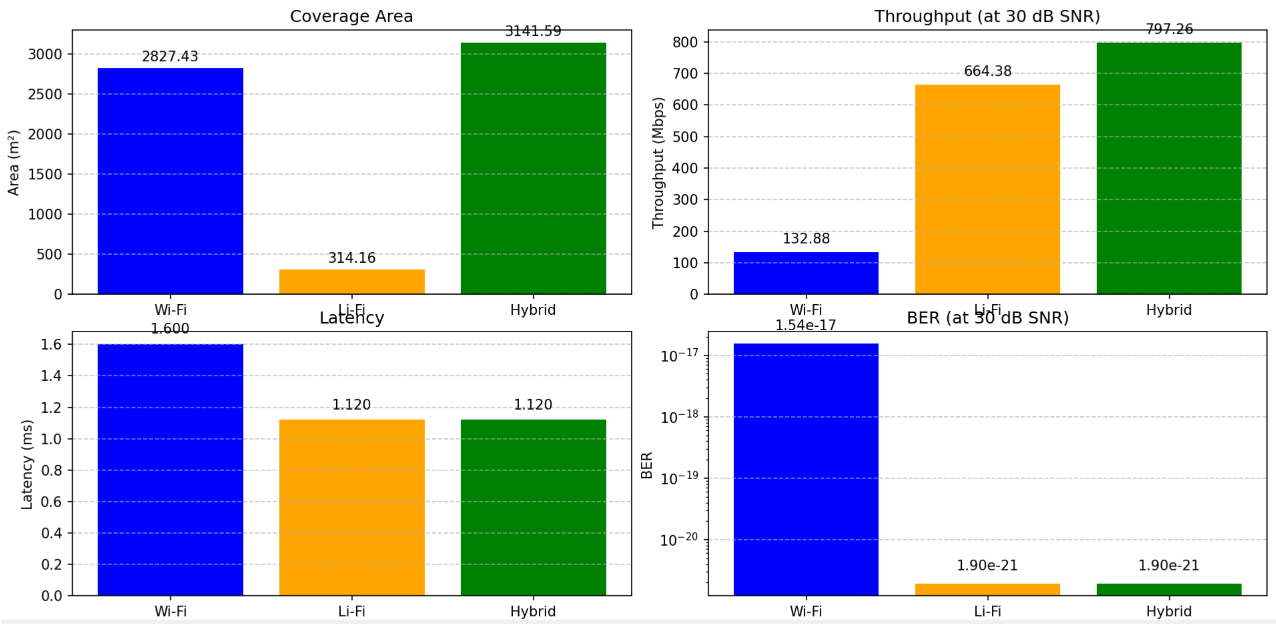

Fig. 4. Graphs/Plots

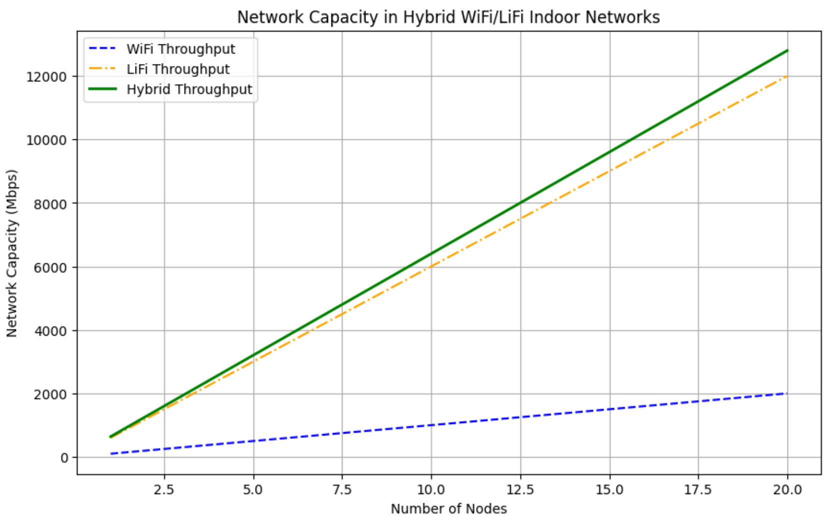

Fig. 5. Network Capacity

4. Bit Error Rate (BER) for BPSK

The bit error rate for binary phase-shift keying (BPSK) modulation is:

$$\text{BER} = \frac{1}{2} \cdot \text{erfc}\left(\sqrt{\text{SNR}}\right) \tag{10}$$

where:

- BER: Bit error rate
- $\text{erfc}(\cdot)$: Complementary error function
- SNR: Signal-to-noise ratio (linear)

For the hybrid system, the BER is

$$\text{BER}_{\text{Hybrid}} = \min(\text{BER}_{\text{Wi-Fi}}, \text{BER}_{\text{Li-Fi}}) \tag{11}$$

F. Evaluation and Optimization

Compare pure Wi-Fi, pure Li-Fi, and hybrid performance

Use optimization techniques (e.g., reinforcement learning, fuzzy logic) for adaptive switching

Suggest the enhancements based on findings (e.g., Li-Fi placement, handover algorithms)

G. Documentation and Reporting

Document all models, parameters, simulation results, and conclusions.

Provide visual aids (heatmaps, topology diagrams, throughput graphs) II

TABLE I
PERFORMANCE METRICS

Metric	Wi-Fi	Li-Fi	Hybrid	Unit
2*Coverage Area	2827.43	314.16	3141.59	m^2
	(Radius: 30 m, 10 m)			2*
2*Throughput (at 30 dB SNR)	132.88	664.38	797.26	$\mathrm{Mbit\,s^{-1}}$
	(Bandwidth: 20 MHz, 100 MHz)			2*
2*Latency	1.600	1.120	1.120	ms
	(Packet Size: 12 000 bit, Distance: 20 m)			2*
2*BER (at 30 dB SNR)	1.54	1.90	1.90	
	(BPSK Modulation)			2*

III. RESULTS AND DISCUSSIONS

The graphs in Fig.4 I compare the performance of Wi-Fi, Li-Fi, and a hybrid system in four standard coverage areas, throughput, latency, and bit error rate (BER) at 30 dB SNR. The four bar graphs 4(a), 4(b), 4(c), and 4(d) show how WiFi, LiFi, and a hybrid (WiFi + LiFi) system stack up in different areas. In 4(a) (Coverage Area), the hybrid system covers the most space at 3141.59 m², beating WiFi's 2827.43 m² and LiFi's smaller 314.16 m², since it uses WiFi's wide reach and adds LiFi's strengths. In 4(b) (Throughput at 30 dB SNR), the Hybrid is the fastest at 797.26 Mbps, with LiFi at 664.38 Mbps and WiFi at 132.88 Mbps, showing how the Hybrid mixes LiFi's speed with WiFi's connection. For 4(c) (Latency), LiFi and Hybrid both have the least delay at 1.120 ms, better than WiFi's 1.600 ms, meaning the Hybrid picks up LiFi's quickness. Lastly, in 4(d) (BER at 30 dB SNR), LiFi and Hybrid have the fewest errors at 1.90e-21, much better than WiFi's 1.54e-17, proving they're more reliable. Overall, the Hybrid system brings together WiFi's coverage and LiFi's speed, low delay, and reliability to work better than either one alone. The table highlights these results, emphasizing that the hybrid system offers the best overall performance by combining the advantages of Wi-Fi and Li-Fi. The results are driven by applying the formulas given in the methodology section that demonstrate the graphs and the table. The graph in Fig.5 compares the role of the network in hybrid WiFi/LiFi indoor networks, the number of nodes increasing from 2.5 to 20. The WiFi throughput (shown in blue) remains low and nearly constant at around 1000 Mbps across all scenarios, indicating limited scalability. However, the LiFi throughput (represented by the orange line) and the hybrid system's throughput (shown as a green solid line) increase steadily. By the time they reach 20 nodes, both LiFi and the hybrid system achieve a throughput of approximately 12,000 Mbps. This highlights how LiFi significantly enhances capacity in hybrid setups. The performance of the hybrid system closely mirrors that of LiFi, thanks to its effective integration of WiFi and LiFi technologies.

IV. CONCLUSIONS

The hybrid Wi-Fi/Li-Fi indoor network modeling demonstrates that integrating both technologies significantly enhances overall network performance by combining the broad coverage of Wi-Fi with the high-speed, interference-free transmission of Li-Fi. The simulation results reveal improved data throughput, reduced latency, and better user experience, especially in high-density and light-optimized environments. This hybrid approach proves to be a promising solution for next-generation indoor wireless communication systems and ensuring more reliable connectivity.

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