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Light-fidelity as next generation network technology: a bibliometric survey and analysis

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Abstract

This paper delivers a systematic review and a bibliometric survey analysis of Light-Fidelity (Li-Fi) indoor implementation in Next Generation Network (NGN). The main objective of this study is to design a communication network based on NGN-Li-Fi for the indoor implementation which aims to increase user Quality of Service (QoS). The main merits and contributions of this study are the thorough and detailed analysis of the review, both in literature surveys and bibliometric analysis, as well as the discussion of the implementation model challenges of Li-Fi in both indoor and outdoor environments. The issue articulated in an indoor communication network is the possibility of intermittent connectivity due to barriers caused by line-of-sight (LOS) between the LED transmitter and receiver, handover due to channel overlap, and other network reliability issues. To realize the full potential and significant benefits of the Next Generation Network, challenges in indoor communication such as load-balancing and anticipating network congestion (traffic congestion) must be addressed. The main benefit of this study is the in-depth investigation of surveys in both selected critical literatures and bibliometric approach. This study seeks to comprehend the implications of Next Generation networks for indoor communication networks, particularly for visible light communication channels.

1. Introduction

In December 1969, the ARPA Network witnessed 4 connected node-to-node communication, which evolved into billions of interconnected devices 50 years later [1]. The origin of the internet is meant for resource sharing. The evolution of the Next Generation Network, from the 1G to 5G has changed the way the Internet is utilized. The paradigm shift from resource sharing to content sharing is now taking place as the communication resource allows users to do so. As the newer generations of networks come along, it brings higher possibilities of greater bandwidth and thus lower latency. Dimensions of Internet infrastructure have shifted dramatically, most notably with the implementation of Cloud Computing, which can alleviate computation burdens through its service models (IaaS, PaaS, SaaS). To support growing content size and demand for ubiquitous computation, higher throughput becomes a de facto factor of Quality of Service. However, the physical layers, whether guided (wired) [2], [3] or unguided (wireless), can only transmit as far as their physical infrastructure allows.

Network infrastructure is restricted to four types of delay, such as nodal processing, queueing delay, transmission delay, and propagation delay. These challenges encourage the industry to eliminate and shorten the delay through the implementation of Content Distribution Networks (CDN) and caching servers. Van Jacobson mentioned Content-Centric Networking (CCN) in his phenomenal Google Tech Talks in 2006 [4] where content is named based on the content itself and becomes an entity that is referred to by its content name. This concept transforms data transmission from previously location-based (through IP) to content-based (through naming). As a result, if a user wishes to download a file from a server using traditional IP, the user must first translate the request from a URL address to an IP address using Domain Name Server (DNS) and then forward it to the location of the content. In CCN, the request is no longer location-based, so any nodes that may cache the content can respond to this request. The delay restriction can be reduced by implementing CCN because many content requests can be responded to closer to the users, even closer to what CDN has to offer. However, this protocol has not alleviated the physical burden of the transmission bottleneck. The solution must cover the entire data, control, and physical layers.

The fast-paced human communication and the variety of mobile communication can be broadly classified into three communication models: high-speed mobility, low-speed mobility, and static. High-speed mobility is an outdoor communication model, whereas low-speed mobility requires minimal handovers between indoor and outdoor conditions. Both of these conditions apply when a user communicates via wireless devices. Static connections occurred in normal scenarios in indoor environments, using both stationary PCs and wireless devices. Wireless device users in an indoor environment are most commonly found in offices, hospitals, airports, and train stations, among other places. Looking at the transformation of intelligent networks that can be brought together to accommodate large numbers of users in 6G communication services, Li-Fi technology can serve as great enablers for the Next Generation Network (NGN) vision, as shown in Figure 1. The NGN network promises broader applications such as nano network, teleoperated driving, electronic health, underwater communication, and more. The aforementioned applications require denser data and more content to be transacted and analyzed. This new phenomenon, in which data travels faster than ever before, requires a prominent key enabler for a high-speed data career, which is Li-Fi.

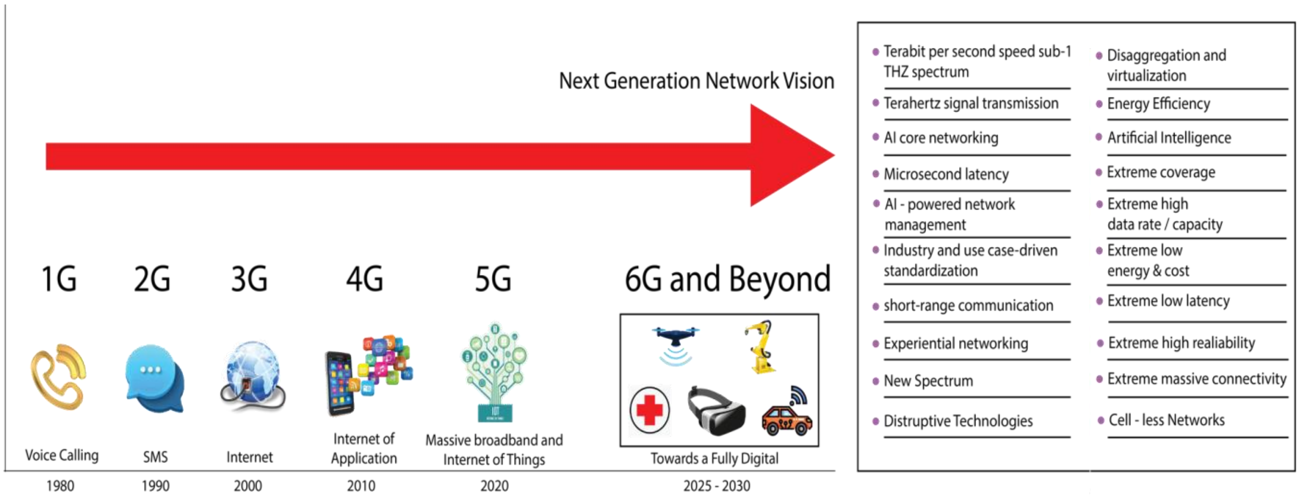

Figure 1. Next Generation Network Vision as Adopted from [5], [6], and [7]

A breakthrough in physical communication structure is on its way. Following the possibilities in Visible Light Communication, research papers on wireless communication via lights emerged quickly (VLC). Pioneered by Harald Haas in his TEDGlobal 2011 talks [8], wireless data in every lightbulb, he coined the term Light-Fidelity (Li-Fi), which piques the interest of researchers. Recommendation standard on the indoor implementation of VLC is also made available by ITU in Recommendation G.9991 [9]. However, as of now, only a few known studies are focusing on the further development of indoor Li-Fi and the challenge of its capacity in highlighting network quality of service and user quality of experience.

Li-Fi has the potential to be a key player in the future indoor network communication paradigm, where it could eliminate bottleneck and congestion issues in the user edge area network. These scenarios are frequently encountered when multiple users attempt to access the same data files repeatedly, such as when several students attempt to access the same files at the same time (synchronous communication) or when multiple participants in the same building/room attempt to communicate via teleconferencing (real-time communication). In both scenarios, users' demands are high and churn as a result of the same interest data being requested at the same time. This phenomenon frequently caused problems in indoor communication, where communication was hampered and interrupted as a result of flash crowd data requests. Thus, by utilizing Li-Fi communication, these issues may be mitigated and prevented from occurring in the future. As a result, the problems derived for this study are:

1. Li-Fi communication gains research interest in recent years. The current works in Li-Fi are centered on software simulation and hardware configuration components. However, a thorough analysis of its indoor implementation is still evolving, so there is a need to survey current indoor Li-Fi technology and implementation. An extensive study of indoor Li-Fi network architecture in both software and/or hardware environments is deemed necessary in order to improve network resources and reduce network consumption.
2. Following point 1), it is important to analyze the implementation of Li-Fi area boards in many aspects of network communication further through surveys and bibliometric research to understand the strengths and weaknesses, as well as the challenges and opportunities, in this new attractive and emerging technologies, particularly in its relevant indoor communication areas.

Based on the derived problem, this study will investigate how Li-Fi communication can be further developed to facilitate load balancing and achieve Quality of Service (QoS) for synchronous and real-time traffic from multiple hosts in indoor environments in the future. This study includes four phases of research methods in order to meet QoS requirements and better understand the technological needs of Li-Fi in indoor environments. Phase 1 reviews concepts and schemas centered on the research theme. Phase 2 is a literature study and evaluation of the latest methods. Phase 3 proposed the design of the NGN-Li-Fi hybrid architecture and model. Phase 4 is the final implementation and evaluation. The following section goes over the research method phases in retrospect.

2. Research Method and Procedure

The most important aspect of pursuing a bibliographic review metric is locating the most relevant collection that matches the intended review. The problem with the current literature is that it contains many new topics and intersections between review themes, such as those that use the same words but infer different meanings. The study in Light-Fidelity, has broad themes, such as Physics, Photographic Technology, and Biology. Knowing the broad topic in this field, performing a systematic review becomes more important and requires a meticulous approach to find the key literature and put a scope and boundaries. This section describes the methodology used to conduct the critical review, gap derivation from the existing approach, which results in a proposed architecture based on the identified gap, and the final evaluation.

2.1 Research Procedure

The first approach is to review the concept and obtain knowledge in the respected field. This is accomplished through two steps: reviewing fundamental concepts and defining the critical problem. To complete the first task, a well-known journal core collection, Web of Science, is used to obtain state-of-the-art information on the topic. Additionally, Google Scholar and Scopus are also selected learn the breadth and depth of the topic. The key authors and high-impact publications are then filtered using refined keywords such as Light Fidelity, Li-Fi, and Next Generation Networks. Then, the main articles resulting from the procedure are then collected and reviewed. From the analyzed articles, it is concluded that the area in which Li-Fi is gaining popularity, is indoor implementation. Hybrid implementation of indoor and outdoor communication is also found in some of the collected articles. The surveyed articles are presented in the next section below.

Because Li-Fi and NGN are popular topics, it is critical to examine the technology that surrounds them. Therefore, the second task is completed, which is a bibliographic analysis of the Li-Fi and its potential technological implementation. As of the time of writing, there was no bibliographical review analysis of Light-Fidelity. The following section delves deeper into the bibliometric survey and analysis.

Because this study focuses on comprehensive literature and bibliographic analysis, parts three and four are derived based on the needs of the next generation network needs and demand, which reflect potential future use-cases. Among the heterogeneity of devices, the implementation can be classified into indoor and outdoor needs, which both have their own unique characteristics. While this study focuses on indoor communication, which is thoroughly discussed in the following chapter, the composition of Li-Fi implementation, which applies both indoor and outdoor, is also discussed to provide context.

2.2 Bibliographic Survey and Analysis

This study used a systematic approach to perform a literature review of 1000 Google research items. Research questions guide a systematic review process by defining the study's subject, object, and scope [10]. In recent years, researchers have been more interested in Li-Fi communication. The current Li-Fi research concentrates on software simulation and hardware configuration components. Comprehensive research on indoor Li-Fi network architecture in software and hardware environments is thought necessary to improve network resources and reduce network usage—the challenges and opportunities with this new and exciting technology. As a result, we developed the following research questions: RQ1. What is the current academic state of Light Fidelity communication research? and RQ2. What are the future communication research trends in terms of Light Fidelity?

This study identifies a primary collection of keywords linked to these two research questions, which were proclaimed as the main aims of the systematic review method related to research. The following source types were used for bibliometric analyses: journal citation records, conference papers, books, book chapters, and patents documents. We used the bibliographic technique with VOSviewer software to analyze the citations of the examined publications.

The magnitude of the dots associated with each node signifies seminal, often cited research products, which can be highlighted using this manner. The size of the dots represents the weights assigned to each publication based on the number of citations. We obtained 1000 items from the database, spanning the years 2012 to 2022. Furthermore, we excluded articles that were irrelevant to our research questions and had been incorrectly captured by our research keywords. We stick to articles written in English and exclude articles written in other languages to avoid replicability issues for the international community. As a result, 151 articles were retrieved and deemed relevant, and their bibliometric results are shown in Figure 2. The overlay colors, as seen in the Figure 2, provide a network visualization captured from the retrieved articles.

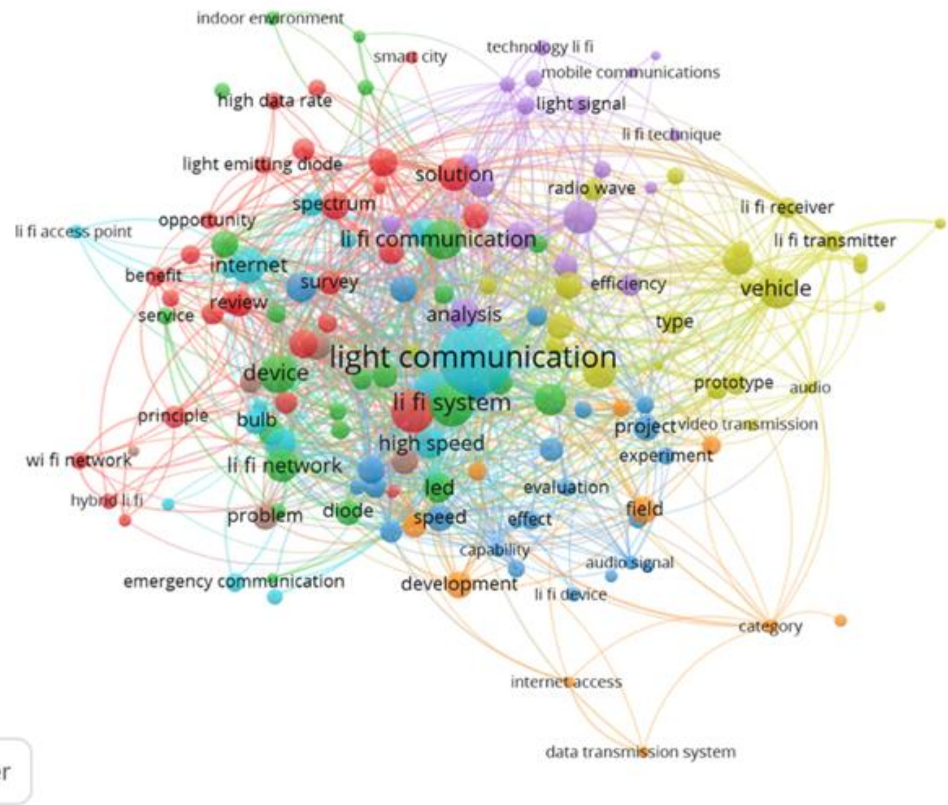

Figure 2. Bibliometric Mapping Result of Light Fidelity (Li-Fi) Communications as Retrieved from Google Scholar

To ensure scientific robustness and inclusivity, we also retrieved Scopus research data collection using the similar systematic approach described above. We collected a literature review of Scopus research, using the exact keywords from 2012 to 2022. With the same exclusion criteria for irrelevant articles, 200 articles were chosen and considered relevant, and their bibliometric results are shown in Figure 3.

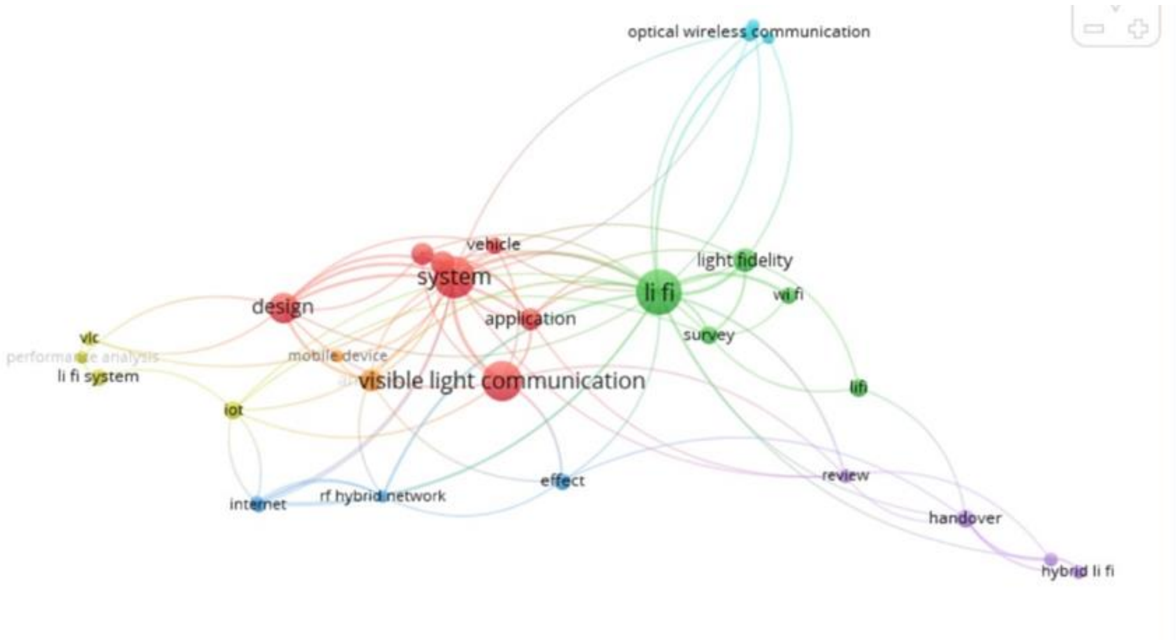

Figure 3. Bibliometric Mapping Result of Light Fidelity (Li-Fi) Communications as Retrieved from Scopus

3. Results and Discussion

The rapid development of Light-Fidelity (Li-Fi) is one of the fastest-paced technological advances from infancy to maturity, resulting in products that can penetrate the market. The industry as a key driver of growth, combined with a wide range of user needs, presents an opportunity for the advancement of Li-Fi technology. To name a few, there are PureLiFi, which was pioneered by Prof. Harald Haas [11], on which this research is based, LinkRay by Panasonic [12], Trulifi by Signify [13], Lucipanel by Lucibel [14], OEM LiFi by Oledcomm [15], and many more. Looking at the many industries that have flooded the market, the academic sector is maintaining its levels and keeping up with technology. Critical areas and sophisticated issues are being scrutinized, which include optimization in indoor and outdoor environments (communication areas in sea, earth, air and land), gigabit communication, hardware and software hybridization with Artificial Intelligence, and energy preservations.

3.1 Survey Results on Indoor Li-Fi Implementation

The key feature of Li-Fi is its ability to deliver high-speed wireless communications and is intended for indoor communication. The reason for this is that light interference occurs less frequently indoors than it does outdoors. The use of light in Li-Fi brings benefits in that there is much less security concern in Li-Fi because light cannot penetrate walls, reducing vulnerability concerns such as being tapped by an intruder. The previous section has focused on the areas of bibliometric analysis of the communication capacity benefits from Li-Fi. This section focuses on the surveyed literature review, which analyzes how performance measures to ensure Quality of Services in the implementation of Li-Fi in indoors.

Table 1. Survey Results on Indoor Li-Fi Implementation

Ref.	Methods	Characteristic	Performance Measure
[16]	Simulation of a hybrid Wi-Fi and Li-Fi network on a Software-Defined Network	Indoor	Network performance is substantially improved by hybrid Wi-fi and Li-Fi networks, which also benefit application services such as indoor positioning and physical layer security with performance measures includes SINR coverage probability, spectral and energy efficiency, network capacity, quality of service, and user fairness.
[17]	Calculating the ratio of the signal-to-noise ratio (SNR) of the randomly oriented device and the upward-facing device using the distributions.	Indoor	When the influence of random terminal orientations is taken into account, the performance improves.
[18]	Access Point (AP) selection algorithm that takes into account the random orientation of user equipment (UE) to address the problem of load balancing.	Indoor	Characterize device random orientation in optical wireless systems and investigate its impact on user performance metrics like SNR and BER. Also, while considering the LOS channel gain, compute the probability density function (PDF) of SNR for a randomly oriented device.
[19]	The distribution of the aggregate signal interference using the cumulant generating function (CGF).	Indoor	Investigate how modifying parameters of a modulation scheme and room dimensions affect the characteristics of aggregate signal interference
[20]	To improve the system's performance, researchers are looking into the structure of Angle diversity receiver (ADRs).	Indoor	The optimization challenge is defined as maximizing system performance under the constraint of constructing at least one LOS link between the AP and the ADR. The ideal FOV of the PD and the optimum number of PDs are determined by solving the optimization issue.
[21]	An RSSI-based handover algorithm that takes into account the threshold and hysteresis level for hybrid Li-Fi/RF-based networks	Indoor	Calculate the association probability, which is the chance that a UE will be connected with a particular AP. The effect of changing the threshold and hysteresis level on the probability of handover is discussed.
[22]	Networks that combine Li-Fi and Wi-Fi. This research developed an adaptive handover system for HLWNets that can change the network preference.	Indoor	Without light path obstacles, regular deployment of Wi-Fi APs is considered. The handover rate is determined by the cellular topology, which has two extreme cases: null Wi-Fi and the full area. In these circumstances, a homogenous Li-Fi or Wi-Fi network is equivalent.

Ref.	Methods	Characteristic	Performance Measure
			Alternatively, they consider a scenario in which the Wi-Fi zone covers half of the total area.
[23]	Based on evolutionary game theory, a distributed load balancing technique has been developed (EGT)	Indoor	The suggested game is developed from AP selection and time resource allocation in which a Nash Equilibrium (NE) is attained when no user modifies its AP in two neighboring periods of the signal frame.
[24]	The joint optimization problem, which consists of Centralised Optimisation and Fuzzy Logic Facilitated Algorithm, is created to identify a network-level selection for each user over some time.	Indoor	Monte Carlo simulations are used to assess the suggested method's performance, with a threshold value of 0.8 being used.
[25]	Handover skipping approach based on reference signal received power (RSRP) as a replacement for conventional handover skipping methods, which rely on information about the user's trajectory that is not available at the access point.	Indoor	The simulations used in this work are Monte Carlo simulations, which are used to assess the performance of the suggested method. Determining the handover target by combining the value of RSRP and its rate of change
[26]	The FL system in this study leverages not only the channel state information (CSI) but also the user speed and intended data rate to evaluate whether a handover needs to be prompted.	Indoor	In the current state, the RF AP would be assigned to users when they are at the Li-Fi cell edge or outside the Li-Fi coverage, and the Li-Fi APs serve u, the cumulative distribution function (CDF) of the user data rate with the proposed dynamic handover scheme is evaluated along with a conventional algorithm to optimize the system throughput only based on the signal-to-interference-plus-noise ratio (SINR) of Li-Fi and radio frequency (RF) links and the handover
[27]	Access Point Assignment (APA) approach for hybrid Li-Fi and Wi-Fi networks is proposed in this study, taking into account Li-Fi channel obstruction. The suggested solution treats the problem as an optimization problem, intending to maximize system throughput over time by leveraging users' statistical data on channel blockage.	Indoor	Monte Carlo simulations are used to assess the suggested method's performance in comparison to instant load balancing (ILB) and signal strength technique (SSS). The proposed solution boosts system throughput by up to 90% and 56% over ILB and SSS, respectively, according to simulation results.
[28]	This study proposes a new Load Balancing (LB) strategy that focuses on improving network throughput over time. To maximize the throughput of a hybrid network at a given time instance, a cooperative load balancing scheme was devised.	Indoor	Monte Carlo simulations are used to compare the suggested method's performance to that of instant load balancing (ILB) and signal strength technique (SSS). Simulation findings show that, as compared to ILB, the suggested strategy can greatly lower the rate of handover.
[29]	The optimal resource allocation (RA) scheme and a low-complexity RA method are proposed in this research for OFDMA-based Li-Fi systems.	Indoor	In the TDMA system, the performance of the two schemes is evaluated and compared to a benchmark RA scheme in terms of computational complexity, data rate, and user fairness.
[30]	Novel spectral effective cooperative transmission techniques for downlink in indoor light-fidelity (Li-Fi) cellular networks, also known as optical attocell networks, are proposed in this research. Dual-hop decode-and-forward (DF) relaying with the help of one or two neighboring base stations is the foundation for downlink cooperation (BSs)	Indoor	The average spectral efficiency of the frequency reuse (FR) and fractional frequency reuse (FFR) systems, as well as the cooperative FFR (CFFR) system with non-orthogonal DF (NDF) and joint transmission with DF (JDF) schemes, were presented using Monte Carlo simulation in this study.
[31]	Based on the existing physical layer (PHY) of the ITU-T specification G.9991, a time of flight for the localization system.	Indoor	Propose a new Li-Fi positioning technique based on wireless propagation times between MD and multiple ceiling-optical frontends (OFEs)
[32]	For Li-Fi cellular networks, the study evaluated evaluating and the sojourn time. Monte-Carlo simulations are also employed for tilt angle on the journey time.	Indoor	Provides an analytical examination of the sojourn time for indoor Li-Fi cellular networks, based on a random waypoint (RWP)mobility model.

Ref.	Methods	Characteristic	Performance Measure
[33]	The fundamental element and propagation channel of a Li-Fi Attocell (LAC) Network, as well as Li-Fi as an indoor adjunct to RF communications, are discussed in this paper. The simulations were done in MATLAB.	Indoor	Examine the illuminance distributions and received power of direct and reflected light for single and multiple phosphor-based white LEDs.
[14]	Li-Fi is used in the study as a potent complement or alternative to Wi-Fi and 4G.	Indoor	Introduce new features to satisfy two major societal needs: well-being and high-speed communications
[34]	The goal of the research was to model random orientation and apply it to a Li-Fi system based on direct-current-biased orthogonal frequency-division multiplexing (DC-OFDM).	Indoor	The influence of diffuse links due to reflection and user blockage is considered in the analysis of DC-OFDM.
[35]	addresses communication system requirements in modern industry, with a focus on industrial data and Li-Fi scenario applications. The simulation employed is only limited to virtual circumstances.	Indoor	Examine numerous data sources used in modern factories, as well as possible offers and requirements on communication systems, such as transportation machine data, IoT data, control data, AR/VR data, and additional mobile device data
[36]	Technological approach through VLC, Li-Fi, Fiber Optic	Indoor	To analyze the performance of Non-orthogonal multiple access (NOMA) in a multiuser Li-Fi network, the researchers used simulation in Monte Carlo simulations. At each user, the performance metrics are measured using the Cumulative Distribution Function (CDF) of the equivalent Signal-to-Interference-plus-Noise ratio (SINR) and Bit Error Rate (BER) calculated using DCO-OFDM.
[37]	This study proposes a power allocation technique for a multi-user Li-Fi system. A complex eye transmitter is used in this system, which consists of many LEDs pointing in different directions.	Indoor (Computer Simulation)	It displays the findings of the transmitter using a 30-degree semi-angle and a four-user system. At 1 dBm average transmission power, the transmitter model may achieve a 10-5 average Bit Error Rate (BER).
[38]	The U-OFDM modulation and demodulation algorithm is used in this study.	Simulation/Indoor	It uses extensive Monte Carlo simulations to verify the theoretical Bit Error Rate (BER) estimates. A linear AWGN channel is used to test the performance of U-OFDM.
[39]	This study examines the differences between Visible Light Communication (VLC) and Light-fidelity communication (Li-Fi).	Indoor/Explanation/Review	It demonstrates how Li-Fi extends VLC by utilizing LEDs to create fully networked wireless systems. Li-Fi transmitter and receiver ASICs for miniaturized transceivers capable of 1 Gb/s transmission were also shown.
[40]	Demonstrates how Li-Fi extends VLC by utilizing LEDs to create fully networked wireless systems. Li-Fi transmitter and receiver ASICs for miniaturized transceivers capable of 1 Gb/s transmission were also shown.	Indoor	This study compares the performance of Li-Fi to that of Wi-Fi in terms of rate speed and security.
[41]	The data is delivered from a transmitter to a receiver using light as a medium to control the speeds of two motors in this work, which is integrating Li-Fi into a communication system and demonstrating the systems.	Indoor/Vehicle to Vehicle Communication	It depicts a VLC demo model in a stationary environment. The Li-Fi systems are being utilized as a testbed for self-driving automobiles in the future. To communicate between vehicles and streetlamps, some cars use Li-Fi technology. These bulbs are used to connect to the internet at rapid speeds. The purpose of this work is to use the speed of another DC motor as a transmitter to control the speed of a DC motor that is attached to the receiver. It also connects all peripherals with an Arduino Uno microcontroller.
[42]	This study explains the deployment of Li-Fi in Remote Health Monitoring using suitable sensors.	Indoor	This study is providing healthcare services remotely by involving real-time monitoring of temperature and heart rate. The measured parameters are sent using the optical communication system in the visible wavelength region.

Ref.	Methods	Characteristic	Performance Measure
[43]	Using ns-3 with focuses on SNR and BER and goodput	Hybrid	General implementation of nodes that have both VLC and Wi-Fi channels for interchangeable communication measured through SNR and BER and goodput
[44]	A hybrid network combines the high-speed data transmission offered by visible light communication (VLC) and the ubiquitous coverage of radio frequency (RF) techniques. Method: Simulation benchmarks by introducing three conventional APS methods, namely (a) the signal strength strategy (SSS), (b) the load balancing (LB), and (c) the optimization method.	Indoor wireless communications.	Emerging technology for future communication Improving (a) the system throughput and (b) user's experience, also it (c) challenges the process of access point selection (APS) due to the mixture of heterogeneous access points (APs). Better than the conventional (optimization) method by achieving a close-to-optimal throughput at significantly reduced complexity.

3.2 Indoor Li-Fi Analysis

Li-Fi will probably not completely replace Wi-Fi, and these two technologies can be used together to achieve a more efficient and secure network. Although Li-Fi performs well in transfer rate, it has several limitations, including the impossibility of light passing through walls and the inadequacy of Li-Fi when used outdoors in direct sunlight or under other circumstances. Due to this, some studies, including those in [16], [33], [35], [38], and [39] have expanded on technology in general. Research [39] introduced the working of Li-Fi technology, the architecture, the modulation, the performance, and the problems viewpoints to provide a reference and expertise to design some of the Li-Fi technology. Although the technical merits of this work have not been thoroughly examined, the piece serves as a solid starting point for more in-depth investigation. In [33] the authors performed the channel estimation for the downlink system by analyzing the illuminance distribution and received power for direct and reflected light concerning single and multiple phosphor-based white LEDs, the frontend elements, and the propagation channel of a LiFi Attocell (LAC) Network discussed Li-Fi as an indoor complement to RF communications, equipped with MATLAB simulation. The calculations and simulations of this research show that Li-Fi can serve as a complementary technology to RF communications and surpass some of its limitations, with average LOS values receiving absolute power -3.87dBm and 2.28dBm were obtained, which provide the value more above the received signal power of user equipment (UE).The previous study [16] provides a comprehensive survey study that is a great and pleasant way to begin the journey of Li-Fi discussion. The hybrid Li-Fi and Wi-Fi network (HLWNet) presents a fresh overview of the communication between the two technologies. A dive into the challenges of these technologies' integration are well elaborated. Their study presented and discussed the Li-Fi handovers, which are identified as a key issue in Hybrid Wi-Fi and Li-Fi networks, especially a decision between a vertical handover and a horizontal handover. Low-complexity load balancing techniques are essential to HLWNets because Wi-Fi Access Points are susceptible to traffic overload.

Additionally, a number of researches that goes into more technical detail are described below. The energy efficiency and spectral efficiency for the traditional and hybrid OFDM-based VLC modulation techniques are developed in [30] and [38]. This research [30] suggests a brand-new, spectrally efficient cooperative transmission approach with introduced and analyzed two collaboration protocols, non-orthogonal DF (NDF) and joint transmission with DF (JDF). Considered is a multiple-access system based on fractional frequency reuse (FFR) and direct current optical orthogonal frequency division multiplexing (DCO-OFDM). The indoor VLC channel also employs a Lambertian propagation model with line-of-sight (LOS) propagation. For downlink in optical attocell networks, new spectrally effective cooperative transmission techniques based on the CFFR-NDF and CFFR-JDF protocols are suggested. The throughput of the optical attocell downlink is estimated in this study using the Shannon-Hartley upper bound. Using Monte Carlo simulations, the average spectral efficiency inside an optical attocell is investigated, and the spectral efficiency and signal-to-interference-plus-noise ratio (SINR) for user equipment (UE) with random coordinates in an attocell are obtained for each scheme. Meanwhile, the study [38] helps to ensure the QoS with reasonably priced energy. Through theoretical analysis and computer simulations, the comparisons of these schemes employing various modulations, such as ACO-OFDM, PAM-DMT, DCO-OFDM, ADO-OFDM, HACO-OFDM, and LACO-OFDM, are investigated. Computer simulations are used to examine and compare these conventional and hybrid modulation methods, which should be taken into account in practice depending on the illumination and transmission requirements. This study came to the conclusion that while spectral efficiency can be achieved in a variety of ranges, different strategies perform differently in terms of energy efficiency. Other research [37] notably suggested a power allocation technique to implement a multi-user Li-Fi system using a compound eye transmitter and the non-negativity property of the transmitted signal in a Li-Fi system, with several LEDs pointing in different directions. The prior approach, which involved building a pre-coder by determining the inverse or identifying the eigenvectors of the channel matrix to reduce interference, was enhanced by this technique. Results demonstrate that a signal shaping technique is still necessary even when interference is entirely reduced by pre-coders in Li-Fi (as has been elaborated by the previous research). The computer simulation findings reveal that the proposed multi-user transmission technique achieves acceptable average BER performance while considering the single-cell multi-user optical wireless MISO system.

The availability and alignment of line-of-sight (LOS) link significantly impact the optical wireless communications (OWC) channel's dependability. The lack of a suitable model for random orientation, where most studies on optical OWC have ignored the impact of random orientation in their performance analyses, becomes one of the motivations for research [18]. This research focused on the random orientation using a Laplace distribution for the static user equipment (UE) and emphasized the significance of system performance evaluation. By examining the impact of receiver orientation, the polar and azimuth angles on the LOS channel gain, this paper has investigated the device orientation and evaluated its significance on system performance. This study examined the bit-error ratio (BER) of optical orthogonal frequency division multiplexing with DC bias (DCO-OFDM). The novelty of this research is also covered by the ability to evaluate the impact of device orientation on a cellular network while taking non-line-of-sight links into account, as well as other performance metrics like throughput and user quality of service.

Another study [45] discusses a backhaul solution that can achieve a higher network sum-rate while using less power. This backhaul proposal is vital since the join capacity required by Li-Fi users could be higher than the core network provided by the ISP. The study in reference [17] critically examines and discusses the relevance between angles and their impact on user equipment position. It is emphasized that docked devices, such as laptops, are primarily in a sitting position, whereas a user in other devices may randomly position or place their handheld device orientation. The works highlighted in References [21] and [34] study the need to comprehend the possibility of user equipment rotation, which may result in degraded performance. The issue with Li-Fi in handheld devices is that humans have a tendency to rotate and shift position unintentionally, resulting in an orientation change. These changes lead to the device facing another Li-Fi access points, which trigger a handover.

Handover skipping is introduced in the [22] and [25] to achieve a handover to non-adjacent cell. The presented methods consider the Li-Fi smaller coverage compared to Wi-Fi network which would result to a ping-pong effect either between Li-Fi network or to the Wi-Fi. The handover skipping is performed by taking into account both SINR and rate of change. The result allows to determine the Access Point that can be skipped based on user’s velocity, such those that are move in a slow-paced or high paced. The former study evaluated the proposed work in random deployment of Wi-Fi AP, and the letter utilized weighted average to determine the handover skipping upon the user’s velocity. One of the challenges in Li-Fi is ensuring load balance, especially since the location of the Li-Fi does indeed overlap with Wi-Fi. The work in reference [24] proposed techniques that use fuzzy logic to ensure the complexity of determining the attachment point at the network level. The proposed methods in their study achieved the highest throughput among all methods but the lowest fairness in the simulation results if the number of users is less than 5. Fuzzy logic techniques reported in [26] to support handover utilizing user speed and desired data rate.

The challenges in Li-Fi hybrid ecosystem are also due to the overlaps with the Wi-Fi. While it is true that Wi-Fi have broader ranges in which the Li-Fi coverage overlaps, these results in blockages. The study in reference [27] discussed the findings that the new method formulates an optimization problem involving the performance degradation caused by channel blockage based on users' statistical information of channel blockage. This work highlighted the need to improve from the conventional load balancing which results in frequent handovers to a technique proposed as Access Point Assessment (APA) methods to helps user equipment switched from Li-Fi to Wi-Fi in the event of blockage. The work in Reference [28] continues to improve the Load Balancing in order to achieve higher throughput. While the signal strength strategy (SSS) method is relatively good for handover mechanisms, it does not prove to be a suitable parameter when there is overlapped access between Li-Fi and Wi-Fi. Another approach known as instant load balancing (ILB), leads to frequent handover. This is because, while SSS produces fewer handovers than ILB, it can cause traffic congestion, particularly on Wi-Fi, compromising system throughput significantly.

The topic discussed in reference [31] was based on the G.9991 chipset generation to gain better utilization in the communication technology. Their research presents a possible scenario in which smart factories benefit from their mostly indoor environments and high data load. The G.9991 informs the potential extensions of the network architecture reference model and suitable topologies, such as Peer to peer (or point to point) topology, Point to multipoint topology, Multipoint to multipoint, Relayed mode, Centralized topology.

With the ability for users to roam around the area and move from one light to another, a study in sojourn time is conducted and reported in Reference [32]. Their study analyzes and estimates users’ attachment points with regards to its connection towards the serving access points based on the user speed. Their study reported the handover scheme criteria, which allowed the user to be handed over to the next point of attachment based on the strength of the received signal. Their study, however, did not look at the residence time for hexagonal cells or the Poisson point process deployment model.

Research conducted in reference [36] provides a solution that combines non-orthogonal multiple access (NOMA) with a successive interference cancellation (SIC) approach to achieve interference avoidance. The study in reference [41] discusses on the network optimization through traffic engineering. Li-Fi is not able to provide an internet connection when there is no light source. The main disadvantage is that Li-Fi systems can only be used in a small area and cannot penetrate through walls because light cannot pass through physical barriers.

3.3 Survey Results on Li-Fi in Outdoor Implementation

Li-Fi can be implemented in both indoor and outdoor scenarios. In the outdoor implementation, the Li-Fi can be part of Intelligent Transport System (ITS) for Next Generation Network as presented in [46] . However, it is well noted that outdoor implementation will results in more challenges. This section will discuss further on the Li-Fi implementation for outdoor communication. Among the research that presents numerous of opportunities of Li-Fi implementation in outdoor are presents in [47] for vehicular light implementation and in [48] whereby light-based communication is used for underwater communication. Further, initiatives for underwater communication have been discussed by author in [49].The remaining of this section further discussed the implementation of Li-Fi in outdoor.

Table 2 Survey Results on Li-Fi in Outdoor Implementation

Ref	Methods	Characte ristics	Performance Measure
[50]	Reconfigurable intelligent surfaces (RIS) are being integrated into Li-Fi-enabled networks.	Indoor and outdoor	Envisioned RIS-enabled smart Li-Fi was used both outside and indoors. Higher reliability is achieved by introducing and managing channel gains in order to provide ideal conditions for effective power allocation and, as a result, successful consecutive interference cancellation. Dynamic RIS tweaking to modify the decoding order of users regardless of their location
[51]	The channel model, multiplexing protocols, FOV, noise, multipath, and errors are all covered in depth in this study of LED positioning systems.	Indoor and outdoor	LED location algorithms have been classified into three groups in the literature: RSS, TOA/TDOA, and AOA. The LED positioning systems that were surveyed were divided into four categories: photodiode-based systems, camera-based systems, hybrid systems, and outdoor systems.
[52]	The research employs an OFDM waveform that adheres to the HESU (high-efficiency single-user) protocol. For all selected CIRs, packet error ratio (PER) simulations were used to discover the best frequency.	Indoor and outdoor	Analyze the potential performance losses using the existing 802.11ax PHY layer for 802.11bb. However, the root-cause question to determine the common mode (CM) physical (PHY) layer between two methods is whether how often Li-Fi encounters (experiences) the flat channels.
[53]	Provides a framework for dimming control of ASCO-OFDM-based Li-Fi utilizing pulse-width modulation (PWM). utilizing MATLAB for simulation	Indoor and outdoor	Evaluates the BER performances of PWM based ASCO-OFDM, ADO-OFDM, DCO-OFDM, and ACO-OFDM for both electrical and optical power limited channels. The pulse width of the PWM based ASCO-OFDM signal is varied accordance with the dimming or brightness level.
[54]	Li-Fi with Spatial Multiplexing	Simulation	The simulation was done in Matlab to determine the Bit Error Rate (BER) estimation using the Monte Carlo approach. This study compared the suggested CD SMX (coherent detection spatial multiplexing) system with a CD SM (spatial modulation) system and an IM/DD SM system based on the system BER value to ascertain the result of the method utilized.
[41]	This paper describes an SDN-enabled heterogeneous network (HetNet) that includes Li-Fi, LTE Femto, cell, and Wi-Fi access points (AP). MATLAB is used in this study to evaluate analytical mathematical models.	Outdoor	This research is evaluating the performance of the SDN-enabled HetNet and applications convergence, developing a traffic engineering (TE) to support dynamic agnostic downlink flows routing to APs and differentiated granular services across the HetNet.

3.4 Outdoor Li-Fi Analysis

A study in [40] reports the author's work in Li-Fi implementation, with the results being insufficient when this system is deployed outdoors, either in sunlight or under other conditions. However, there is a drawback for this system: it is quite difficult for SDN applications to provide the guaranteed, reliable, and stable services to the wireless user equipment [41]. The work in [50] presents comprehensive practical implementations, and measurements over practical setups are required to evaluate performance in real-world scenarios. Realistic and accurate channel models were required to capture the fundamental performance limits of RIS-assisted Li-Fi systems, especially in an outdoor environment. A survey study on positioning systems in [51] provided comprehensive analysis, but it did not promote the development of more accurate and robust LED positioning systems.

Study in reference [54] oversees the implementation of a photo mixing optimization and mitigates the occurrence of field mismatching. According to their findings, the proposed method's total power consumption achieves better BER performance with higher bandwidth and is reported to have a linear increase with the number of transmitter/receivers. Study in reference [55] discusses two types of system model, namely light propagation model and the signal combining schemes. This is one of the spectacular approaches that allows a user's equipment to benefit from a double source cell configuration. The transmit power of the double source cell is equally split between the positive and negative sources, which degrades the performance of the noise-limited system.

4. Conclusions and Future Works

Professor Harald Hass implemented and proposed the concept of Light Fidelity (Li-Fi) for the first time at the University of Edinburgh. Li-Fi refers to 5G and beyond technology of visible light communication (VLC) systems that use an LED lightbulb or a laser diode, such as a Vertical Cavity Surface Emitting Laser (VCSEL), as a medium for average or even higher speed data communications, rather than air as a medium for Wi-Fi networks. Therefore, Li-Fi has a great potential to be a key player in the future indoor network communication systems paradigm, where it can eliminate some issues related to the current bottleneck and traffic congestion in the user edge area network. This benefit was demonstrated in this study by conducting an in-depth bibliometric survey and analysis, which can be useful for any researcher working in a related field.

In the future, this study will look into how Li-Fi communication can be improved to facilitate load balancing (LB) and achieve Quality of Service (QoS) for synchronous and real-time traffic from multiple hosts in indoor environments. On the other hand, simulation studies can be conducted to produce and demonstrate the mobility and handover capabilities, as well as the competitive performance gains, from the hybrid system of Li-Fi and Wi-Fi heterogeneous networks (HLWNets) in terms of packet delay, throughput, packed drop ratio (PDR), and fairness among many users. Finally, timely and open research directions for physical layer security (PLS), visible light communication (VLC) systems, including some measured applications based on indoor and outdoor channel models, incorporating user mobility and device orientation into channel models, and combining RF and VLC integrated systems, could be significant potential realizations of such technologies in the near future.

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