# LiFi Technology: A Breakthrough for Massive Data Rates in Indoor Applications

**Rahul Sharma, Devendra Singh Gurjar, Elvis Rahman, Aditya Raghav, Pranjal Shukla, and Vivek Mishra**

## 1 Introduction

The data traffic is increasing at a tremendous pace, and along with it, the number of devices connected to the Internet is growing as well. Since the radio-frequency (RF) spectrum is already crowded, it would not be able to satisfy the rising demands [1, 2]. Light fidelity (LiFi) has emerged as a novel technology that uses visible light for downlink communication and lumination. Compared to RF systems, LiFi can provide a much higher signal-to-noise ratio (SNR). Moreover, the available unregulated bandwidth for LiFi communication is several times higher than the entire RF spectrum. It can also provide enhanced security as light does not penetrate through opaque objects.

In a broad sense, LiFi is a fast and cheap optical version of WiFi based on visible light communication (VLC). Typically, VLC uses light emitting diodes (LEDs) to transmit data wirelessly using intensity modulation and a photodiode at the receiver terminal [3]. Since LEDs are already prevalent at homes, offices, and streetlights, LiFi

R. Sharma · D. S. Gurjar (✉) · E. Rahman · A. Raghav · P. Shukla · V. Mishra
National Institute of Technology Silchar, Silchar, Assam, India
e-mail: devendra.gurjar@ieee.org

R. Sharma
e-mail: sharma_ug@ece.nits.ac.in

E. Rahman
e-mail: elvis_ug@ece.nits.ac.in

A. Raghav
e-mail: adityaraghav_ug@ece.nits.ac.in

P. Shukla
e-mail: pranjal_ug@ece.nits.ac.in

V. Mishra
e-mail: vivek_ug@ece.nits.ac.in



S. Mukherjee et al. (eds.), *Intelligent Systems for Social Good*,
Advanced Technologies and Societal Change,
https://doi.org/10.1007/978-981-19-0770-8_6

can use existing lighting infrastructure. Also, LiFi uses light for realizing communications. Therefore, it can be effectively used at places such as chemical manufacturing plants and aircraft cabins where RF transmission is too dangerous. Although LiFi is still in the developmental phase and it is not available for public use, several companies are working towards developing and marketing the LiFi based networking solutions.

### *1.1 Related Works*

LiFi can very well resolve the issue of limited bandwidth for wireless communication for indoor applications. Several works have highlighted the importance of considering LiFi for such applications along with WiFi. In particular, the authors in [4] have appropriately classified LiFi from VLC and discussed the similarities and differences between the two. It has been shown that a unique LiFi-WiFi hybrid network can eliminate interference in LiFi and, at the same time, it can cover blind spots. But, there are chances of frequent handovers for mobile users, which can be resolved using fuzzy logic-based dynamic handover techniques. Further, authors in [5] have categorized existing network topologies related to LiFi and illustrated that the overall network performance can be significantly improved by implementing a hybrid LiFi/WiFi network. LiFi provides significant economic opportunities and will enable various industries to grow manifolds. However, there exist multiple scientific challenges. Load balancing in hybrid LiFi-WiFi networks is one such critical challenge. Hybrid LiFi-WiFi networks (HLWNets) can achieve higher throughput than LiFi or WiFi networks alone. Still, access point selection for HLWNets is tricky, and user mobility is of great concern [6]. However, this problem can be addressed using the mobility-aware load balancing (MALB) technique. In [6], the authors have proposed two novel methods considering single and multiple transmissions modes. In the single transmission method, users can be transferred between different access points. It has been shown that MALB with single transmission can suppress vertical handover at the cost of an increased rate of horizontal handover. In the multiple-transmission method, users can access both WiFi and LiFi, and vertical handover can be avoided entirely.

Moreover, the authors in [7] have focused on access point allocation and user mobility in HLWNets by suggesting a new load balancing scheme for HLWNets. Herein, the users are assigned to a type of network out of the three types of available networks in HLWNets, LiFi, WiFi, and LiFi-WiFi. Nodes in the primary two classes are handed over in the same network when needed. Both LiFi and WiFi can serve the users pertaining to the third category in case of light blockage.

The research work in [8] has investigated handover in HLWNets and introduced a novel handover method that is based on reference signal received power and not on user trajectory. The suggested handover system makes use of dynamic network performance that adapts to the node’s velocity. Nodes having higher mobility are likely to be served by WiFi, whereas the LiFi access point supplies slow-moving

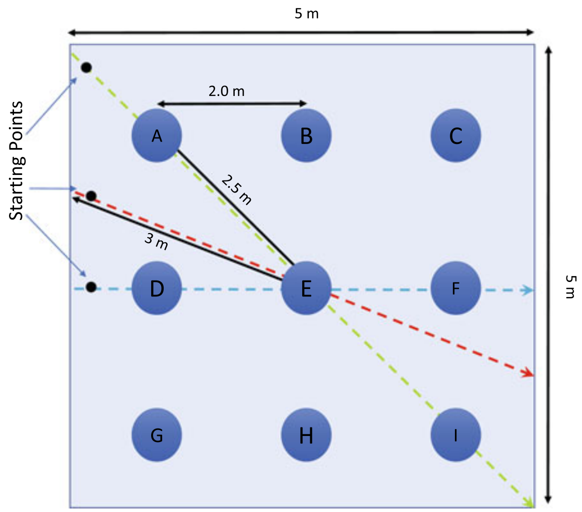


**Fig. 1** Movement trajectories considered in [10] with luminaries colored blue

nodes with the greatest SNR [9]. Because the considered metric is widely utilized in existing handover methods, the approach does not need any new signaling between the user and the access point.

## 1.2 *Channel Model for LiFi*

Although, LiFi has been extensively studied, the existing research literature for channel modeling and characterization is somewhat limited. In reality, each LiFi transceiver design must include the channel model. For designing realistic LiFi transceivers, realistic channel models will help categorize the achievable performance.

(i) Most of the works on VLC channel modeling consider the transmitter and receiver to be fixed, which is not very realistic. Practically, the receiver can be mobile. Also, it has been characterized by the assumptions of vacant rooms neglecting the humans' interference or any other objects. In [10], a more realistic approach has been used to come up with a mobile VLC channel model using non-sequential ray tracing. This model visualizes a standard room having multiple luminaires, objects, and human interference. For this model, a person having an appropriate device steps in through various trajectories inside the room, as shown in Fig. 1. The channel impulse response and path loss are then obtained for these trajectories. It has been observed that the received power changes considerably with the change of location inside the room.
(ii) Most of the channel models, including given in [10], consider that the receiver always kept vertically facing directly upward. Such an assumption is not suitable

for all devices as the majority of users hold devices in a position comfortable to them. Such orientation can heavily impact the user's throughput. Recently, authors in [11] have introduced two-channel models for stationary users, namely, the modified truncated Laplace model and the modified Beta model.

### *1.3 Difference in LiFi Channel Mode and WiFi Channel Mode*

In general, VLC and RF communication technologies are utilized in a wide range of wireless communication applications. VLC employs light as a communication channel, whereas RF uses electromagnetic radiation. Because WiFi employs a radio frequency channel, it suffers from interference from adjacent access points (routers), but LiFi does not suffer from comparable interference concerns as it employs an LED channel. The LED channel outperforms wireless RF systems like WiFi in terms of increased security, electromagnetic interference reduction, and ultra-dense cellular reuse. As a result, LiFi might provide considerable relief from overcrowding in the RF spectrum and meet future connectivity needs as required for the Internet of Things (IoT). A basic block diagram consisting of all the necessary components required for realizing LiFi communications is depicted in Fig. 2. There are plenty of applications of LiFi due to its offered attributes. Some specific advantages can be noted as follows.

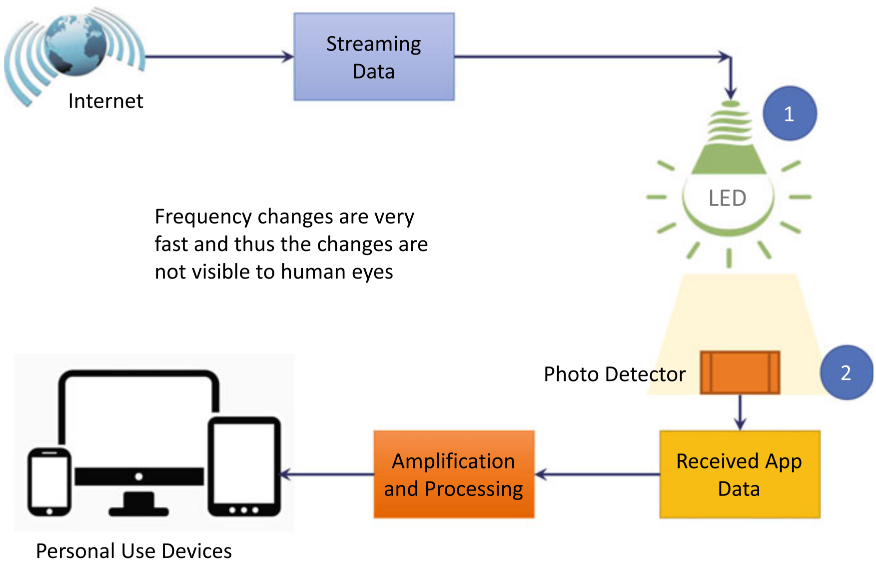


**Fig. 2** Basic blocks for LiFi communications

1. It has higher bandwidth and so overcomes the RF transmission capacity constraint.
2. When both source and receiver are in line of sight (LoS) within the same room, VLC communication works effectively. Nobody in another room can intercept data communication based on VLC. As a result, unlike RF transmission, VLC provides better security.
3. The VLC source is used for both lighting and communication, and it consumes very little power that makes VLC a power-saving system.
4. It is unaffected by EM radiation from RF transmissions.

The main concern with LED channels using VLC communication is that other ambient light sources might cause interference with VLC-based communication. Moreover, it has a short range of coverage. Integrating VLC with a wireless setup is complicated. Other issues with the VLC system include air absorption, shadowing, and beam dispersion, among others. Both the source and the receiver must be in the LoS. As a result, achieving non-LOS communication is challenging. The data transfer speed is greater in the LED channel than the RF channel, and the security risk is also less using LED media than the RF channel. Also, the higher frequencies are attenuated more strongly in LEDs, which causes another problem. This necessitates an iterative trade-off between boosting transmit power at high frequencies and tolerating a smaller total throughput from expanding the constellation size at lower frequencies. To increase the performance of LED communication channels, sophisticated modeling of the physics of light production in semiconductor junctions can be used. Indeed, the nonlinear dynamics of photon emission events provide a rich source of inspiration for developing LED communication models. Novel DSP approaches for solving challenges like nonlinear distortion with minimal complexity and latency are also inspired by a trustworthy LED channel model. The LED channel models and DSP approaches encompass current major research and development trends in LiFi with the grand goal of enabling next-generation communication and IoT applications. The LED channel enables secure communication since it uses LOS communication within the room, but the RF channel are vulnerable for eavesdropping because RF signals can pass through walls and be intercepted by someone in another room.

LiFi employs ordinary LEDs to allow data to transmit at speeds of up to 224 gigabits per second. Light can be used to transmit data with this technology because light intensity changes faster than the sensitivity of human eyes. LiFi's transmission range is 100 times greater than WiFi's. This technology's data transfer may be accomplished using light. The efficient LEDs are the most important components of this system. LEDs' ON/OFF activity allows for data transfer in the form of binary codes, but the human eye is unable to perceive this transformation. Thus the bulbs appear to have a consistent intensity. As WiFi communication uses an RF channel for transmission, radio signals, antennas, and routers become the three basic parts of a wireless network. WiFi networking is only feasible because of radio waves. WiFi cards are installed on PCs and cell phones. Antenna and routers send the radio signals, and WiFi receivers, such as computers and mobile phones with WiFi cards, pick up the signals.

## 2 Networking in LiFi

The broad spectrum of visible light is utilized for downlink transmissions in LiFi, whereas the infrared-based communication in the uplink. LiFi refers to broader network systems that incorporate multi-user, bidirectional, and broadcast communication. Multiple access points (APs) can be used in a LiFi network. These numerous APs form microcellular systems to render high-data-oriented connectivity to various wireless users simultaneously. Two-way communication can be formed among an AP and user equipment (UE) in a LiFi network, allowing an AP to serve several users at once. Further, backhaul links connecting APs and the gateway are necessary to connect globally. As a sequence, powerline communications, power-over-Ethernet, or optical fiber can be used to offer these backhaul connections. Moreover, existing LED lighting installations can be used for the LiFi downlink.

Infrared spectrum has been preferred for uplink communications because visible light considered for the downlink may cause distractions for the mobile user. In addition, it has the benefit of preventing interference between the uplink and downlink, allowing for simultaneous transmission. Despite some preliminary investigations on the infrared-based uplink, more extensive research is needed for such systems. A variety of RF-based communication technologies, such as Bluetooth, WiFi, can also be explored. Although these technologies are widely available, they may cause interference with existing RF wireless networks. However, only RF/VLC hybrid connection employing VLC for downlink can offload significant data traffic while maintaining low latency.

Frequent handover due to mobility of users, multiple access considering a large number of users, and co-channel interference are essential things to handle in a complete LiFi network, as shown in Fig. 3. In LiFi, users can face horizontal and vertical forms of handovers. The authors in [12] have conducted an early investigation

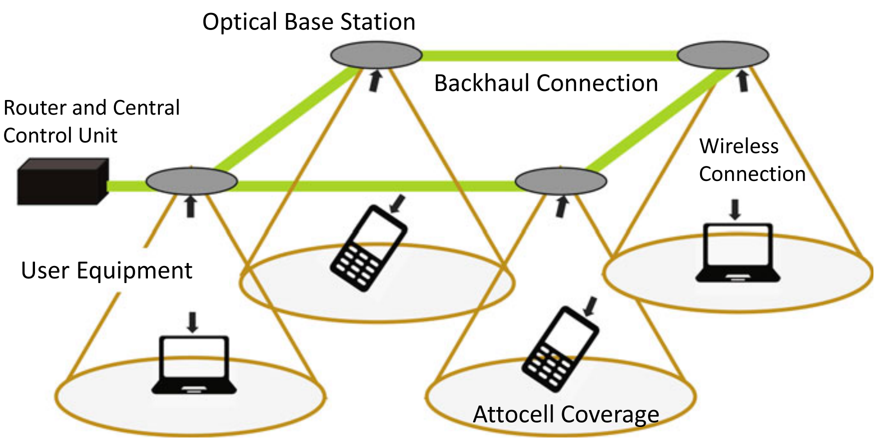


**Fig. 3** The illustration of LiFi networks applied to indoor wireless networking

on the horizontal handover method in LiFi networks. A shift in the serving AP from one radio access technology (RAT) to another is referred to as a vertical handover. Mobile users may be moved from a LiFi AP to a WiFi AP if none of the LiFi APs can provide a stable link. This can happen if the user's speed is high or the dwell time in a cell is too short of establishing a meaningful communication link. When a user slows down and comes within range of a lightly loaded LiFi AP, it may be beneficial in handover to that LiFi AP to alleviate the WiFi network and run more effectively (e.g., ensuring fewer packet collisions). A vertical handover system based on the forecast of uncertainty can reduce transmission times considerably. In [13], the authors have suggested a vertical handover approach considering the estimates of uncertainty metrics.

## 3 Challenges in Deployment and Operations

Energy and big data management in smart cities bring together diverse professional viewpoints on essential subjects that underpin successful smart city development. The majority of the worries regarding 5G's alleged detrimental impact on health arise from the fact that its cell towers are so different in construction from those supporting today's 3G and 4G cellular networks. As a result, LiFi is the most critical choice for achieving high data rates and meeting smart city requirements. LiFi can handle a large number of users who are required to connect everything to the internet, often known as the IoT. Because of their rapid reaction time, extended operating lifetime, and inexpensive cost, LEDs are the best choices for LiFi system deployment. It does, however, impose certain restrictions. The following section discusses an overview of the difficulties and obstacles of deploying a LiFi system.

### *3.1 Techniques Involved in Transmission and Modulation*

Commercial LiFi communication currently has a maximum operating distance of 1-50 m. However, because LiFi is a LoS communication system, this distance is much shorter than its radio frequency equivalent. Furthermore, the data speeds that may be achieved with LiFi are restricted to some lower amount. However, a substantial investigation is underway in this area to increase data rates by experimenting with various techniques and different types of materials of LED and photo-sensors. Even in LiFi, high-speed communication may be achieved by adopting a modulation method with high spectral efficiency. The use of trichromatic LEDs instead of phosphorescent LEDs resulted in a three-fold increase in throughput.

### 3.2 Optical Wireless Channel for Indoor Communications

The LiFi based communication is highly affected by the presence of LoS transmission, and any misalignment can significantly degrade performance. However, utilizing non-LoS communication channels, the shadowing effect created by obstructing the direct ray route among the transmitting LED and photo-sensor may be exploited to reconstruct data.

### 3.3 Receiver Device and Its Properties

In LiFi systems, photosensors at the receiver side detect the variation in light intensity. Image sensors or photodiodes might be used as photosensors. The photodiode transforms the amount of light detected into a photo-current. The performance of different photodiodes has been well investigated. It has been observed that avalanche photodiodes can be utilized for LiFi communication because of their tinier size, lower cost, and quicker reaction time. Nevertheless, the LiFi system's performance may be in the presence of sunlight and other bright fixtures. Thus, interference impacts can be considerably minimized by employing specialized filters and selecting a suitable receiver configuration. The LiFi communication system discovered that photodiodes for fixed receivers and image sensors for mobile users are ideally matched.

### 3.4 MIMO Optical Wireless Communications

Owing to the configuration limitations of small beamwidth receivers, using standard RF multiple-input multiple-output (MIMO) methods for LiFi poses a significant predicament. Even minor misalignment affects the communication quality. As a result, developing effective receivers and sensible transmitter deployment-based modulation techniques to enable MIMO is a promising area to explore for further investigation.

### 3.5 Cross-Layer Load Balancing

In case of heavy traffic or blockage, the network traffic must be transferred from LiFi to RF or vice versa. In order to perform this task, appropriate load balancing must be implemented. The parameters of the physical layer and media access control (MAC) layer can be optimized at a central unit load balancing system by utilizing a two-tier buffer structure. In terms of data rates, dynamic cross-layer load balancing results in overall increased performance.

### 3.6 Illumination Requirements

A good LiFi system should be able to handle varied dimming levels. Pulse width modulation and continuous current reduction are two methods that can perform dimming operations in indoor LiFi communication systems.

### 3.7 User Movement Modeling

User mobility and device orientation should be studied and simulated while constructing a LiFi network to research and offer smooth connections. The random waypoint model is often utilized to mimic a node's movement. Nevertheless, in real-world settings, it is unworkable. Users at a retail mall will undoubtedly move differently than those in an office setting. Furthermore, the user data rate would be affected by the unpredictable orientations of LiFi receivers, which should be adequately simulated. An orientation-based random waypoint mobility design was developed mainly for LiFi mobile devices, and it was evaluated considering the rate of handover in actual circumstances.

## 4 Coexistence of LiFi and WiFi

High signal strength in the interior environment of a building is rare, except in dense WiFi networks where contention is possible. Similarly, ultra high speed LiFi communications can be realized only when the transmitter and receiver are in LoS. On the other hand WiFi can be used within its range even if the transceivers are not in LoS. This motivates the idea of integrating WiFi with LiFi for more stable and faster communications as depicted in Fig. 4. Conventionally, the WiFi signal's intensity weakens as the distance between AP and users grows, even with a strong WiFi connection in a structure having various sorts of walls and other obstacles. As a result, if the signal strength in one room is significantly reduced, WiFi users will have poor connectivity and sluggish speeds. High interference signals from adjacent WiFi APs and lack of bandwidth can also cause slow connectivity when a WiFi AP's limited bandwidth is shared by numerous active users.

To achieve multi-Gbps peak data speeds, the WiFi development explores higher frequencies with the new spectrum for indoor scenarios (at 60 GHz) so that it can serve numerous users concurrently. At the same time, tri-band (2.4, 5, and 60 GHz) IEEE 802.11ad wireless local area network (WLAN) deployments are starting to enter the customer business. On the other hand, optical wireless communications systems explicitly based on VLC technology, also known as LiFi, offer dual-functionality to transmit data based on the intensity of optical sources. WiFi has been improved as the primary scalability element for wireless capacity. However, notably, WiFi's long-

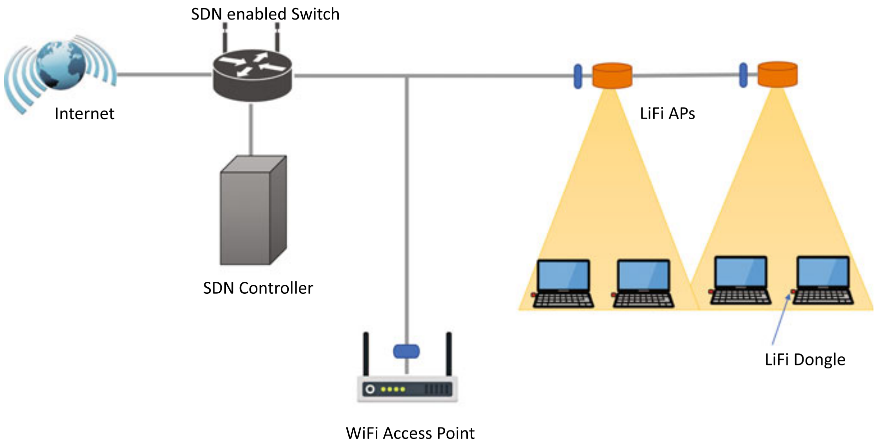


**Fig. 4** Hybrid WiFi-LiFi network

term performance might be harmed in dense deployments as the carrier's capacity decreases.

For instance, the first node who discovers an unused channel is permitted to initiate the communications, regardless of the channel's quality. However, if another user with a better channel requests service later, the request will not be fulfilled since the initial link will not be disrupted due to the CSMA/CA requirement that the next transmission will only begin if the channel is free. The problem is made worse because the increasing adoption of IP video streaming results in higher data usage and the necessity for continuous gap-free data transmission. As a result, WiFi uses concurrent multi-user transmission as the following step, comparable to Long-Term Evolution, allowing multiple users with multiple-input and multiple-output transmissions. In densely populated areas, cooperative behavior is essential. It is also worth considering beamforming between the neighboring APs. However, defining such a new form of simultaneous communication will need a significant standard effort. Furthermore, with a higher number of antennas, there are complexity constraints. A potentially intriguing study topic is the coexistence of WiFi and LiFi. Figure 5 shows that the signal is available in all the directions in a standalone WiFi network, but the data rate of each connected device is low, and the load on the WiFi access point is relatively high. On the other hand, the data rate for connected devices with LiFi standalone networks is very high. Still, if there is a blockage of LiFi light signals in between the device and the LiFi access point, the data rate drops to zero, even when the device is within the range of LiFi coverage as shown in Fig. 6. Further, Fig. 7 depicts that by combining both types of access points in a hybrid network, we can overcome the shortcomings of both types of networks. For example, if there is a blockage for LiFi light signals, the WiFi access point may connect that device. When LiFi connectivity is available, there is no need to waste WiFi bandwidth.

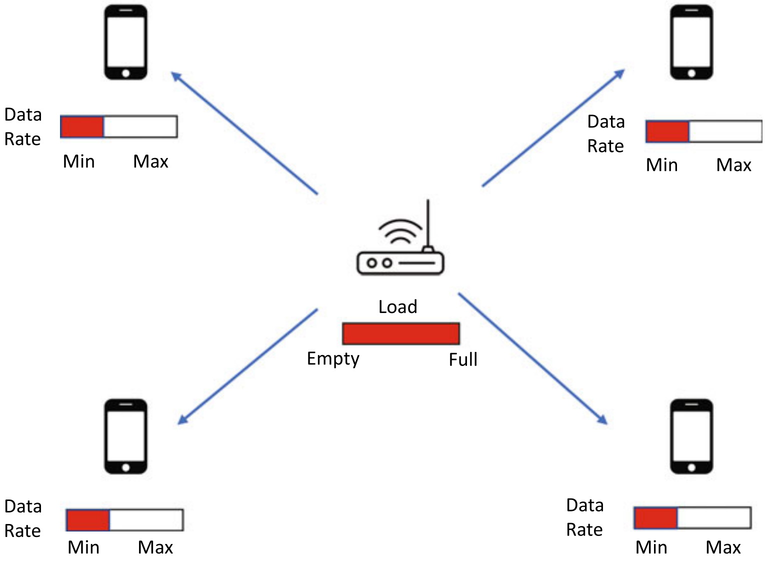


**Fig. 5** WiFi standalone network

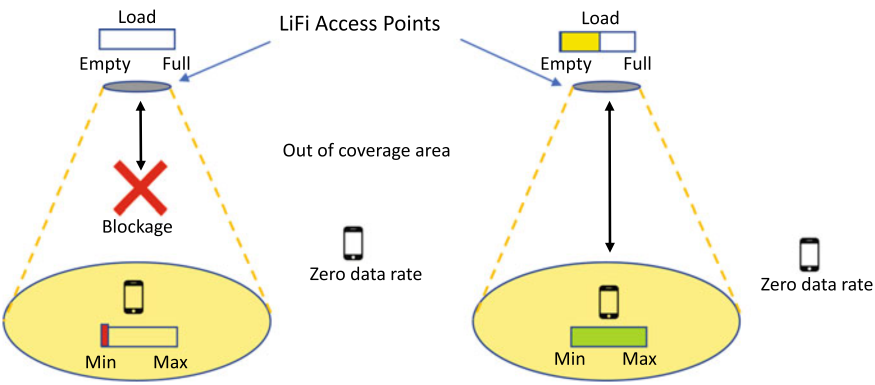


**Fig. 6** LiFi standalone network

## 4.1 *Load-Balancing Techniques for Hybrid LiFi-WiFi Networks*

When multiple devices are running on the same WiFi, the connection speed can be significantly reduced as shown in Fig. 5. However, in a LiFi access point, one can access a high-speed connection in the presence of multiple devices connected through the same AP if they are in the vicinity of the AP. If the users are not in the vicinity of LiFi AP, they will not be served by that particular AP as shown in Fig. 6

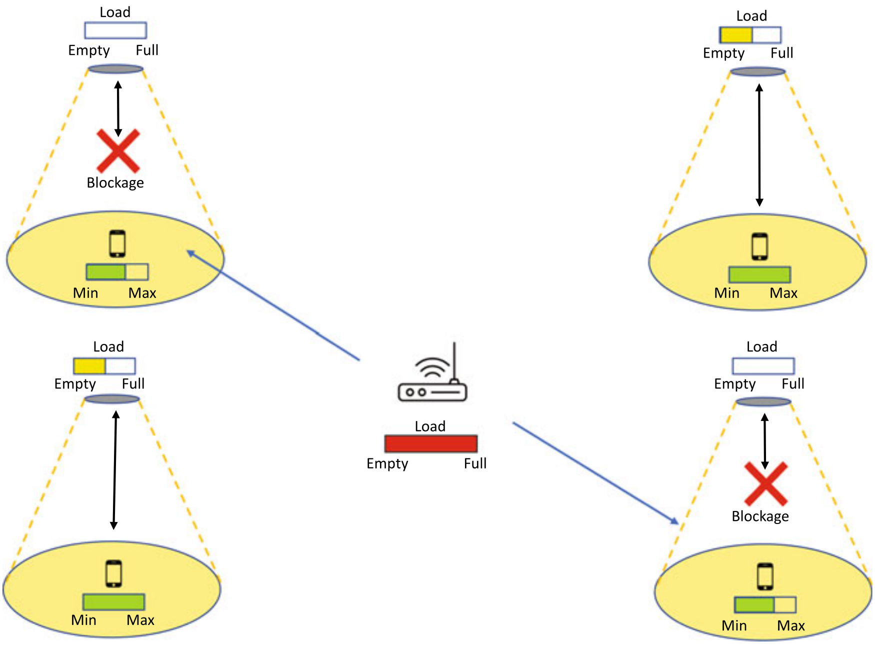


**Fig. 7** WiFi-LiFi hybrid network

Therefore, the interaction between WiFi and LiFi networks will undoubtedly reduce the chance of link failure and improve system performance. This integration can be considered as cross-network technology where a lot of work needs to be done related to load balancing, channel allocation, user mobility, hybrid AP planning, etc. There are several ways to solve the load balancing problem:

- One can adopt a method involving nonlinear programming mixed-integers. However, this comes with high computational complexity.
- A game-theory-based categorized strategy has been developed that needs less computing complexity but provides only an asymptotic solution to the global optimum.

The later method turned out to be universal in solving complex problems. However, as a rule, this heuristic approach has low tractability, making it difficult to conduct an analytical test and prove its effectiveness. A recent study examined the load distribution of LiFi/WiFi hybrid networks in extreme cases, and it was found that with appropriate load balancing solutions for the user, service and overall quality improved by up to 80% compared to specific solutions. It should be noted that the service level refers to the level of quality of user service, which is defined as an average value.

In addition to improving the performance of the communication system for transmission and energy savings, it is also subject to evaluation. In a comprehensive study of the RF/ VLC hybrid network, the load balancing function is used in terms of energy consumption. LiFi and RF-based hybrid networks can significantly improve energy efficiency.

### *4.2 Framework for Parallel Transmission in LiFi*

The parallel transmission in LiFi technology takes into account an internal wireless network with several LiFi APs. These APs are built inside LED ceiling lights that are perpendicularly pointing downwards [14]. They are organized in a square lattice topology to represent standard illumination arrangement in an indoor environment, such as an office. Interfering signals are regarded as noise by the APs, which reuse optical frequency bands. Each AP is made up of several LEDs with different wavelengths for lighting purposes (Table 1).

### *4.3 Mobility Modeling*

A few studies have looked into user mobility models for indoor environments. These studies are typically based on a certain floor plan that includes rooms and corridors [14]. It is presumed in this article that there are no cubicles or corridors, and users are free to roam around. The random waypoint, which is a widely used synthetic model for mobility, is used to mimic freely moving individuals. Users travel in a zigzag pattern from one waypoint to the next, with the waypoints allocated at random. The user walks about in a wide outdoor area, such as a 1000 m by 1000 m zone, in the original RWP model, changing pace as it approaches each waypoint. The user's pace is kept constant for a brief length of time in an indoor situation where the distance between two destinations is quite short. An excursion refers to the user's mobility during this time. When the current trip is completed, the user selects a new pace and

**Table 1** Parameter of different wavelengths [14]

| Wavelength (nm) | 450 | 500 | 600 | 650 |
|---|---|---|---|---|
| Luminous efficacy | 27 | 205 | 340 | 68 |
| PD responsivity | 0.15 | 0.23 | 0.37 | 0.44 |
| Intensity percentage (%) | 10 | 55 | 20 | 15 |
| Optical output power | 9.3 | 6.7 | 1.5 | 5.5 |
| Modulated optical power | 3.6 | 2.3 | 1.5 | 1.2 |

continues on their journey. The user's speed is considered to be evenly distributed between 0 and 2 $v$, with $v$ indicating the average speed.

### 4.4 Light Path Blockage Model

When a LiFi link is obstructed, two variables influence its performance:

(i) how often the blockage happens
(ii) how long the obstruction lasts.

The first component impacts the average user throughput, whereas the second influences the handover rate caused by bottlenecks [14]. To characterize light-path obstructions, two metrics are used: the occurrence rate and the occupancy rate. The incidence rate, indicated as, is the average number of blockages that occur per unit of time. The Poisson point process is believed to govern this rate, which is commonly used to simulate random occurrences like packet arrival at a switch. The occupancy rate is the percentage of time during which the user encounters obstacles. We presume that various APs are blocked independently. Signals from several APs may be blocked in practice. This may be seen in the case of a high occupancy rate, where signals from numerous sources are combined. At the same time, APs are likely to be prohibited.

### 4.5 Choice of Subflows

A number of subflows are evaluated, which are chosen according to the signal strength strategy rule, which states that each user selects a number of APs that offer the greatest SINR values. A subflow can fail in one of two ways

- Loss of connection
- Increased traffic congestion.

In the first case, a handover can be used to allow a new subflow to join the existing link and maintain connectivity. There are two choices in the second case. One solution is to switch out the congested subflow for another. However, this might have an impact on other users' APs results, perhaps causing a chain reaction. The alternative is to avoid using the crowded subflow and redirect traffic to other subflows. Because the congestion conditions among APs are equivalent under the assumption of evenly dispersed users, this alternative is used in this study.

## 5 Current Standardization of LiFi

The International Telecommunication Union (ITU-T) has been involved in LiFi since 2015 as part of the G.vlc project. The ITU G.9991 recommendation for high-speed connectivity for VL and IR products was published in 2017. A high-quality network is crucial for the development of new technologies. Since 2015, the International Telecommunication Union (ITU-T) has been advising on high-speed connectivity for VL and IR products. The 802.15.7r1 Task Group (TG) was created in 2015 by the Institute of Electrical and Electronics Engineers (IEEE) to drought a revision to the IEEE 802.15.7 standard, which defines the PHY and MAC layers for short-range wireless optical communication utilizing VL [15]. The goal of 802.15.7r1 was to include IR and near-UV wavelengths, as well as alternatives like optical camera communications and LiFi, in addition to VL. The IEEE 802.11 working group for local area networks created the amendment TG-802.11bb in 2018, with the goal of developing technical requirements for enabling low-cost and low-energy devices for LiFi mass-market and assisting manufacturers and operators in providing universal 802.11 components. The aim is to reuse the 802.11 MAC for optical spectrum communications, which has a low adoption rate, and create a PHY that supports UL and DL operations in an optical wavelength range ranging from 380 to 5,000 nm. An association called LiFi Consortium was formed by a group of big telecommunication companies and industries in order to improve high speed wireless communications based on the optical wireless technology to provide considerable relief from overcrowding in the RF spectrum. The job of bringing high-speed, ubiquitous LiFi technology to market has begun at the University of Strathclyde in Scotland.

## 6 LiFi Application in Industries

LiFi offers a large variety of applications in live streaming, hospitals, workplaces, manufacturing facilities, schools, retail, and many more. LiFi can deliver communication 200 times faster than WiFi theoretically typically at around more than 200 Gbps. The benefits are summarized as follows:

1. GPS capabilities that are extremely accurate
2. Eco-friendly
3. Enhanced indoor connection
4. There are no health hazards
5. Very cost-effective
6. Faster than a typical network connection and there is no electromagnetic interference
7. Enhanced security.

LiFi has great potential to transform overall experience of passengers and in flight connectivity if used in aerospace. Transmitting data through light is attracting the interest of several airline companies. According to their analysis, using LiFi on airplanes would save the equivalent of 20 passengers' weight per flight. The reason being optical fibers weigh an order of magnitude less than copper. Airlines will be able to eliminate Internet connection equipment beneath seats, which will result in significant weight loss overall, increasing their profit per flight. However, owing to the installation of LiFi in the cabin, flight attendants will be able to approve in-flight payments instantly in the future. LiFi will help pilots and provide new applications for passengers since it is safer than WiFi and does not pose any risk of electromagnetic interference.

Major aerospace companies are looking into installing LiFi in their plane cockpits to connect the pilot's controls and equipment in a more accessible and safe manner. In the future, LiFi has the potential to improve the passenger experience. The inclusion of LiFi in the cockpit reduces the number of cables and reduces weight significantly. While WiFi has the potential to solve this problem, it must be used with caution due to its susceptibility to outside influence and hackers. On the other hand, LiFi is safer since, unlike WiFi, it cannot be transmitted through hulls and windows, making tapping from outside impossible. Similar to these improvements, other industries are benefiting from the development of LiFi technology.

## 7 Conclusion

This chapter discussed various aspects of LiFi, including the receiver and transmitter architecture and channel model. Also, we have emphasized the potential applications of LiFi in industries and smart cities. Various challenges related to user mobility, security, and load balancing have been presented. Further, we have motivated the concept of hybrid WiFi and LiFi to improve the reliability and achievable rate and end-users. Due to their distinct communication characteristics, both VLC and RF communications coexist. VLC, for example, is best for short-range communication, but RF is best for long-range communications. In particular, VLC offers suitable attributes for interior use, whereas RF can provide a better experience in indoor/outdoor applications.

## References

1. Mandloi, M., Gurjar, D., Pattanayak, P., Nguyen, H.: 5G and Beyond Wireless Systems: PHY Layer Perspective. Springer Nature (2020)
2. Gurjar, D.S., Upadhyay, P.K.: Performance analysis of zero-forcing-based multiple-input multiple-output two-way relaying in overlay device-to-device communications. IET Commun. **10**(6), 699–708 (2016)
3. Pathak, P.H., Feng, X., Hu, P., Mohapatra, P.: Visible light communication, networking, and sensing: a survey, potential and challenges. IEEE Commun. Surv. Tutorials **17**(4), 2047–2077 (2015). https://doi.org/10.1109/COMST.2015.2476474

4. Haas, H., Yin, L., Wang, Y., Chen, C.: What is LiFi? J. Lightwave Technol. **34**(6), 1533–1544 (2016). https://doi.org/10.1109/JLT.2015.2510021
5. Haas, H., Yin, L., Chen, C., Videv, S., Parol, D., Poves, E., Alshaer, H., Islim, M.S.: Introduction to indoor networking concepts and challenges in LiFi. IEEE/OSA J. Opt. Commun. Netw. **12**(2), A190–A203 (2020). https://doi.org/10.1364/JOCN.12.00A190
6. Wu, X., Haas, H.: Mobility-aware load balancing for hybrid LiFi and WiFi networks. IEEE/OSA J. Opt. Commun. Netw. **11**(12), 588–597 (2019). https://doi.org/10.1364/JOCN.11.000588
7. Wu, X., Haas, H.: Load balancing for hybrid LiFi and WiFi networks: to tackle user mobility and light-path blockage. IEEE Trans. Commun. **68**(3), 1675–1683 (2020). https://doi.org/10.1109/TCOMM.2019.2962434
8. Wu, X., O'Brien, D.C., Deng, X., Linnartz, J.P.M.G.: Smart handover for hybrid LiFi and WiFi networks. IEEE Trans. Wireless Commun. **19**(12), 8211–8219 (2020). https://doi.org/10.1109/TWC.2020.3020160
9. Soltani, M.D., Arfaoui, M.A., Tavakkolnia, I., Ghrayeb, A., Safari, M., Assi, C.M., Hasna, M.O., Haas, H.: Bidirectional optical spatial modulation for mobile users: toward a practical design for lifi systems. IEEE J. Select. Areas Commun. **37**(9), 2069–2086 (2019). https://doi.org/10.1109/JSAC.2019.2929381
10. Miramirkhani, F., Narmanlioglu, O., Uysal, M., Panayirci, E.: A mobile channel model for VLC and application to adaptive system design. IEEE Commun. Lett. **21**(5), 1035–1038 (2017). https://doi.org/10.1109/LCOMM.2017.2651800
11. Arfaoui, M.A., Soltani, M.D., Tavakkolnia, I., Ghrayeb, A., Assi, C.M., Safari, M., Haas, H.: Measurements-based channel models for indoor LiFi systems. IEEE Trans. Wireless Commun. **20**(2), 827–842 (2021). https://doi.org/10.1109/TWC.2020.3028456
12. Vegni, A.M., Little, T.D.C.: Handover in VLC systems with cooperating mobile devices. In: 2012 International Conference on Computing, Networking and Communications (ICNC), pp 126–130 (2012). https://doi.org/10.1109/ICCNC.2012.6167395
13. Liang, S., Tian, H., Fan, B., Bai, R.: A novel vertical handover algorithm in a hybrid visible light communication and LTE system. In: 2015 IEEE 82nd Vehicular Technology Conference (VTC2015-Fall), pp. 1–5 (2015). https://doi.org/10.1109/VTCFall.2015.7390808
14. Wu, X., O'Brien, D.C.: Parallel transmission LiFi. IEEE Transactions on Wireless Communications **19**(10), 6268–6276 (2020). https://doi.org/10.1109/TWC.2020.3001983
15. Popadić, M., Kočan, E.: LiFi networks: Concept, standardization activities and perspectives. In: 2021 25th International Conference on Information Technology (IT), pp. 1–4 (2021). https://doi.org/10.1109/IT51528.2021.9390098