Coexistence of Wi-Fi and Li-Fi Towards 5G: Concepts, Opportunities, and Challenges

Aranjay Rewanwar (20927312)
Juhi Bachani (20979706)

I. INTRODUCTION

Fifth generation (5G) access expected to be obtainable after 2020 will be able to satisfy demand for ever increasing data rates and low latency. In comparison to already accessible 4G technologies, 5G targets high throughput using more bandwidth and high frequencies at low cost and reduced power consumption. More bandwidth is needed to be allotted to 5G and available bandwidth is to be used more effectively than the previous generation. As the demand for wireless voice and data services has increased, the number of mobile devices with multimedia capabilities and Internet access is expanding rapidly. The user's main activities utilizing data capacity now and in the coming years are watching HD streaming movies and videos, playing online games, and accessing cloud-based services. In a few years, most of the data traffic is likely to occur from indoor locations and operators are struggling to meet this demand while maintaining adequate service quality. In comparison to outdoor propagation, indoor wireless medium exhibits high demand for video and cloud-based data expected to increase, and it is a major impetus for the adoption of the additional spectrum including the use of optical wireless media, making the design of 5G indoor communication systems even more challenging. In terms of network topology, heterogeneous networks (HetNets) will play a key role in integrating a diversified spectrum to provide high quality-of-service (QoS), particularly in a wide range of wireless coverage zones, such as open outdoor environments, office buildings, homes, and underground places. In a HetNet, where RF macrocells, RF-SCs, and O-SCs comprise a three-layer network, Li-Fi-enabled indoor luminaires (lights) can be depicted as optical SCs (O-SCs), enabling increased coverage at user-occupied sites, and Li-Fi microcells that increase capacity by using the optical spectrum.

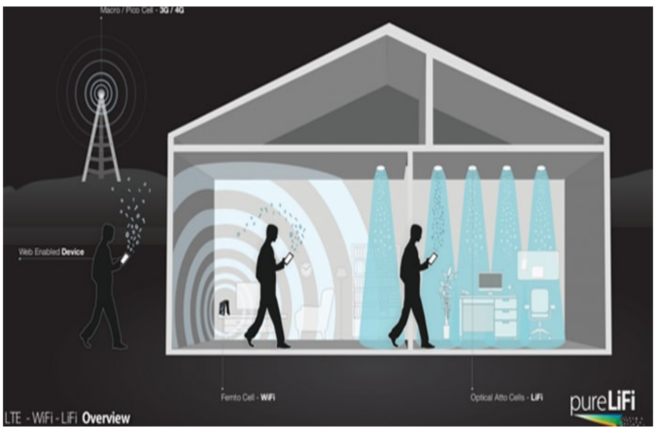

Figure 1: Demonstration of Li-Fi and Wi-Fi

II. ENHANCEMENT OF LI-FI OVER WI-FI

High signal strength in indoor access Wi-Fi networks indicates a fast and reliable Wi-Fi connection, except in dense Wi-Fi networks where the connection is possible using the concept of tree topology (multiplexing) with the collapse of the frequency band from neighboring Wi-Fi routers and shifting the connection from one router to another establishes network disconnection. Light fidelity (Li-Fi) technology solves these problems by using a peer-to-peer network (one-to-one communication) to make connectivity more secure, fast, and simple to use. High interference signals from surrounding Wi-Fi APs and/or several active users sharing a Wi-Fi AP's limited bandwidth can also cause slow connectivity in Wi-Fi, which is resolved in Li-Fi because the property of light is that it travels faster in the air (Refraction of Light) with the same polarization as light is emitted in all directions as series of waves having the same speed for all users in one space using Li-Fi technology with excellent connectivity. Li-Fi is recommended for high-speed connectivity, but it has some drawbacks, it provides the ideal speed for short ranges, especially in indoor facilities. When it comes to long-distance connectivity, Wi-Fi is the better because it uses radio frequency (RF) waves for connectivity, which are generated from towers that are spaced evenly apart, as well as the Wi-Fi technology, which uses a router and modem for its connection, which has (RJ45) Ethernet port that can be easily connected to computers and laptops by a simple Ethernet cable for experiencing high speed.

III. THE STATE OF WIRELESS AND MOBILE COMMUNICATION

Wi-Fi's wavebands have a high absorption rate and are best used in a line-of-sight environment. Higher frequencies and additional spectrum are being considered in the Wi-Fi development to achieve multi-Gb/s peak data speeds (60 GHz) indoors and to serve multiple users concurrently. Many common obstacles, like walls, pillars, and home appliances, can significantly restrict range, but this also helps avoid interference between multiple networks in congested areas. Indoors, an access point (or hotspot) typically has a range of roughly 20 meters (66 feet), but some newer access points claim a range of up to 150 meters (490 feet) outdoors. Hotspot coverage can be as limited as a single room with radio-wave-blocking walls, or as vast as many square kilometers (miles) with roaming allowed between overlapping access points.

Although line-of-sight is ideal for Wi-Fi signals, they can transmit, absorb, reflect, refract, diffract, and up and down fade through and around man-made and natural structures. Metallic structures (such as rebar in concrete and low-e coatings in windows) and water have a significant impact on Wi-Fi transmissions (such as found in vegetation). Because of the complicated nature of radio propagation at standard

Wi-Fi frequencies, especially around trees and buildings, algorithms can only forecast Wi-Fi signal strength for any given location concerning a transmitter to some extent [1]. The IEEE 802 protocol family includes Wi-Fi. At the data link layer, the data is structured into 802.11 frames, which are essentially like Ethernet frames but have additional address fields [2]. For LAN routing, MAC addresses are utilized as network addresses. IEEE 802.11 defines the MAC and physical layer (PHY) specifications for modulating and receiving one or more carrier waves in the infrared and 2.4, 3.6, 5, or 60 GHz frequency bands to transport data. The IEEE LAN/MAN Standards Committee designed and maintains them (IEEE 802). The standard's first version was published in 1997, and it has since undergone numerous revisions. The standard and revisions form the foundation for Wi-Fi-branded wireless network products. While each modification is legally withdrawn when it is included in the most recent version of the standard, the business sector prefers to sell to the revisions since they succinctly express product capabilities [3]. However, defining such a new model of simultaneous transmissions to numerous users that is backward compatible will necessitate a significant standards effort. Furthermore, with a larger number of antennas, there are complexity restrictions. The difficulty of linear MIMO equalizers is generally known to scale with N3, where N is the number of antennas, whereas optimal scheduling difficulties, particularly between the beams of several nearby APs, are NP-hard. A workable solution has recently been developed because of these standardization, scalability, and complexity difficulties, as well as the growing demand for Wi-Fi, scalability is limited, and alternate wireless media should be considered [4].

IV. Increasing Capacity And Density

Due to the issues, we propose an additional tier in wireless HetNets made up of indoor gigabit SCs to provide additional wireless capacity where it is most needed. In a HetNet, where RF microcells, RF-SCs, and O-SCs comprise a three-layer network, Li-Fi-enabled indoor luminaires (lights) can be depicted as optical SCs (OSCs). The performance of a single Wi-Fi AP or numerous Wi-Fi APs should be improved by offloading traffic to the most localized and directed Li-Fi. Aside from high-speed traffic unloading and seamless connectivity, the proposed Li-Fi & Wi-Fi system also has certain novel characteristics, such as improved O-SC security and indoor location [5]. According to operators, 80 percent of mobile traffic happens indoors; thus, the combination of Li-Fi and Wi-Fi has a lot of promise in future HetNets, including next-generation (5G) mobile telecommunications systems [6, 7]. To our knowledge, current research focuses on improving the performance of each of the technologies separately, despite the evident need for reliable Wi-Fi and Li-Fi coexistence solutions [8].

Li-Fi-enabled light fixtures, or luminaires in lighting jargon, give data access to stationary and quasi-stationary mobile users, as shown in Figure 2. This strategy can reduce congestion and free up RF resources to serve users who are more mobile or outside of the Li-Fi coverage region. More highly mobile customers will be able to rely on the Wi-Fi network's expanded coverage. User devices (UDs) in the Li-Fi and Wi-Fi network must be Li-Fi-enabled. The evolution of cellular networks can be used as a benchmark for evaluating the development of Li-Fi-enabled devices.

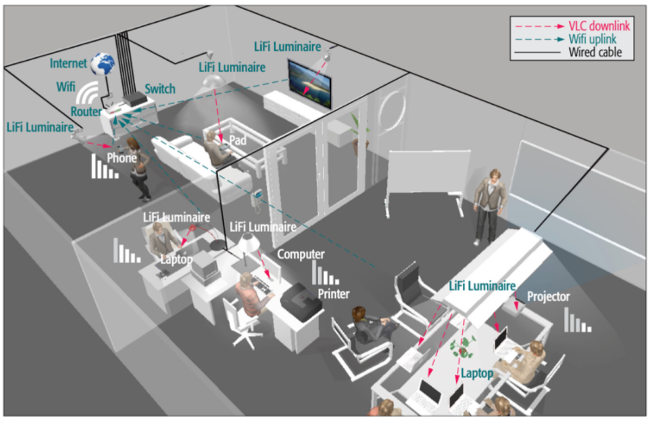

Figure 2: The proposed Li-Fi and Wi-Fi HetNet

Mobile technologies, which have progressed from 1G to 4G, have paved the way for the marketing of increasingly powerful and pricey consumer devices. Li-Fi-enabled smartphones provide manufacturers with significant economic potential by enabling richer mobile broadband experiences. Most current smartphones support numerous radios and protocols out of the box. Even while the Li-Fi and Wi-Fi network will most likely be asymmetric, with Li-Fi serving as the downlink, this should free up Wi-Fi system capacity to accommodate any future traffic-uploading expansion.

V. Modulation Techniques For Li-Fi

Single carrier and multiple carrier modulation techniques are the most common modulation techniques used in Li-Fi systems. Single carrier modulation approaches include on-off keying (OOK), pulse position modulation, unipolar pulse amplitude modulation (PAM), pulse width modulation, and pulse amplitude modulated discrete multi-tone modulation. These low-speed single carrier modulation schemes are simple to implement. Because of its simplicity, the OOK modulation is more popular for low-medium data rate transmission. A bit "1" is represented by an optical pulse in OOK, whereas a bit "0" is represented by the absence of an optical pulse. The most prevalent types of OOK are the return-to-zero (RZ) and non-return-to-zero (NRZ) schemes.

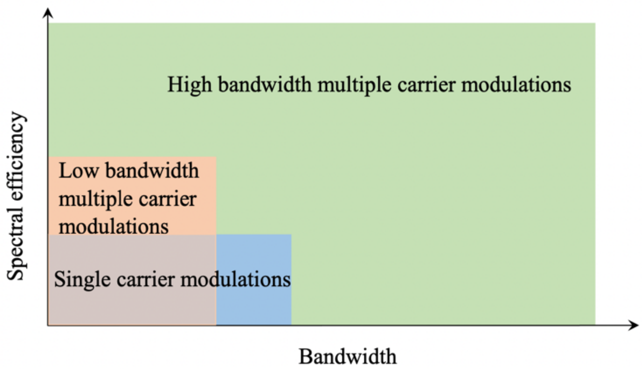

Figure 3: A comparison of single carrier and multiple carrier modulations in terms of spectral efficiency.

The bit duration is equal to the duration of the transmitted pulse to indicate "1" in the NRZ scheme, but they are not equal in the RZ scheme, i.e., the pulse fills only a portion of the bit "1". Single carrier modulation systems are known to be susceptible to inter-symbol interference (ISI). As a result, applying these modulation techniques requires more complicated equalizers at the receiver to counteract the ISI over the dispersive channel as the needed data rate grows. Multi-carrier modulation techniques are more spectrum efficient than single carrier modulation schemes and can provide larger data speeds.
The introduced ISI in Li-Fi systems is the result of signal transmission across a dispersive optical channel at high data rates while also using off-the-shelf bandwidth-constrained LEDs. OFDM has several advantages, including 1) efficient use of spectrum, 2) channel robustness against frequency selectivity by splitting it into narrowband flat fading subcarriers, 3) simple channel equalization by using a single-tap equalizer (while adaptive equalization techniques are used in single carrier modulation schemes), and 4) computational efficiency by using fast Fourier transform (FFT) and inverse FFT (IFFT) techniques.

VI. Multiple Links And Aggregation

Because luminaires are dispersed across our living environments, it is common to "see" multiples at once. A multichannel receiver can make use of this phenomenon. Consider the possibility that the lighting infrastructure could support MIMO transmission via a multi-detector UD. Conciliating the ideal link or linkages involving one or more luminaires in the presence of several UDs, on the other hand, is difficult. Mobility and shifting UD orientation make this more challenging. As a result, accurate sensing of the optical link quality between individual luminaires inside the UD receiver's field of view is crucial and necessitates extensive research. Previous research has assumed that the transmitter knows every UD in the room's channel state information (CSI). However, correct CSI may be easier to achieve in a static environment and acquiring the CSI in the case of user mobility is an estimation problem that cannot be error-free from a practical standpoint. For time-varying single-input single-output (SISO) and MIMO wireless channels, it's crucial to understand the impact of channel estimate error on system throughput in a multi-user context. One significant part of network densification [9], which is considered as the key mechanism for wireless evolution over the next decade, is increasing the density of APs, while interference management is critical. Interference control is unavoidable across multiple network domains in the 3rd generation partnership project (3GPP) heterogeneous networks (HetNets) [10], because they use the same carrier frequencies. Li-Fi and Wi-Fi do not interfere with each other because they operate on distinct spectra. Furthermore, the CSMA/CA protocol used by Wi-Fi can reduce co-channel interference (CCI) to a nil level. As a result, we'll concentrate on Li-Fi interference management approaches.
Connecting a user to many optical channels, on the other hand, maybe advantageous when the application requires high throughput. Because each room has many Li-Fi-enabled luminaires, modulation frequency sub-bands and wavelengths can be reused at a distance to increase throughput. Like LTE-Advanced, carrier, and channel aggregation is a significant strategy for increasing overall transmission bandwidth. Aggregation in the Li-FI and Wi-Fi network necessitates efficient methods for splitting overall traffic across the RF and optical connections, handling packet drops on individual links, and reordering packets as needed. Higher layer protocols, such as the transmission control protocol, are visibly affected by these difficulties (TCP). Three alternative access possibilities can be examined in circumstances where a user can be hooked to a single luminaire (SISO configuration) or many luminaires simultaneously (MIMO configuration). The user is first served by a single luminaire with the best link quality. Multiple luminaires serving a single user may be used to meet the needs of that user. However, the number of luminaires serving a single user can be adjusted based on resource availability to ensure fairness and minimum QoS across numerous users, especially in a dense user scenario.

VII. Illumination Requirements

A suitable design of the positioning or arrangement of the LEDs within the contemplated indoor Li-Fi system is one effective approach to boosting the energy efficiency of HWL-Nets. Minimal energy consumption and the desired illumination pattern can be obtained by optimizing the placements and adjusting the output power levels of the LEDs. When developing an energy efficient HLWNet, it's critical to consider the room's illumination constraints. The illumination needs for an indoor setting should be in the range of 300 to 1500 lx, according to the International Organization for Standardization (ISO) on light and lighting [11]. The illuminance of a room is often low in the corners and high in the center. To achieve the ISO criterion for uniform illuminance, a thorough design is necessary. The illuminance level at each place can be calculated as follows, according to [11]:

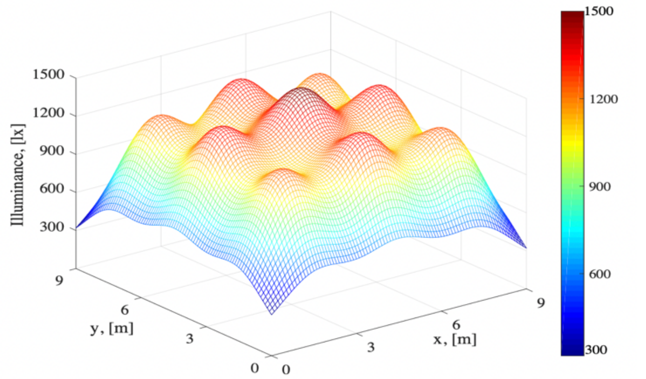

Figure 4: Demonstration of Li-Fi and Wi-Fi

The number of LEDs is represented by NLED, and the Lambertian order, m, may be derived using the half-intensity angle, m = 1/ log2 (cos (1/2)). I and I represent the radiance and incident angles at the point (x, y). Figure 4 depicts the distribution of illumination at various points in a 909 m2 room with 9 APs. The illuminance level at the corners is low, as expected, but the space between LEDs is built in such a way that the minimum illumination requirement of 300 lx is achieved.
Several publications [12], [13] have explored simultaneous energy-efficient design and lighting constraints. The authors of [12] focused on the difficulty of designing an energy-

efficient LED configuration while keeping lighting limits in mind. [13] proposes a fast game-theory-based approach for maximizing energy efficiency under lighting limitations. To examine the rivalry among VLC pairs to attain optimum energy efficiency, the generalized Nash equilibrium model was adopted. As a result, it's critical to think about lighting while designing HLWNets, not just to meet the room's lighting needs, but also to create an energy-efficient hybrid network.

VIII. A Prototype System Proof Of Concept And Results

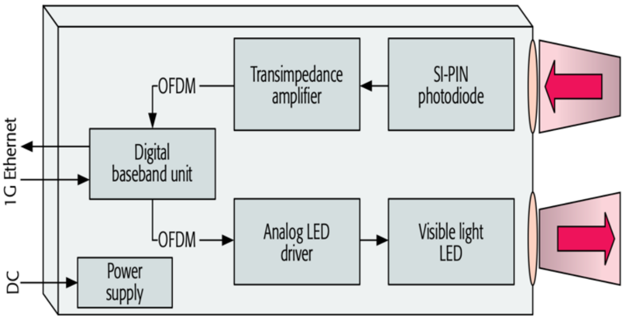

Figure 5: The Li-Fi Transceivers

The proposed Li-Fi and Wi-Fi HetNet is put to the test utilizing bidirectional high-speed Li-Fi transceiver devices that supply real-time data and meet the OSI protocol stack layers 1 and 2. The gadget, whose principle is depicted in Figure 5, employs a high-power phosphorus-converted LED (PC-LED) that can provide both illumination and data transmission in tandem. An analog modulation bandwidth of up to 180 MHz is achieved using a customized LED driver. A large-area high-speed silicon PIN photodiode is employed in the receiver, along with a trans-impedance amplifier (TIA). Both the LED and the photodiode use a plano-convex 1" lens to focus the beam and increase the receiving area, respectively. A digital baseband unit (BBU) sits behind the analog transmitter and receiver circuitry, converting Ethernet packets into DC-biased orthogonal frequency division multiplexing (OFDM) signals and vice versa. The OFDM signals have a 70 MHz bandwidth. To reconstruct the received symbol constellations, the BBU uses pilot-assisted channel estimation and frequency-domain equalization.

The error vector magnitude (EVM) is calculated from the received pilot sequence and sent back to the transmitter. The bit loading is adjusted based on the channel quality as a function of frequency. After forward error correction, the data rate is increased as much as feasible to ensure that no errors occur. The possible data rate is accomplished while avoiding outages due to changing channel circumstances such as varying illumination levels, thanks to the techniques utilized in link adaptation, which are implemented in real-time as a closed loop.

IX. Proof Of Concept Experiment

A proof-of-concept hybrid Li-Fi and Wi-Fi configuration is constructed [14, 15], using a single Wi-Fi AP and a single Li-Fi AP. Three systems are compared in this article. The Wi-Fi is solely used to connect to the Internet in the first version. The second system, known as a hybrid system, is like the first, but one of the users' downlinks is connected via a Li-Fi link. In the third method, known as an aggregated system, one user is simultaneously connected to both Wi-Fi and Li-Fi. Figure 6 shows the hybrid system (a) and aggregated system (b) designs (b). The unidirectional Li-Fi link is used in the hybrid system to supplement the traditional Wi-Fi downlink, whereas, in the aggregated system, both bi-directional Wi-Fi and Li-Fi links are completely employed to increase possible throughput and offer reliable network connectivity.

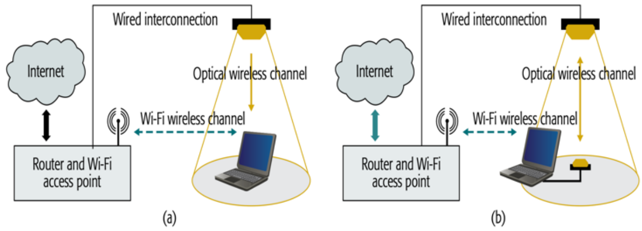

Figure 6: configurations of the a) hybrid system, and b) the aggregated system

The average throughput of the three systems was tested at various distances between the Wi-Fi and Li-Fi frontends in Figure 6a. The Li-Fi frontends are perfectly aligned in this design (i.e., zero off-axis displacement). The Wi-Fi router's setting is set to "up to 54 Mb/s" to ensure reliable connectivity in a congested environment. Although the Wi-Fi signalling strategy is in principle dependent on the received SNR, the Wi-Fi-only throughput displayed in Figure 6a is nearly constant in the Li-Fi AP's coverage area because Wi-Fi performance degrades when the distance exceeds 25 meters, where VLC connectivity is already absent. Near the Li-Fi AP, the hybrid system more than doubles throughput, but it quickly degrades as distance rises. When the distance is raised to roughly 4.1 m, the throughput of a Wi-Fi-only system exceeds that of a hybrid system, because the downlink capacity of Li-Fi declines with distance, eventually becoming inconsequential. It's worth noting that the hybrid VLC system's throughput statistics are solely dependent on the Li-Fi downlink's capacity.

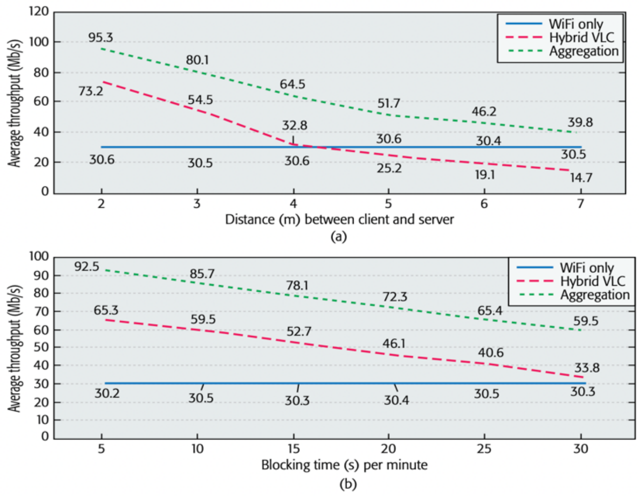

Figure 7: a) throughput vs. distance; b) throughput vs. blockage duration

The aggregated system triples the possible average throughput, and its lowest bound is higher than the Wi-Fi-only system's average throughput. As a result, the aggregation technique not only increases the available combined bandwidth but also ensures that the network connection is dependable. Individual users can achieve considerably better performance near the Li-Fi AP due to Li-Fi's unique short-range characteristic. It's also worth noting that Li-Fi and Wi-Fi users can get service both inside and outside of this limited coverage region.

X. Conclusion

This survey opens several doors for field research on the existence of both Wi-Fi and LIFI, with Li-FI giving an enhanced interior experience by delivering high data speeds and security, and Wi-Fi providing increased off-loading opportunities. HetNets are useful in this situation because they provide additional wireless bandwidth at the required location, resulting in increased indoor connectivity. Li-Fi has evolved into a ubiquitous system technology with unique networking capabilities for universal application, allowing a variety of device platforms to connect over the internet at high rates. The integration of two technologies produces an output that is needed in the field.

XI. References

[1] "WiFi Mapping Software:Footprint". Alyrica Networks. Archived from the original on 2 May 2009. Retrieved 27 April 2008.

[2] "3.1.1 Packet format" (PDF). IEEE Standard for Ethernet, 802.3-2012 – section one. 28 December 2012. p. 53. Archived (PDF) from the original on 21 October 2014. Retrieved 6 July 2014.

[3] Stobing, Chris (17 November 2015). "What Does WiFi Stand For and How Does Wifi Work?". GadgetReview. Archived from the original on 1 December 2015. Retrieved 18 November 2015.

[4] V. Jungnickel *et al.*, "The Role of Small Cells, Coordinated Multipoint, and Massive MIMO in 5G," *IEEE Commun. Mag.*, vol. 52, no. 5, 2014,pp. 44–51.

[5] W. Guo *et al*., "A Parallel Transmission MAC Protocol in Hybrid VLC-RF Network," *J. Commun.*, vol. 10, no. 1, 2015.

[6] S. Wu, H. Wang, and C.-H. Youn, "Visible Light Communications for 5G Wireless Networking Systems: From Fixed to Mobile Communications," *IEEE Network*, vol. 28, no. 6, 2014, pp. 41–45.

[7] M. Rahaim, A. Vegni, and T. Little, "A Hybrid Radio Frequency and Broad- cast Visible Light," *Proc. GLOBECOM Wksps.*, 2011.

[8] Z. Huang and Y. Ji, "Design and Demonstration of Room Division Multi- plexing-Based Hybrid VLC Network," *Chinese Optics Lett.*, vol. 11, no. 6, 2013, pp. 1671–7694.

[9] N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damn- janovic, R. T. Sukhavasi, C. Patel, and S. Geirhofer, "Network den- sification: the dominant theme for wireless evolution into 5G," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 82–89, Feb. 2014.

[10] A. Damnjanovic, J. Montojo, Y. Wei, T. Ji, T. Luo, M. Vajapeyam, T. Yoo, O. Song, and D. Malladi, "A survey on 3GPP heterogeneous networks," *IEEE Wireless Commun.*, vol. 18, no. 3, pp. 10–21, Jun. 2011.

[11] T. Komine and M. Nakagawa, "Fundamental analysis for visible- light communication system using led lights," *IEEE Trans. Consum. Electron.*, vol. 50, no. 1, pp. 100–107, Feb 2004.

[12] H. E. Ramy E. Ali, "Energy Efficient LED Layout Optimization for Near-Uniform Illumination," in *Proc.SPIE*, vol. 9954, 2016, p. 995406.

[13] X. Tang, P. Ren, and Z. Han, "Energy Efficiency Competition for Visible Light Communication under Illumination Constraint," in *Proc., APSIPA Annual Summit and Conf.*, vol. 2018, 2018, pp. 12–15.

[14] S. Shao *et al*., "An Indoor Hybrid WiFi-VLC Internet Access System," *Proc. Wksp. CellulAR Traffic Offloading to Opportunistic Networks (CAR- TOON)*, Philadelphia, 2014.

[15] S. Shao *et al.*, "Design and Analysis of a Visible-Light-Communication Enhanced WiFi System," *OSA/IEEE J. Optical Commun. Netw. (JOCN)*, vol. 7, no. 10, 2015, pp. 960–73.

[16] D. Ghosh, S. Chatterjee, V. Kothari, A. Kumar, M. Nair and E. Lokesh, "An application of Li-Fi based Wireless Communication System using Visible Light Communication," 2019 International Conference on Opto- Electronics and Applied Optics (Optronix), 2019, pp. 1-3, doi: 10.1109/OPTRONIX.2019.8862366

[17] S. Murawwat, R. Mehroze, K. Rabbi, A. Moeen and T. Sheikh, "An Overview of LiFi: a 5G candidateTechnology," 2018 International Symposium on Recent Advances in Electrical Engineering (RAEE), 2018, pp. 1-6, doi: 10.1109/RAEE.2018.8706906.