Performance of Light-Fidelity (Li-Fi) over fixed line and cellular backhaul connections

Joseph C Balaam
Laith Al-Jobouri

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Author 1
Department of...
Institution name
Town, Country
email@email.com

Author 2
Department of...
Institution name
Town, Country
email@email.com

***Abstract*—This paper takes an examination into how increased demand for wireless data services will cause capacity limitations within the radio frequency spectrum; the optical spectrum is viewed as an attractive solution that uses light as a transmission medium for alternative connectivity. Overall, this paper finds Li-Fi to be particularly suited to facilitating data communications, however, there is inherently scope for future research opportunities as issues surrounding the availability of 5G cellular services and disruptions to the line of sight are addressed in time.**

***Keywords*—lifi, wireless, optical spectrum, light waves, cellular.**

I. INTRODUCTION

Within the past decade, demand in wireless data services has increased by sixty percent [1]; should such demands continue, twelve-thousand times more bandwidth than that used in the present day would be required. In total, 6 THz of bandwidth is sought after, whereas the radio frequency (RF) spectrum, for which these data services are carried, measures at only 0.3 THz; this means there is a significant shortfall [2]. Moreover, whilst the speed of fixed lines is anticipated to increase, cellular speeds, are on average, expected to offer far more bandwidth, given the increasing uptake of 5G cellular services, thus yielding more demand [3].

The use of the licence-free optical spectrum offers an experimental, yet attractive, solution with the potential to positively contribute towards future communications. By comparison to the congested RF spectrum, the amount of bandwidth required to support anticipated demand makes up a mere 0.8 percent of optical space [2], therefore offering copious resources for research opportunities.

Light-Fidelity (Li-Fi) is best defined as "a wireless communication technology that uses infrared and visible light for high-speed data communication" [2]; the technology is rather analogous to the inception of Wi-Fi, though has the advantage of being able to be deployed within environments where Wi-Fi is not suitable, in addition to having the ability to alleviate pressures within the RF spectrum by offering another medium to transverse. Li-Fi research, however, is largely constrained by its nascent use, particularly within niche domains, and as such, findings are somewhat speculative, limited and inconclusive.

The purpose of this paper is to assess the performance of Li-Fi over both a fixed line and cellular backhaul to substantiate if the technology is suitable in catering for the expected demand in network usage.

II. BACKGROUND INFORMATION

A. Suitable Environments

Whilst Li-Fi may be supported within a variety of locations, the primary use case resides within commonplace environments; namely that of home, office and educational facilities. Largely, this is because they are the environments in which existing wireless communication platforms - specifically Wi-Fi - mostly operates. Moreover, given the number of luminaires in situ of such locations [4], it is possible to make use of existing lighting infrastructure for providing a Li-Fi connection to end users [Fig. 1].

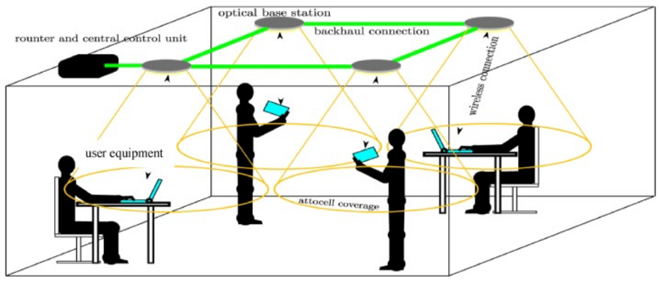

Fig. 1. Demonstration of Li-Fi communications [2].

B. Vulnerabilities

One of the significant drawbacks of Li-Fi is the inability of the emitting light to penetrate opaque objects [5]. As such, this may make communications challenging as signal would be displaced when users roam across varying areas of a location. Naturally, this may produce a cost issue as a vicinity would need multiple Li-Fi access points (APs) capable of redistributing the connection in parallel to receiver movement.

Second, there is conflicting evidence surrounding the possible interference of other light sources. For instance, sunlight is regarded as a "constant interfering signal" [2], though research suggests this may only degrade performance as little as 1.5-4.5 percent [6]. Furthermore, it is suggested that electrical and optical filters may be introduced to discard such interference, thus making the receiver(s) solely respondent to the light emitting from a Li-Fi transmitter [2], thereby mitigating such an issue.

III. TECHNICAL OVERVIEW

Li-Fi is supported by the unregulated resources of the optical spectrum to supply bandwidth of 780 THz, either over visible or invisible (infrared) light [Fig. 2]. Such bandwidth sums ten thousand more than that offered by the radio spectrum, thus more than supportive of the 6 THz required to support predicted demand.

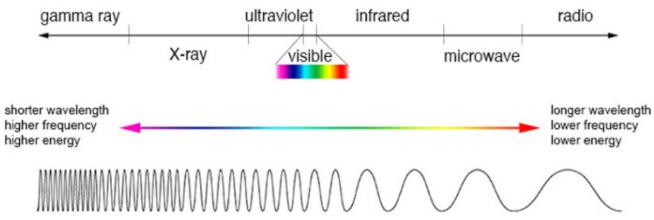

Fig. 2. Electromagnetic Spectrum [7].

In essence, the technical operation of Li-Fi is that of a binary string produced from the transmitter containing encoded data. Such data is encrypted and relayed to the receiver by way of illumination [Fig. 3], alternating between the state of 'on' and 'off' representing '1' and '0', respectively [8]. This is always at a rate that is imperceivable to the human eye, thus making any visible light appear static; "the lowest frequency at which the lights are modulated is in the region of 1MHz… [whereas] the refresh rate of a computer screen is about 100Hz; this means the flicker-rate of a Li-Fi light bulb is 10,000 higher… therefore, there is no perceived flicker" [2].

Within a traditional Li-Fi unit, the luminaire comprises of four distinct components; a Light-Emitting Diode (LED), a power amplifier (PA), a printed circuit board (PCB) and an enclosure in which they are contained [9]. An Ethernet port is found on the PCB and is used to facilitate a connection to the network; a microcontroller allows the flicker rate of the LED to be regulated based upon the material sent from the network connection, which is relayed by the PA to produce the source of light [10].

There is a significant variety of Li-Fi devices available on the market, with bi-directional speeds varying anywhere between 100 Mbps to 1 Gbps in commonly available consumer units [11]. By utilising an array of LEDs for parallel data streams, in addition to utilising multiple colours of the optical spectrum, there is an ability for such speeds to exceed 10 Gbps [12, 13], thus already capable of achieving abilities only now available with Wi-Fi 6 technology. It is conclusive, therefore, that given the advantages afforded to Li-Fi in its infancy, there is potential scope to exercise further technological advances to align with ever-changing user expectations.

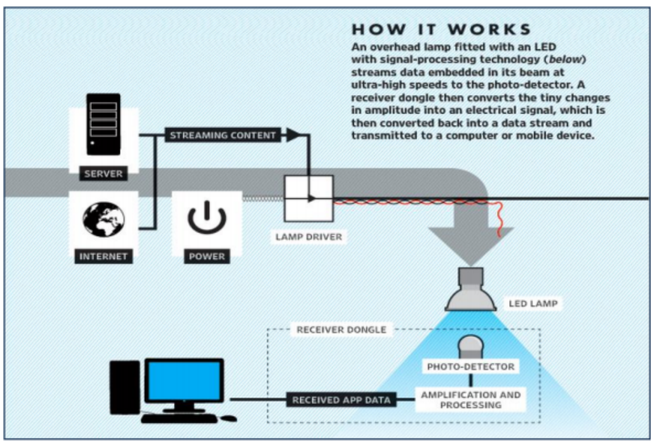

Fig. 3. How Li-Fi works [12].

The Institute of Electrical and Electronics Engineers (IEEE) are to publish its 802.11bb standard in relation to mass-market Li-Fi devices [Fig. 4]. It is expected that advances in research will mean a peak data rate of 5 Gbps can be comfortably obtainable, which offers a fair and realistic estimate by comparison to the 10 Gbps peak available in industry, when subject to more intricate conditions.

Standard	IEEE 802.11bb	IEEE 802.15.13	ITU G.vlc
Main target	Mass-market	Industry, enterprise	In-premise network
Peak data rate (Gbps)	5	10	2
Wavelength range (nm)	800 - 1000	190 - 10,000	190 - 5000
Multiuser	Yes	Yes	Yes
Handover	Yes	Yes	No
Date of completion	2021	July 2020	March 2019
Chipsets	No	No	Yes

Fig. 4. Standardisation of Li-Fi [14].

Dependant on the type of device, some Li-Fi models are equipped with a controller system [14, Fig. 5] to better manage the operation of multiple APs. One significant benefit to such a system is the technical security offerings that may be employed to bolster confidence of having a network that is greater protected. With this considered, network owners may administer user authentication (with optional active directory integration) [14] to enable connection between a Li-Fi transmitter and receiver. This offers a notable difference when compared to a standard Wi-Fi connection, given it would usually operate on the basis of a shared password, to which access is largely uncontrollable. By enabling user authentication, network administrators have a better understanding of whom is connected to their network and what activities they are undertaking on it.

Overall, the technical examination of Li-Fi systems affords them a rather favourable position, and should further research continue, there is no reason to suggest that further IEEE standards will not be formalised, and as such, the potential of a 10 Gbps bi-directional connection in mass markets may be very possible.

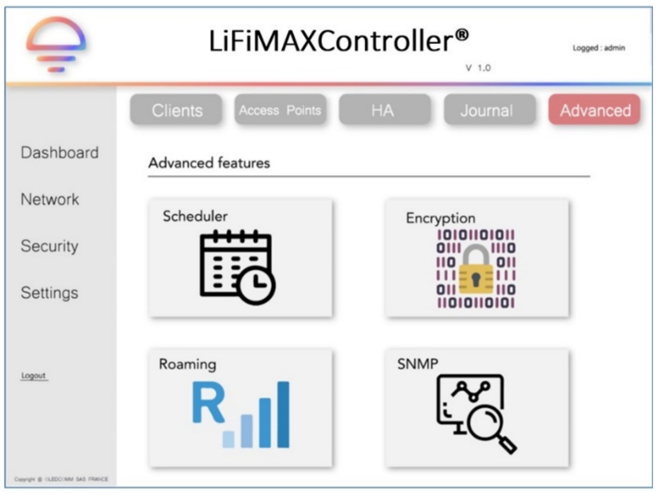

Fig. 5. Example of a controller system [15].

IV. Research Design

It is important to undertake a well-considered research design that accounts for rigorous and reliable methods to assist the authenticity of the produced outcomes. This section comments of the hypothesis, paradigm and methodology to be undertaken to best support this.

A. Hypothesis and Paradigm

Such hypothesis is that the optical spectrum would be suitable in aiding RF spectrum capacity. Until a suitable methodology can be established to return results to support this claim, the null hypothesis - relating to the disproval of such a notion - is the accepted present situation. Should the null hypothesis be proven false, future exploration into improving the results may be possible and justifiable. This research encompasses a positivist paradigm to account for a single truth or reality, in that if the statistical output accounts for disproval of the null hypothesis, then the actual hypothesis of the research would become true.

B. Methodology

The research is undertaken by way of field experiments using quantitative analysis given it is the most appropriate way to produce the most accurate and true to life results [16]. Li-Fi will be assessed over both a fixed line and cellular backhaul connection, with tests repeated three times to sum an average for increased reliability of findings. Moreover, the experiments are to take place across two sites and over a number of variables to account for both external and internal validity. 4G will be used given 5G is not available at the sites.

C. Site Survey

A survey of each site [Tab. I] allows key information to be accounted for [17] should it be necessary to account for it in shaping the implementation of the experiment [Fig. 6, Fig. 7].

TABLE I. Li-Fi Site Survey

Factor	**Li-Fi Site Survey**	
	Site 1	***Site 2***
Site	University Institition	Private Property
Type	Educational	Residential
Line	40 Mbps down / 10 Mpbs up	100 Mbps down and up
Size	10.5Lx 8.5W x 2.6H (M)	4.9Lx 3.6W x 2.3H (M)

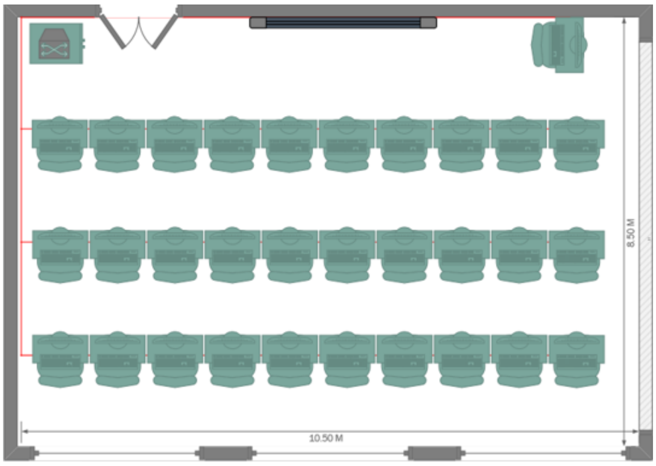

Fig. 6. Site 1 Floor Plan [not to scale]

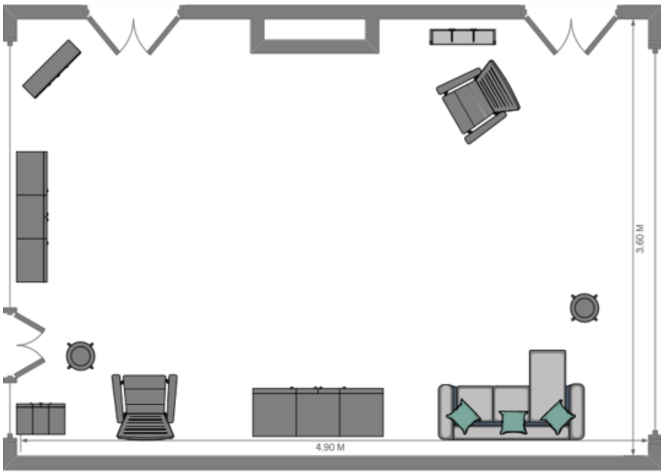

Fig. 7. Site 2 Floor Plan [not to scale]

D. Experimentation Variables

The research design takes into account a number of variables to better represent the overall findings attributable to the Li-Fi equipment used [Tab. II].

1) Location: The education facility offers a large open space with multiple users that could use the Li-Fi devices. By contrast, a home environemnt offers a smaller space with less users; comparing the data upholds the reliability and practicality of the data.

2) Distance: Geographical measurements allows the performance of Li-Fi to be assessed in its entirity; distance will be increased until the maximum space between desk and ceiling is reached. This will use both a recessed and a non-recessed shell surrounding the Li-Fi AP.

3) Line of Sight (LOS): Differences in data as a result of adjusting the LOS needs considering. Under realistic settings, a direct LOS between tranmitter and receiver is unlikely; distruptions to LOS by way of distance and physical objects is therefore necessary. This will, again, use both a recessed and a non-recessed shell surrounding the Li-Fi AP.

4) Lighting: Given the conflciting data surrounding the impact of light, the performance of Li-Fi will therefore be examined under bright light and darkness to yield a solid conclusion.

5) Connections: Simutaneous connections to the same Li-Fi AP will examine how bandwidth is divided between end devices and how this may affect the performance of the equipment's operation.

TABLE II. Li-Fi Equipment

Li-Fi Equipment	
Make and Model	***Properties***
Oledcomm LiFiMax	Light source: Infrared Download data rate: 100 Mbps Upload data rate: 100 Mbps Coverage: 90 degrees Maximum number of users: 16 Plug and Play: Yes Encryption: 128-bit AES

V. RESULTS AND DISCUSSION

The implementation was heavily aligned to the research design and accounted for all the proposed experimentation techniques. Overall, the experiments were completed successfully and produced some rather interesting conclusions. This discourse explores what can be understood from the results.

A. Li-Fi Compared over Distance

Within a fixed line setup, results remained largely consistent, with speeds not reducing until distance between transmitter and receiver was at a minimum – this is likely due to the saturation of the infrared light and the intensity of the connection. Moreover, results were wholly better at Site 1, almost probably because of the commercial infrastructure and capabilities of the backhaul, by contrast. Using 4G, outputs were worse in comparison, though this was a cited limitation of the project. Conversely, as over the fixed line, the results between sites using 4G remained consistent, highlighting the reliability of the Li-Fi system [Fig. 8].

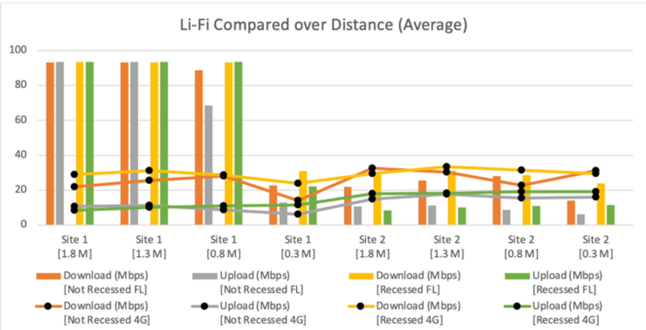

Fig. 8. Li-Fi Compared over Distance (Average)

B. Li-Fi Compared over LOS

Broadly, performance is lower than with a direct LOS, though still perfectly functional. Largely, speeds reduce as the distance between the transmitter and receiver widens. Common across both variables, a recessed connection was marginally better, likely because the light can focus on a given area without being lost to its surroundings. Both environements are, however, inclusive of lighter coloured surfaces, which naturally reflect lightwaves, and so it may be necessary to examine this using darker surfaces for a fairer judgement [Fig. 9].

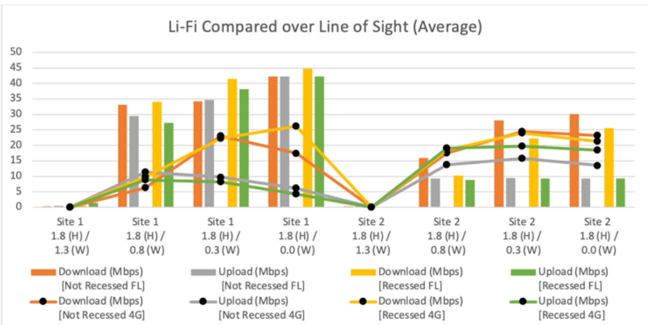

Fig. 9. Li-Fi Compared over Line of Sight (Average)

C. Li-Fi Compared over Disruption to LOS

Across both sites, and both backhauls, the variables acted the same; this presents clear validity. Specifically, by interrupting the signal, first with cardboard, and second with a laptop, the connection was lost. By contrast, when determining physical security through a glass window, the connection was still maintained, albeit at a much-reduced level, likely because of refraction. It is conclusive, therefore, that to confine the signal to a given area and have complete physical security, all surfaces must be opaque.

With this considered, it is thought that the movement of people would not present an issue, this is because there would be an element of distance between them and the AP as well as the supplementation of additional APs to facilitate uninterrupted coverage [Fig. 10].

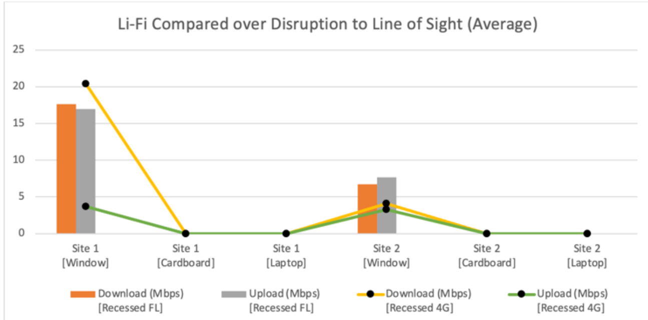

Fig. 10. Li-Fi Compared over Disruption to Line of Sight (Average)

D. Li-Fi Compared over Light

There was no notable difference within a change of lighting - this also suggests significant internal and external validly; first, because the variable of light has been seen to not impact on efficacy, and second, the results are mirrored across environments, thereby confirming the outputs [Fig. 11].

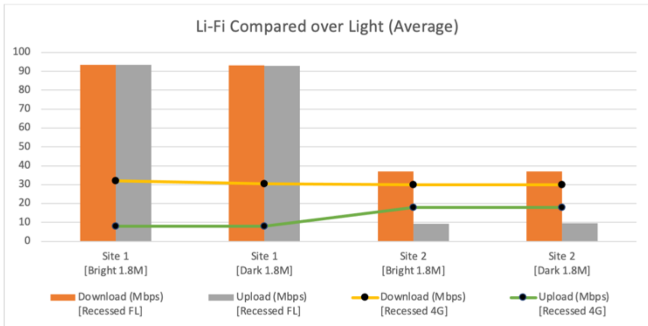

Fig. 11. Li-Fi Compared over Light (Average)

E. Li-Fi Compared over Simultaneous Connections

Given the Li-Fi AP can host multiple users, it was necessary to determine how multiple end devices would be supported. It can be interpreted that across a fixed line backhaul, at both sites, the bandwidth was divided between the end devices. This was not, however, an equal split despite running the tests in parallel, they did not finish concurrently, and as such, additional bandwidth then became available which skewed the internal validity of the results. By contrast, the 4G results are more representable as the bandwidth is already divided between connections of the cell site, thus broadly similar in output [Fig. 12].

Cumulatively, given these results, it may be wise to repeat such a variable in future and with a larger number of identical end devices to fully understand the data to produce a greater element of validity.

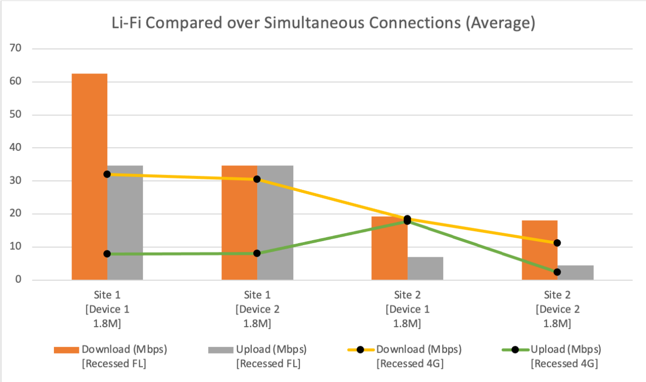

Fig. 12. Li-Fi Compared over Simultaneous Connections (Average)

VI. Future Work

Li-Fi has a valuation of $4.2bn with an estimated global growth of 74.6% predicted by 2025 [18], with the Gartner 'Hype Cycle' model presents Li-Fi as a technology that is "on the rise" [19]. However, it is commented that Li-Fi "will be adopted slowly, if at all" [20] and researchers should "focus on areas in which Li-Fi have advantages over more widely available technologies, such as Wi-Fi" [20], which, therefore, may justify a form of transitional period.

Considering this, Li-Fi should first be assessed using more capable APs, such as those supporting 1 Gbps speeds. This should take place under non-oversubscribed 5G backhauls to understand the impact of the latest generation of cellular technology; this will also facilitate use for different application types such as virtual and augmented reality. Secondly, this should be compared against the similarly capable and latest Wi-Fi 6 (802.11x) technology to determine which returns the preferable results. Lastly, additional research should extend to more environments to yield greater external validly; this may be complemented with roaming receivers in mobile devices to better assess LOS and bring about any differences in internal validity when such receivers become available.

VII. Limitations

One of the problems faced was the impact of the COVID-19 regulations; this meant the experiments were difficult to undertake to the fullest extent such as understanding the user experience of the Li-Fi devices. Second, whilst the Li-Fi model used did represent the best value for money, faster speeds could, however, have been obtained by using a more capable Li-Fi system. This, however, would have produced a cost issue when the capabilities of the Li-Fi system were not yet known, not to mention it making no difference to the available cellular backhaul because of the bottlenecks attributable to 4G technology.

VIII. Conclusion

In conclusion, the null hypothesis can be comfortably dismissed with the overall aim of this research met. There is, however, further scope to solidify the findings with future work; that is using more capable Li-Fi equipment alongside 5G, in addition to having more simultaneous connections to bolster confidence of reliability and practicality. Until that point, there is approximately twenty years until an alternative solution to the RF spectrum is required; this time can be used for further evaluation to ensure user experiences continue to be upheld.

References

[1] P.J. Winzer, D.T. Neilson, "From Scaling Disparities to Integrated Parallelism: A Decathlon for a Decade," *Journal of Lightwave Technology,* vol. 35, issue. 5, pp. 1099-1115, Mar 2017.

[2] H. Haas, "LiFi is a paradigm-shifting 5G technology," *Reviews in Physics,* vol. 3, pp. 26-31, Oct 2017.

[3] Cisco. "Cisco Annual Internet Report (2018–2023)," Cisco Systems., San Jose, CA, 2020.

[4] A. Sarkar, S. Agarwal, A. Nath, "Li-Fi Technology: Data Transmission through Visible Light," *International Journal of Advance Research in Computer Science and Management Studies,* vol. 3, issue 6, pp. 1-12, Jul 2015.

[5] F. Aftab, U. Khan, S. Ali, "Light Fidelity (Li-Fi) Based Indoor Communication System," *International Journal of Computer Networks and Communications,* vol. 8, issue 3, pp. 21-31, Jun 2016.

[6] M. S. Islim, M. Safari, S. Videv, H. Haas, "A proof-of-concept of outdoor visible light communications in the presence of sunlight," Expo. LED Professional Symposium, Bregenz, Austria, 2016.

[7] Labster (no date), *Electromagnetic spectrum* [Online]. Available: https://theory. labster.com/electromagnetic-spectrum/

[8] M. Chauhan, A. Kulai, "Li-Fi – Let There Be Light," *International Journal of Engineering Trends and Technology,* vol. 28, issue 4, pp. 163-165, Oct 2015.

[9] A. Lakhani, H. Gurnani, V. Vaniya, "Li-Fi Technology - A review on future data transmission technology at lightning speed," in *National Conference on Emerging Trends in Engineering and Technology*. Gujarat, India, 2016.

[10] R. Sharma, Raunak, A. Sanganal, "Li-Fi Technology - Transmission of data through light," *International Journal of Computer Technology and Applications,* vol. 5, issue 1, pp. 150-154, Jul 2015.

[11] F. Aftab, "Potentials and Challenges of Light Fidelity Based Indoor Communication System," *International Journal of New Computer Architectures and their Applications,* vol. 6, issue 3, pp. 92-102, Oct 2016.

[12] A. Chakraborty, T. Dutta, S. Mondal, A. Nath, "Latest advancement in Light Fidelity (Li-Fi) Technology," *International Journal of Advance Research in Computer Science and Management Studies,* vol 5, issue 12, pp. 47-53, Jan 2018.

[13] Nischay, "A Review Paper on Li-Fi Technology," *International Journal of Engineering Research and Technology,* vol. 5, issue 23, pp. 1-5, Apr 2018.

[14] B. Béchadergue, B. Azoulay, "An Industrial View on LiFi Challenges and Future," in *Conf. International Symposium on Communication Systems, Networks and Digital Signal Processing*, Porto, Portugal, 2020.

[15] Oledcomm (2018) *Our Products* [Online]. Available: https://www. oledcomm .net/our-products/

[16] K. Tanner, "Experimental Research," In K. Williamson and G. Johanson, Eds. *Research Methods : Information, Systems, and Contexts.* Kidlington: Elsevier, 2018, pp. 337-356.

[17] S. Farahani, *ZigBee Wireless Networks and Transceivers*. Oxford: Elsevier, 2008.

[18] IndustryARC (2019). *Li-Fi Market - Forecast (2020 – 2025* [Online]. Available: https://www.iindustryarc.com/Report/15025/LiFi-market.html

[19] S. Fabre (2018). *Hype Cycle for the Future of CSP Wireless Networks Infrastructure* [Online]. Available: https://www.gartner.com/en/documents/3885393/hype-cycle-for-the-future-of-csp-wireless-networks-infra/

[20] N. Jones and B. Ray (2018). *Emerging Technology Analysis: Approach Li-Fi With Caution Because Adoption Will Be Slow* [Online].. Available: https://www.gartner.com/en/documents/3878684/emerging -technology-analysis-approach-li-fi-with-caution/