Performance and Environmental Impacts Review of Li-Fi and Wi-Fi Technologies

C. W. D. Lumoindong[1], A. Muslim[2], B. M. Nasreddin[3] and M. Galina[4]
Electrical Engineering Department, President University
Jl. Ki Hajar Dewantara, Kota Jababeka, Cikarang Baru, Bekasi, Jawa Barat
[1]dlumoindong@ymail.com, [2]andremuslim@gmail.com, [3]mhm.bura@gmail.com, [4]miagalina@president.ac.id

Abstract: Nowadays, internet connectivity is one of the staple things in human lifestyle, especially for those who live in cities. There are a lot of ways to connect to the internet, and one of them is using Wi-Fi (Wireless Fidelity) connection. Wi-Fi connection is seen as the most reliable connection, until Li-Fi (Light Fidelity) technology is coined in 2011. Li-Fi uses visible light as data transfer medium instead of radio frequency (RF) signal used by Wi-Fi. Theoretically, Li-Fi is able to reach hundred times of Wi-Fi connection speed due to their use of light as data transfer medium. Li-Fi is also expected as a solution to environmental problems caused by Wi-Fi. The RF signal used by Wi-Fi can cause some environmental problems such as growth inhibition and diseases to organisms including humans. The visible light used by Li-Fi is expected to cause minimal effects to the environment, as Li-Fi uses common LED light bulbs which are used as home lighting apparatus. In this review, by using descriptive research methodology the performance and environmental impacts of both Wi-Fi and Li-Fi are analysed to determine whether Li-Fi is really capable to be a 'greener' replacement to Wi-Fi technology. As the conclusions, performance wise Li-Fi is expected to be able to provide faster connection than Wi-Fi. In terms of energy consumption, Li-Fi has a lower energy consumption, a wider range of usage, a greater security, and less environmental impact, Li-Fi can be seen as a 'greener' yet more efficient technology compared to Wi-Fi.

Keywords: *Wi-Fi, Li-Fi, Telecommunications, Wireless, Environmental.*

Abstrak: *Dewasa ini, koneksi internet adalah salah satu kebutuhan dan gaya hidup manusia, terutama bagi mereka yang tinggal di wilayah perkotaan. Ada banyak cara untuk terhubung ke internet, salah satunya melalui koneksi Wi-Fi. Koneksi Wi-Fi dianggap sebagai salah satu koneksi yang terpercaya, hingga teknologi Li-Fi akhirnya mulai diperkenalkan pada tahun 2011. Li-Fi menggunakan cahaya tampak sebagai medium dalam perpindahan data, tidak seperti Wi-Fi yang menggunakan sinyal RF (Radio Frequency). Secara teoritis, Li-Fi dapat mencapai ratusan kali kecepatan Wi-Fi karena penggunaan cahaya sebagai medium perpindahan data. Li-Fi juga diperkirakan mampu mengatasi masalah-masalah lingkungan yang disebabkan oleh Wi-Fi. Sinyal RF yang digunakan oleh Wi-Fi dapat menyebabkan berbagai masalah lingkungan seperti hambatan pada pertumbuhan dan penyakit pada makhluk hidup, termasuk manusia. Cahaya tampak yang digunakan oleh Li-Fi diperkirakan akan menyebabkan dampak yang minimal terhadap lingkungan karena Li-Fi menggunakan lampu LED yang biasa digunakan untuk penerangan rumah, sehingga Li-Fi dianggap sebagai teknologi yang lebih ramah lingkungan daripada Wi-Fi. Dalam kajian ini, dengan menggunakan metode penelitian deskriptif performa dan dampak terhadap lingkungan dari Wi-Fi dan Li-Fi akan dianalisa untuk menentukan apakah Li-Fi benar-benar mampu menjadi pengganti teknologi Wi-Fi yang lebih ramah lingkungan. Sebagai kesimpulan, kinerja Li-Fi diharapkan dapat memberikan koneksi yang lebih cepat dibanding Wi-Fi. Dalam hal konsumsi energi, Li-Fi memiliki konsumsi energi yang lebih rendah, penggunaan yang lebih luas, keamanan yang lebih baik, dan dampak lingkungan yang lebih sedikit. Pada akhirnya Li-Fi dapat dilihat sebagai teknologi 'hijau' dan lebih efisien dibandingkan dengan Wi-Fi.*

Kata Kunci: *Wi-Fi, Li-Fi, Telekomunikasi, Nirkabel, Lingkungan.*

INTRODUCTION

Nowadays, human can easily socialize with one another. There are many platforms that provided some sort of application for human to communicate each other. For example, application for video calling and sending short messages. Not only to socialize, but also to do other activities such as shopping and study. All of this can be achieved conveniently by internet. There are many types of internet connectivity, one of them is using wireless network or Wi-Fi (Wireless Fidelity). The term of wireless because Wi-Fi is using Radio Frequency (RF) to transmit data signals (Foster & Moulder, 2013). Wi-Fi technology is able to reach a bandwidth speed of 50-100 Mbps (Cisco, 2018).

However, the average downlink data transfer rate of commercial Wi-Fi is 10.9 Mbps and uplink speed is 2.8 Mbps (Kolhe & Mandavgane, 2017) which is relatively low for this millennial era.

As time comes by, user demand for data continues to grow at an exponential rate and causing the use of devices with internet connectivity is increased Since the radio frequency (RF) resources is limited, the increasing of internet usage made the capacity of WiFi is reduced. Due to the limitations of Wi-Fi, Li-Fi comes into surface. Rather than Wi-Fi that use radio frequency to operate, Li-Fi is using an LED (Light Emitting Diode). As stated by German scientist Hass and Islim (2017), Li-Fi is theoretically able to achieve a bandwidth speed of 5 Gbps using select laboratory equipments.

Currently Wi-Fi technologies are widely used around the world, approximately 61% of American households have Wi-Fi connectivity installed (Thota, 2012). However, exposure of RF may pose some threats to human body. Although the exposures are far from the international limitation (IEEE, 2006), prolonged exposure from multiple sources can be hazardous. Therefore, Li-Fi technology is prospected to replace Wi-Fi, since Li-Fi utilizes visible light which poses minimal harm. The utilization of visible light, which is more environmental-friendly compared to RF also makes Li-Fi technology seen as a 'greener' technology compared to Wi-Fi.

This review is centered towards the comparison of Wi-Fi and Li-Fi technologies in terms of their performance and environmental impacts. The result may determine whether Li-Fi technology is suitable to be an environmental-friendly replacement to current Wi-Fi technology.

METHODOLOGY

As mentioned before that the purpose of this review is to analyze the performance and environmental impacts of both Wi-Fi and Li-Fi and determine whether Li-Fi is really capable to be a 'greener' technology replacing Wi-Fi technology. by using descriptive research methodology the performance and environmental impacts of both Wi-Fi and Li-Fi are analysed to determine whether Li-Fi is really capable to be a 'greener' replacement to Wi-Fi technology, which will describe as follows.

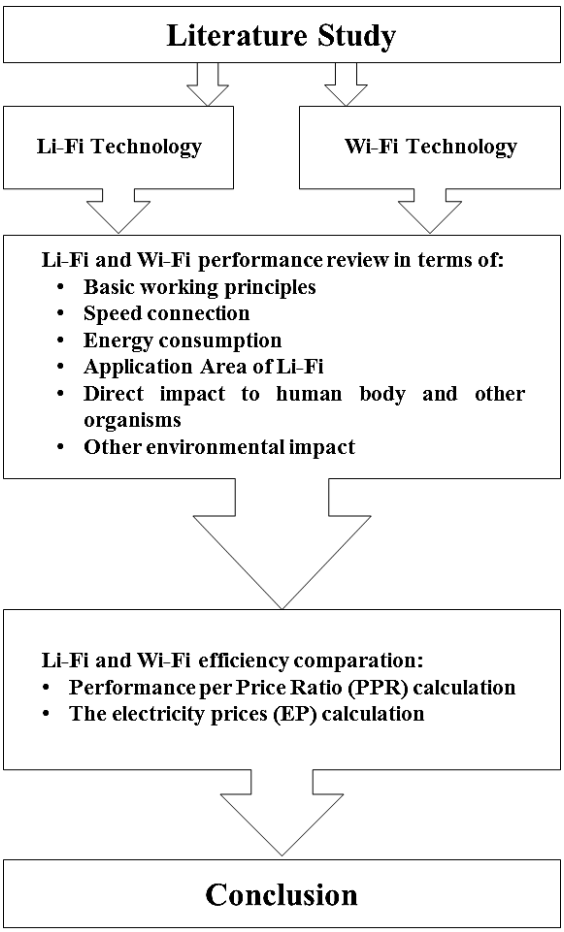

Figure 1. Research Methodology

LITERATURE REVIEW

Definitions and Working Principles

Wireless data transfer can be achieved utilizing any types of electromagnetic wave. Basically, a wave is a disturbance that can travels from one location to another. Because wave can propagate, it can carries information along the way. The great thing about electromagnetic wave is that it does not require a medium to propagate.

Wi-Fi is a commercial name that used for wireless networking technology that certified in accordance with the standards issued by the Institute of Electrical and Electronics Engineers (IEEE) (Foster & Moulder, 2013). These standards are adopted by Wi-Fi Alliance, which is a group of wireless connectivity-related industries with standart defined IEEE 802.11. In addition, the device or router with a "Wi-Fi certified" access point should allow any "Wi-Fi certified" devices to connect to a network and vice versa. Wi-Fi utilizes electromagnetic radiation in the range of Radio Frequency to send the data signal. The illustration of Wi-Fi working principle is shown in Figure 2.

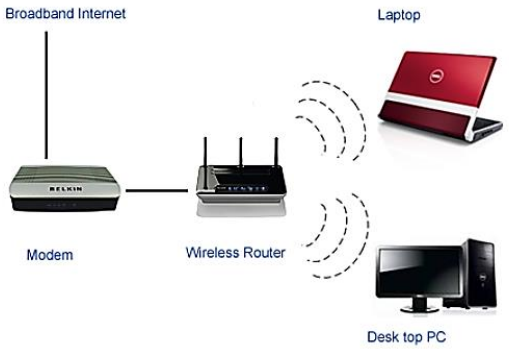

Figure 2. Wi-Fi Working Principle
Sources: (Broadband Analyst UK. 2018)

On the other hand, Li-Fi or called D-LIGHT by its inventor is a communication system that use LED as a things to transmit the signal and it is operate at visible light band (Ekta & Kaur, 2014). Li-Fi (light Fidelity) technology a term defined by IEEE 802.15 standardization comittee, is based on Visible Light Communication (VLC) principles for data transmission, The visible light (VCL) is unregulated and unlicensed THz spectrum, which is sending the data by the light at speeds undetectable to human eyes. VLC is free from any health concerns, and it does not cause any electromagnetic interference harmed to human body, so it claimed as eco-friendly green technology. Both Wi-Fi and Li-Fi has its own frequency to operate. Wi-Fi commonly uses 2.4-5GHz to operate (Shetty, 2016). Furthermore, in Wi-Fi technology it use router to transmit the data in the range of RF. So, the router or called as an access point transmit the signals and device with a wireless card can recognize those signal and translate it into useful information. Li-Fi, in other hand, use visible light band to operate.

Li-Fi technology uses LED light source as both a transmitter and a receiver (sometimes photodiode are also used) in data transmission process. The data signal is represented in binary code which are 1's and 0's, 1's means the LED is on and 0's means the LED is off. VLC uses brisk pulse of light that cannot be followed by human eye to transmit the data (Ekta, 2014). In addition, a photo detector is installed at the device to receives the signal and translate it to original data. Therefore, the brightness LED and the photo detector are the main component of Li-Fi communication system. The illustration of Li-Fi working principle is shown in Figure 3.

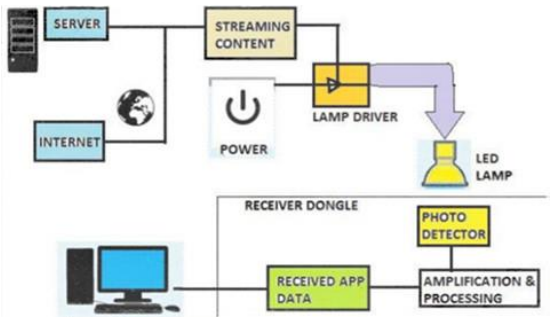

Figure 3. Li-Fi Working Principle
Sources: (Sodhi, A. & Johnson, J, 2015)

Technical Informations

Wi-Fi operates at 2.4-5 GHz RF (Shetty, 2016). Most Wi-Fi connections in Indonesia operate at 2.4 GHz, while recent routers are capable to operate at 5GHz. The bandwidth of Wi-Fi connections are capped around 50-100 Mbps regardless of their operating frequency (Mutthamma, 2013). One of the most used Wi-Fi router in Indonesia is FiberHome AN5506-04 (Figure 4). This particular router is

claimed to have under 15 watt power usage (FiberHome, 2011).

Figure 4. FiberHome AN5506-04 Wi-Fi Router
Sources: (FiberHome International Co., Ltd. 2011)

On the other hand, the maximum recorded bandwidth of Li-Fi connection transmitted by a single colour LED light bulb is at 1.6 Gbps (Sharma et al., 2014). Li-Fi operates in the range of visible light spectrum (390-700nm), which is equal to 430-790 THz (Ghosal & Panda, 2014).

Assuming that most recent Wi-Fi technology operates at 5 GHz, the minimum operating frequency of Li-Fi Li-Fi is 86,000 times of Wi-Fi operating frequency. Furthermore, Li-Fi technology is expected to operate using one or more LED light bulb(s) which intensity differs faster than the capability of human eye, so human will not detect that the LED is actually flickering. This kind of LED light bulb can be used as a normal light source.

For calculations purposes, the LED light bulb with 33 W wattage. The efficiency of each technology is calculated using Performance per Price Ratio (*PPR*). The equation used to calculate *PPR* is expressed in Equation 1 as below (Oklobdzija, 2008).

$$PPR = \frac{P_f}{P_r} \qquad (1)$$

In Equation 1, P_f (Performance) stands for the maximum expected bandwidth speed, while P_r (Price) stands for the combination of hardware and electricity price as shown in Equation 2. The hardware price (H_P) is the average of required hardware prices in thausands Rupiah, which are Wi-Fi router for Wi-Fi technology and LED light bulb with maximum wattage for Li-Fi technology.

The prices are calculated in Rupiah based on newest price update and excluding basic hardware such as cables. The electricity prices (E_P) are calculated using Indonesian base prepaid electricity price per kWh (kilowatt hour) in Rupiah. The power consumption of Wi-Fi router is based on the average of usual router consumption, which is 9 W (Chiaravalloti, et.al, 2011).

$$P_r = (H_P \times 15\%) + (E_P \times 85\%) \qquad (2)$$

Environmental Impacts

As Wi-Fi transmits data using radio waves, the environmental hazards posed by Wi-Fi is similar to those posed by radio waves. Foster and Moulder (2013) stated that prolonged Wi-Fi exposure may affect fertility, pregnancy outcome, brain development, stress level, and immune system. This was based on an experiment where subjects (mice) are exposed to Wi-Fi signal for 1-2 hours a day for 10-50 days. Redmayne and Johansson (2015) claimed that the effects of Wi-Fi (as one of the forms of electromagnetic field) vary by age. Their study showed that young people are more sensitive to electromagnetic field compared to adults, and the use of Wi-Fi in schools are a high level threat to children health. RF-EMF wave also known as the cause of growth inhibition, especially on plants and insects (90%), birds (70%), and other vertebrates (56%) (Cucurachi et al., 2012).

RF signals are also disruptive if used underwater. Kim, et al (2014) stated that RF signals, including Wi-Fi, are a form of acoustic signals which can disrupt underwater ecologies. This disruption may lead to growth inhibition as found on past studies involving plants and animals.

On the other hand, the effects of Li-Fi to environment are similar to the effects of visible light. The most common one is pigmentation, which is caused by UV rays from visible light. The UVA1 ray in the

range of 300-400nm is known as the cause of skin browning and fading after 2 weeks of irradiation (Mahmoud et al., 2010). In the same experiment using Visible Light range (400-700nm), the pigmentation was spontaneous and surrounded by erythema (skin redness) which disappeared in less than 2 hours. The other negative effect of Li-Fi is from the LED light. LED lights tend to produce blue lights, which are the most damaging light to human eyes as shown in Figure 5 (Ticleanu & Littlefair, 2015). Fortunately, blue lights can only reach the retina if the sources (in this case the LED light bulbs) are directly viewed.

Figure 5. Blue Light Penetration to Retina
Sources: (Ticleanu & Littlefair, 2015)

The other possible hazard is if the LED is broken. Broken LED lights may emit arsenic vapour. However, only a small amount of arsenic concentration was found during testing of recently produced LED lights and the vapour itself is non-lethal.

Application Area of Li-Fi

As stated before, Li-Fi technology utilizes visible light instead of RF, which is used in Wi-Fi technology. Due to the absence of RF in Li-Fi technology, it can be applied to Wi-Fi restricted areas, thus expanding its usage area. The most important area which is restricted to Wi-Fi is hospitals, due to the possibility of RF interference in medical apparatus. This interference will not happen if Li-Fi is used, since visible light will not cause such interference (Sodhi & Johnson, 2015).

Since Li-Fi shares the same equipments with home and street lightings, it can greatly support smart home and smart city projects. When used for smart home concept, Li-Fi can easily connects all supported home appliances which get into its line-of-sight. In smart city concept, conventional traffic lights can be augmented with Li-Fi technology to enhance traffic management (Telecommunications Engineering Center; Sodhi & Johnson, 2015), especially for cities struggling with traffic problems.

Moreover, Li-Fi can be used both in flights and underwater. Providing reliable connectivity to these two areas are previously challenging and most of the viable options are extremely expensive (Kim *et al*, 2014). With Li-Fi, people can easily connect to the internet while in flights since it does not interfere with the pilot's radio (Sodhi & Johnson, 2015). And underwater, Li-Fi can penetrate deeper surfaces without disrupting marine ecologies due to the usage of visible light (Kim *et al*, 2014).

Basically, Li-Fi can be used in almost any sectors which Wi-Fi is prohibited, including gas and oil facilities. These flexibilities also contribute to the faster development of Li-Fi technology as the successor of Wi-Fi.

RESULTS AND DISCUSSION

As stated on the literature section, since Li-Fi does not require additional hardware, then the electricity consumption theoretically lower than Wi-Fi. That is why Li-Fi can be assumed as a 'greener' technology compared to Wi-Fi.

Table 1. Wi-Fi and Li-Fi Price Components

Technology	H_P (Thousands IDR)	E_P (IDR)
Wi-Fi	245	21.2715
Li-Fi	97.5*	48.411

*: The H_P of Li-Fi is halved due to the 'shared usage' with home lighting appliances

From the electricity prices (E_P) perspective, it can be seen that Li-Fi has value much lower than Wi-Fi. The

electricity prices (E_P) are using Indonesian base prepaid electricity price per kWh (kilowatt hour) in Rupiah, excluding basic hardware such as cables. Base on the equation (1) and (2), we can calculate the price components for both technologies as listed in Table 1, while the efficiency components are listed in Table 2, and it calculated based on newest price update which currently is Rp 1,467.00

Table 2. Wi-Fi and Li-Fi Efficiency Parameters

Technology	P_F(Mbps)	P_R	PPR
Wi-Fi	100	47.973	2.085
Li-Fi	1600	55.774	28.687

From Table 2, Li-Fi has approximately 24 times of the *PPR* of Wi-Fi. That means Li-Fi is a prospective replacement for Wi-Fi as Li-Fi is expected to be faster (16 times faster than Wi-Fi) and consumes less electricity (due to the 'shared usage' between wireless network transmitter and home lighting). Therefore, Li-Fi usage will contribute in reducing the electricity and generator fuels (e.g. Coal, Oil, and Gas) usage. Furthermore, Li-Fi usage will reduce the pollution caused by electric generators.

Table 3. Wi-Fi and Li-Fi Comparison Table

Parameters	Light Fidelity (Li-Fi)	Wireless Fidelity (Wi-Fi)
Data transfer speed	>1Gbps	50-100 Mbps
Operating frequency	Hundreds of Tera Hz	2.4GHz or 5 GHz
IEEE Standart Comitttee	IEEE 802.15	IEEE 802.11
Medium used for data transfer	Use light as carrier (VLC)	Use Radio spectrum (RF)
Spectrum Range	10,000 times broad in comparison to RF	Less than VLC spectrum
Cost	Cheaper, doesn't need license (free band)	Expensive (due to spectrum charges)
Efficiency	More, LEDs consume less energy and highly efficient	Less, RF consume high amount of energy
Power consumption	Less	More
Environment Impact	Less impact than RF. VLC is free from any health concerns, and it does not cause any electromagnetic interference harmed to human body	Wi-Fi utilizes electromagnetic radiation in the range of Radio Frequency to send the data signal.

Based on the technical comparation, PPR (Performance per Price Ratio), and their effects on environment, Li-Fi technology has its advantage in all discussed aspects against Wi-Fi technology. Li-Fi technology has better speed with lower electricity usage (due to their 'shared usage' with home lighting appliances) and more environtmental-friendly as shown in Table 3.

CONCLUSION

A noticeable hidden cost of Internet connectivity usually goes unstated (if not forgotten), but it relates to the physical environment in which the connection should be housed. The said hidden cost includes, but not limited to health, mental, and environmental cost. These costs are triggered by some factors, including performance, energy consumption, and technology used. Li-Fi, which uses visible light spectrum, are able to achieve this higher speed due to their higher operating frequency and the fact that light travels faster than radio wave. Performance-wise, Li-Fi is expected to be able to provide approximately 16 times faster connection than Wi-Fi. Due to the fact that it uses visible light spectrum instead of RF, Li-Fi has a wider range of usage. Li-Fi has the

potential to provide a reliable internet connectivity in hospitals, power plants, petrochemical plants, airplanes and other Wi-Fi restricted places.

In terms of energy consumption, Li-Fi has a better PPR, which means that Li-Fi can deliver a better connection using the same amount of electricity compared to Wi-Fi. Li-Fi has a lower energy consumption, which later contribute to reduced pollution from electric generators, which mainly use coal, oil, and/or gas. By reducing the electricity demands, the use of coal, oil, and/or gas to generate electricity can be reduced. Li-Fi may affect human skin and vision, but the increased efficiency means less exposure of light is needed to reach the customer level of performance. LED light producers are also keen on perfecting their products to reduce the effects of UV and blue lights emitted from their bulbs, so it is not a major concern.

The use of visible light spectrum also means that Li-Fi has smaller impact to the environment. As known, there was very little impact caused by visible light spectrum to other organisms such as plants, animals, and their ecosystem. So, as LIFI offers greater security, reduced power consumption, and less environmental impact, Li-Fi can be seen as a 'greener' yet more efficient technology compared to Wi-Fi.

REFERENCE

Chiaravalloti, S., Idzikowski, F., & Budzisz, Ł. (2011). *Power Consumption of WLAN Elements.* Berlin: Technische Universität Berlin.

Cisco. (2018). *802.11ac: The Fifth Generation of Wi-Fi*. Retrieved from https://www. cisco.com/c/dam/en/us/products/collateral/wireless/aironet-3600-series/white-paper-c11-713103.pdf

Cucurachi, S., Tamis, W. L. M., Vijver, M. G., Peijnenburg, W. J. G. M., Bolte, J. F. B., & de Snoo, G. R. (2012). A Review of the Ecological Effects of Radiofrequency Electromagnetic Field (RF-EMF). *Environ mental International.* Vol. 51, 116-140.

Ekta, & Kaur, R. (2014). Light Fidelity (LI-FI)-A Comprehensive Study. *International Journal of Computer Science and Mobile Computing*, Vol. 3, 475-480.

FiberHome International Technologies Co., Ltd. (2011). *AN5506-04F GPON Platform Equipment ONU (Optical Network Unit).* Retrieved from http://www.supri wireless.com.br/images/Produtos/Manual/AN5506-04A.pdf

Broadband Analyst UK. (2018). *Guide to wireless router setup configuration.* Retrieved from https://www.broadbandanalyst.co.uk/guides/wireless-networking/

Foster K. R., & Moulder, J. E. (2013). *Wi-Fi and Health: Review of Current Status of Research. Health Physics*, Vol. 105, 561.

Ghosal, B., & Panda, A. K. (2014). Li-Fi a Green Energy Alternative. *International Journal of Computer Applications*, Vol. 95, 11.

Institute of Electrical and Electronics Engineers (IEEE). (2006). *C95.1-2005 - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.* Retrieved from https://ieeexplore.ieee. org/document/1626482/

Kim, H., Sewaiwar, A., & Chung, Y. (2014). Shore-to-Sea Maritime Communication with Visible Light Transmission. *Recent Advances in Electrical Engineering and Computer Science*. Retrieved from http://www.inase.org/library/2014/russia/bypaper/CCCS/CCCS-10.pdf

Kolhe, A. B. & Mandavgane R. N. (2017). A Review: Wireless Communication Using Li-Fi. *International Journal on Recent and Innovation Trends in Computing and Communication*, Vol. 5, 21, 24.

Mahmoud, B. H., Ruvolo, E., Hexsel, C. L., Liu, Y., Owen, M. R., Kollias, N., Lim, H. W., & Hamzavi, I. H. (2010). Impact of Long-Wavelength UVA and Visible Light on Melanocompetent Skin. *Journal of Investigative Dermatology* Vol. 130, 2092–2097; doi:10.1038/jid.2010.95; published online 22 April 2010.

Mutthamma, M. (2013). A survey on Transmission of data through illumination- Li-Fi. *International Journal of Research in Computer and Communication Technology*, Vol 2 (12).

Sharma, R. R., Raunak, & Sanganal, A. (2014) Li-Fi technology. *International Journal of Computer Technology & Application*. Vol 5 (1), 50-154.

Shetty, A. (2016). A Comparative Study and Analysis on Li-Fi and Wi-Fi. *International Journal of Computer Applications*, Vol. 150, 43.

Sodhi, A., & Johnson, J. (2015). Light Fidelity (LI-FI) - The Future of Visible Light Communication. *International Journal of Engineering Research and General Science*. Vol 3 (2), 117-128.

Telecommunications Engineering Center. *Study Paper on LiFi (Light Fidelity) and its Applications.* Retreived from http://tec.gov.in/pdf/Studypaper/lifi%20study%20paper%20-%20approved.pdf

Thota, K. Quoted in Business Wire, April 04, 2012 [online]. Available at www.businesswire.com/portal/site/home/permalink/?ndmViewId=news_view&newsLang=en&newsId=20120404006331&div=-1063439563. Accessed 22 July 2018.

Yin, L., Islim, M. S., & Hass, H. (2017). *LiFi: Transforming Fibre into Wireless*. Edinburgh, UK.

Oklobdzija, G, Vojin (2008). *The computer Engineering Handbook*, Second Edition, Boca Raton: CRC Press.

Redmayne, M., & Johansson, O. (2015). Radiofrequency Exposure in Young and Old: Different Sensitivities in the Light of Age-Relevant Natural Differences. Rev. Environ. Health Vol 30, 323–335. http://dx.doi.org/10.1515/reveh-2015-0030.

Ticleanu, C., & Littlefair, P. (2015). A Summary of LED Lighting Impact on Health. *International Journal of Sustainable Lighting*. Vol 1, 3–4.