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LIFI – A NEW PARADIGM OF WIRELESS COMMUNICATION

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Abstract

Over the past 12 years, significant study has been put into investigating alternate regions of the electromagnetic spectrum that could be able to divert a sizable amount of network traffic away from the radio frequency (RF) domain, which is already overloaded. Due to recent advancements, optical wireless communication (OWC) has emerged as a practical alternative solution to the problems of the impending radio frequency RF spectrum crisis, especially in some locations and circumstances. The majority of mobile data traffic nowadays is spent inside, where light fidelity (LiFi), which is connected to visible light communication (VLC), offers several distinct benefits and efficient solutions to the numerous problems with wireless communication. The majority of the research, advancements, and applications made so far are summarised in the current paper, which also examines various implementations, challenges, the VLC IEEE standard, data modulation methods for the VLC, and the newly developed optical wireless communication technology known as LiFi.

Keywords - *OWC, VLC, LiFi, modulation techniques*

1. INTRODUCTION

The infrared, visible, and ultraviolet bands are all included in the optical frequency range, which extends from 300 GHz to 30 PHz (Peta Hertz). This vast spectral range is similar to the 300 GHz that the RF band represents.

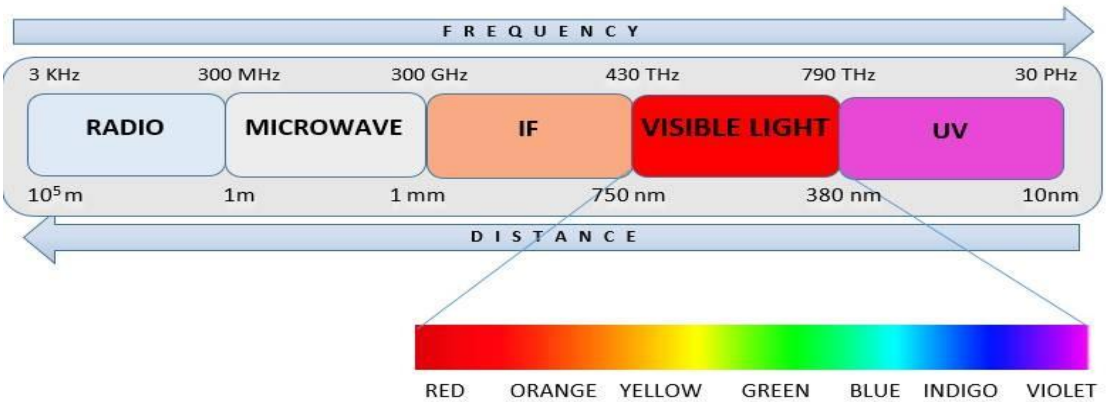


Figure 1. Electromagnetic spectrum

The optical range is indicated on a portion of the electromagnetic spectrum in Figure 1. Optical wireless communication (OWC) systems provide a number of important technological and practical advantages, including low power needs, much higher bandwidth capacity, good security, tolerance to electromagnetic interference, and tolerant spectrum.[1] OWC may be used for a wide range of communication applications, starting with millimeter-range connections made through outside kilometres links within integrated circuits. The development of visible light communication (VLC) as a point-to-point data transmission method sparked early standardisation efforts as part of IEEE 802.15.7.[2]. In order to integrate LiFi, this standard is really still being changed. In order to provide seamless changeover between access points, LiFi uses a full wireless network technology that supports bi-directional multiuser communication. It also uses many access points to construct a wireless network of extremely tiny optical attocells. LiFi is designed to take the place of the well-known, congested, and/or restricted radio wave communication in specific locations and circumstances. LiFi transmits data using light emitting diodes (LEDs). According to published information, Japan's M. Nakagawa Laboratories introduced the VLC idea for the first time in 2003; the VLC ID System Development Kit has been offered there since 2012.[3-5]. They currently perform much of their studies using underwater VLC. At a 2011 TED Talk, Professor Harald Hass of the University of Edinburgh introduced the term "LiFi" VLC technology. As a result of the demonstration's use in practise, the concept's comparison to Wi-Fi caused it to gain popularity quickly. His speech has had more than 2,45 million views as of this writing, demonstrating the topic's widespread popularity.

Many technological and commercial accomplishments have been noted as a result of Harald Hass' presentation; one of the most intriguing is Velmenni, a high-tech hardware firm founded in Delhi and Tartu, Estonia, in January 2014. Currently, Velmenni builds VLC connections that have uses in aviation and can broadcast data at high speeds up to 20 metres. They will submit their concept to the Australian Airbus BizLab. LiFi's weight advantages over Wi-Fi and connected devices like seatback displays were vital to Airbus. In a demonstration at ORANGE Labs in February 2011, European scientists from Germany, Greece, France, Italy, Austria, Slovenia, and the UK worked as part of the OMEGA consortium to send data at a rate of 100 Mbit/s utilising 16 LEDs in the ceiling that illuminated more than 10 square metres. [6].

The University of Strathclyde led the UK consortium EPSRC (Engineering and Physical Sciences Research Council) in the development of tiny, micron-sized LEDs, which have a number of significant advantages. First, they flicker on and off 1,000 times faster than larger LEDs, allowing them to transmit data more quickly, and second, 1,000 micron-sized LEDs can fit into the same space as a single larger 1mm LED. These small LEDs function as individual communication channels.[7].

ByteLight, a startup business with venture capital funding, started their project for indoor location services utilising VLC in 2011. A few years later, in 2015, Acuity purchased their patent portfolio and other intellectual property (IP). The USA business LVX System released its commercial product around the same time and, in 2015, signed a Space Act Agreement (SAA) with NASA to conduct research and development for use on NASA missions, including upcoming deep space expeditions. A positioning system based on VLC was created by the American corporation Qualcomm and debuted in 2016. Leading participants in the LED lighting ecosystem, like Acuity Brands, have adopted this technology because it can enable a wide variety of indoor positioning applications in commercial, office, and industrial contexts.[8]. A high security, electromagnetic compatibility (EMC), and high precision location information platform for smartphones and tablets employing LED illumination were introduced by the Japanese business Outstanding Technology in 2016. In 2016, the Indian students from Mangalore Institute of Technology and Engineering in Moodabidri, who had previously earned the third place in the seventh annual edition of the UNISYS All India Project Competition Cloud 20/20, had successfully transmitted data using light sources. They employed three-color Triplet LiFi in their project, with each colour carrying a distinct data stream. VLC applications in children's clothing and toys, as well as an indoor VLC system based on networked light bulbs, were shown by the Swiss team Disney Research.[9,10] .

A credit-card-sized embedded Linux platform with an LED front-end is the foundation of the OpenVLC project, which intends to create open-source, software-defined technology focused on creating concepts like LiFi [11]. At the 2014 Mobile World Congress in Barcelona, the British company pureLiFi unveiled the Li-1st and announced ambitions to commercialise LiFi devices developed in collaboration with LED manufacturer Lucibel. A modulator that attaches to the light fixture makes up this system, and a USB dongle is used to attach a computer or television. Additionally, a collaboration with Apple was revealed, allowing iPhones to use LiFi through the built-in camera. Recently, the setup of LiFi hotspots for internet access was shown by the Dubai-based operator Du and business Zero.1.

Another notable manufacturer, France's Oledcomm, introduced LiFi devices to the market in 2012. They outfitted a museum in Europe and used them in retail (Leclerc) and the Paris Metro .On May 21, 2015, Carrefour implemented a LiFi system at a hypermarket in Lille with the help of Philips, enabling shoppers to find the items that are on sale. This optical technology was created and the BeamCaster concept was introduced in April 2014 by RiT Technologies, a branch of the Russian business Stins Coman. A router that can send a signal using a laser beam up to 7-8 metres away is the key component of the network. Eight devices simultaneously broadcast the signal at 1.25GBps speed to various areas of a workplace. Sisoft, a software development company in Mexico, outperformed a Scottish research team led by Harald Haas in achieving a 10 Gbps data transfer ratio across a light spectrum emitted by LED lamps. Sisoft is now capable of transmitting audio, video, and Internet data using light emitted by LED lamps. Even Arduino code is available on GitHub allowing builders to create VLC setups at home. The "internet of lights" (IoL) technology and applications are also being developed by major international companies including Philips, Toshiba, Samsung, GE, LG, Innotek, Panasonic, Sharp, Cisco, Rolls Royce, Airbus, and eldoLED, a subsidiary of Acuity Brands.[12]

2. STRENGTH & WEAKNESS OF LI-FI

LiFi has advantages and disadvantages that put it in competition with other industry-specific technologies like RFID and iBeacons as a potential replacement for Wi-Fi radio waves' impending congestion and wireless dead zones. The speed of this new technology is, in our opinion, its most significant strength. Then, safety, affordability, a lack of electromagnetic pollution, making it acceptable for human usage, and greater energy efficiency are some other aspects that need consideration.

High Speed

One-phosphor-coated white LEDs have been used to record data rates of 1 Gbps [13], while an off-the-shelf red-green-blue (RGB) LED has been used to exhibit data rates of 3.4 Gbps [14]. A single colour incoherent LED produced 3.5 Gbps, according to University of Edinburgh researchers [15]. The team led by Haas predicted that commercial rates of up to 100 Gbps will be feasible for LiFi when the entire visible spectrum is used [16]. In a lab setting, LiFi researchers from the University of Oxford reached 224 Gbps (at this speed, five high definition movies can be downloaded in one minute)

[17]. Three readily available RGB laser diodes were used in recent research to produce data speeds of 14 Gbps for LiFi [18]. 2015 saw the achievement of 42.8 Gbit/s for indoor OWC using 2-dimensional optical beam-steering[19].

Figure 2. LIFI's strengths and weaknesses

Security

LiFi optical signals cannot pass through barriers, which is advantageous in terms of security concerns. The same functionality may be used to get rid of cell-to-cell interferences. There have been consistent reports over the past 10 years of increased point-to-point connection data rates utilising commercially available white LEDs in test lab settings [14].

Low Cost

LiFi's implementation may occasionally be less expensive than using other communication methods [20].

Low energy usage

Because communication relies on lighting, which is typically on the majority of the time indoors, the energy consumed for communication would be almost negligible. Even when the lights are seemingly off, data can still be sent using energy-efficient intensity modulation (IM) methods [18], [21].

Electromagnetic smog

It is not produced because LiFi employs the visible light spectrum (VLS), which is unaffected by RF interference. This makes it a more alluring alternative in places that are already risky due to electromagnetic interference, such as refineries, oil platforms, and fuel stations, as well as in close proximity to MRI machines, aeroplanes, and electrical transformer stations.

Health-safe

The technology could potentially find a market among customers who are aware of and impacted by the negative effects of electromagnetic radiation.

License free bandwidth

Hundreds of THz of license-free bandwidth are present in the visible light spectrum, which is 10,000 times greater

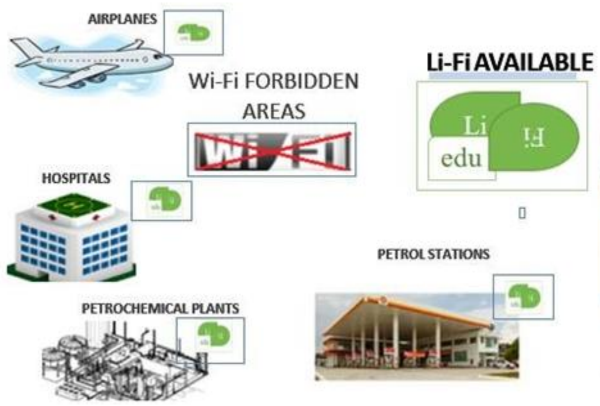
Than the total RF spectrum. On the opposite side of the scale, the LiFi technology as it has been created so far still has certain flaws.

Distance and interferences –

One of the restrictions is distance, which is often limited to no more than 10 metres without artificial light or direct sunlight interfering. Since the photodetectors won't be able to detect the modulating light waves, LiFi cannot be utilised in direct sunshine (or other strange situations with intense illumination). LiFi does, however, function with some level of ambient illumination, as demonstrated by Velmenni and Haas' demonstrations. Since LiFi does not yet have a standard, equipment from different vendors will not function together.

3. APPLICATIONS OF LI-FI

We may sum up some of the many applications for LiFi system that have already been made available globally as an affordable, secure, and ultra-high-speed communication infrastructure as follows:



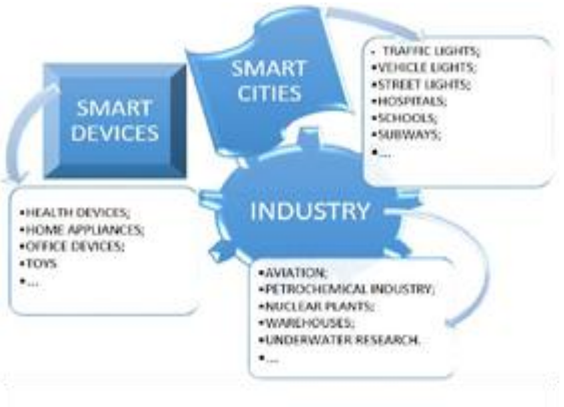


Figure 3. Some of viable applications for LiFi

Figure 4. Three main domains of application

Aircraft: LiFi can serve as a good substitute for wireless connection as Wi-Fi is often prohibited and hence limited during flights with most carriers. The usage of this technology in an aeroplane cabin has further benefits since it allows for flexible layout design and the saving of substantial quantities of cabling, which reduces weight and costs.

Hospitals: Even in locations where Wi-Fi is prohibited, LiFi performance can be improved. For example, they may be utilised in many types of cutting-edge medical equipment to interact with one another and provide quick data interpretation [22].

Petrochemical industry: This sector forbids RF since it processes a variety of radioactive substances.

Nuclear power plants: Because LiFi doesn't produce any electromagnetic interference, it can be a good substitute for Wi-Fi in electromagnetically sensitive environments like nuclear power plants.

In appliances used in the home and office: LiFi systems may be included into appliances used in the house, including as safes, freezers, central heating systems, TVs, clocks, and other devices, to save energy usage and enable intelligent energy management.

Smart lighting: The same communications and sensor infrastructure may be used to monitor lighting and data, establish LiFi hotspots, and illuminate public areas [23]. Vehicle & traffic lights : LED technology is being used to create sophisticated traffic and vehicle lighting systems, including headlights and taillights. For the purpose of traffic management and road safety, traffic lights can also be switched to LED.

Underwater : Because of the salty, highly conductive, and highly attenuating environment, light may transmit underwater where radio frequencies cannot. LiFi transmitters may be used in place of cables as they cause threads in underwater connection. With their headlights, they can transmit information to divers, surface craft, and submarines.

Health surveillance: In the field of health surveillance, wearable LiFi transmitters such as LED bracelets, ear rings, watches, and so forth enable continuous monitoring of a person's state of health and provide an immediate alert to the family doctor of any material changes in health status by connecting to the internet and updating the information online in real time.

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Indoor navigation: The LiFi technology enables indoor navigation (pinpointing an object to within about 10 cm) and offers orientation information (useful for, for example, knowing which direction a customer is looking) wherever LED lights sources are used, such as shopping malls, cinemas, theatres, government offices, work offices, or any indoor locations [24], [25].

4. MISCONCEPTIONS

Figure 5. LiFi's technology common misconceptions

The following are some widespread myths about LiFi technology:

- The experimental studies based on various dimmed intensities done to reach the conclusion that data transfer works even with dimmed light have shown that lights cannot be dimmed [26].

- The human eye finds the flashing light disturbing: The LiFi light flickers at greater rates that are dangerous to the human eye and unnoticeable. The human eye is able to detect flickering at lower rates, between 120 and 150 Hz. The EN 61000-4-15 standard has previously been used to evaluate LED flicker, and the results show that it is not damaging to the human eye [27].
- The LiFi networks can employ different wireless uplink technologies to accomplish full duplex communication as VLC is unidirectional downlink [3].
- The infrastructure for light distribution will be used by the LiFi system, so there is no need to replace the current lighting—only to attach the LiFi equipment [28].
- Only line-of-sight (LoS) technology is used in this application. As Haas had demonstrated at the LiFi demonstration at Edinburgh University, the system can operate outside of the LoS since photo detectors can detect light [4].

5. CHALLENGES FOR ESTABLISHING THE SYSTEM

In general, there are three main modules that are related to the difficulties that all parts of a LiFi network face: the first is the lighting device and the modulation technique used on it (Tx); the second is the indoor communication channel (ICC); and last but not least, the reception device and its characteristics, control, and synchronisation (Rx). Figure 6 illustrates the limitations that are specific to each of the three primary modules (Tx, ICC, and Rx).

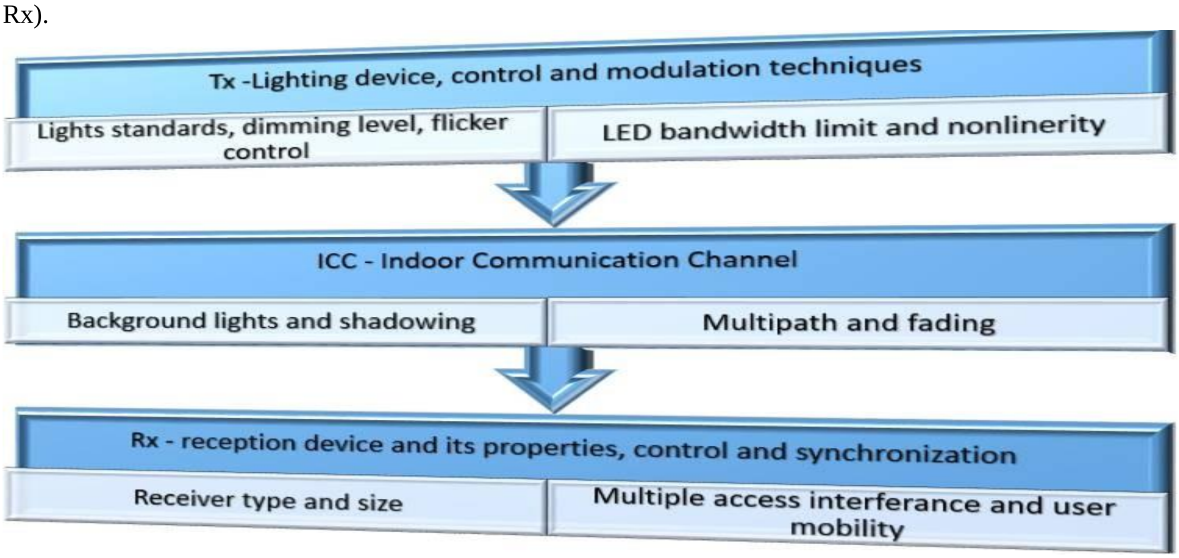

Figure 6. Constraints related to LiFi communication

a) Tx - the lighting apparatus and the modulation method used on it. Since they offer quick modulation and high data rates, LEDs are the most reliable and appropriate optical sources for dual-purpose lighting and communication applications. As such, they serve as the primary component of the LiFi network transmitter.

Two distinct types of LEDs combine various colours to produce white light using various methods. In the first method, a blue LED that emits light is encased in a layer of yellow phosphor that converts some of the blue light into longer-wavelength yellow and red light, which the human eye perceives as white light. The second kind is an LED that comes in three colours: green, blue, and red. These three LEDs are combined into one unique object that emits white light. By altering each colour separately, this type of LED makes it simple to comprehend colours. Although trichromatic LEDs are more expensive, dual-use applications prefer phosphorescent LEDs because they offer a quicker rise time and the ability to independently regulate each colour, doubling overall throughput. Either large bandwidths (quick rise times) or the usage of spectrally efficient modulation methods are required for high-speed communications [29]. The Visible Light Communications Consortium (VLCC) established the IEEE 802.15.7 standard, and it stipulates that the maximum data rate is 96 Mbps for on-off keying (OOK) and color-shift keying (CSK), or 24 Mbps for variable pulse-position modulation (VPPM). A LiFi system must operate at various optical peak to average power ratios (PAPR) in order to provide dimming. This allows for the management of average power, which is proportional to light intensity for a fixed peak power LED. Continuous current reduction (CCR) and pulse width modulation (PWM) are two methods that have been suggested for dimming in indoor LiFi systems [30].

b) ICC – Indoor communication channel - Line-of-sight (LOS) and non-line-of-sight (NLOS) are two different ways that Tx and Rx can communicate. LOS refers to the response received from the direct path to the closest LED, and NLOS is the response received after reflection from walls and other environmental objects. The shadowing effect is the obstruction of the direct route from the LED to the photodetector (PD). In this case, the channel's impulse response only contains the NLOS portion, which is used to retrieve the data. Possible intense background light causes significant data loss or even causes the communication process to stop down, especially if direct sunlight is in the field of vision (FOV) of the PD. Fading might generate losses for the optical system.

c) Rx - receiving apparatus and its features-A photodiode is used in the LiFi receiving system to detect light, which is subsequently converted to photo current. For LiFi systems, silicon photodiodes, PIN diodes, and avalanche photodiodes are employed [31]. Avalanche photodiodes are more costly than PIN photodiodes but have a better improvement. Since other sources of interference, such as sunshine and other interior lights, might interfere with LiFi, optical filters should be created to reduce the amount of DC noise that is present in the received signal. In the event of a stationary receiver, a photodiode is preferable; however, due to the higher FOV in the case of mobility, an image sensor is used in place of a photodiode. Imaging sensor operation requires a lot of energy and is sluggish. Due to this, when considering photodiode and image sensors, an appropriate balance between cost, speed, and complexity should be struck [32].

6. STANDARD PROTOCOL FOR VLC

In 2011, IEEE approved and released the IEEE 802.15.7 VLC standard. The short-range OWC employing visible light standard allows for high-data rates up to 96 Mbps by quickly modulating optical light sources, which may fade while they are in use. It offers dimming-adaptable techniques for high-data-rate visible light transmission that is flicker-free [33]. The physical layer (PHY), which the standard divides into PHY I, II, and III, each describes a mix of several modulation techniques and the media access control (MAC) layer. The PHY I is used for outdoor applications and operates between 11.67 Kbps and 267.6 Kbps; the PHY II is utilised for multiple emissions sources and delivers data speeds between 1.25 Mbps and 96 Mbps using a specific modulation technique called colour shift keying (CSK); the PHY III is used for outdoor applications and operates between 12 Mbps and 96 Mbps. To increase the data rate, which was low with conventional modulation algorithms, CSK was introduced in IEEE 802.15.7. By utilising blue LEDs and yellow phosphor to create white light, the switching capacity is slowed. As a result, using three distinct LEDs, green, blue, and red, is an alternative method of producing white light. Utilising the intensity of the three colours of an RGB LED source, CSK modulates. PHY I and PHY II both accept the on-off keying (OOK) and variable pulse position modulation (VPPM) modulation formats. The PHY I and PHY II layers' Manchester coding contains a DC component for the clock within. Peer-to-peer, star configuration, and broadcast mode are three multiple access topologies that are supported by the MAC layer, which also deals with addressing, collision prevention, and data acknowledgment protocols. The TCP/IP protocol and other levels are connected through the MAC layer [34]. A typical physical layer system model of VLC is shown in Figure 7. Mobility, dimming, visibility, and security support, flicker mitigation schemes, colour function support, network beacon generation if the device is a coordinator, variable pulse amplitude modulation VPAN disassociation and association support, and establishing a trustworthy connection between peer MAC entities are all tasks carried out by the MAC layer [35].

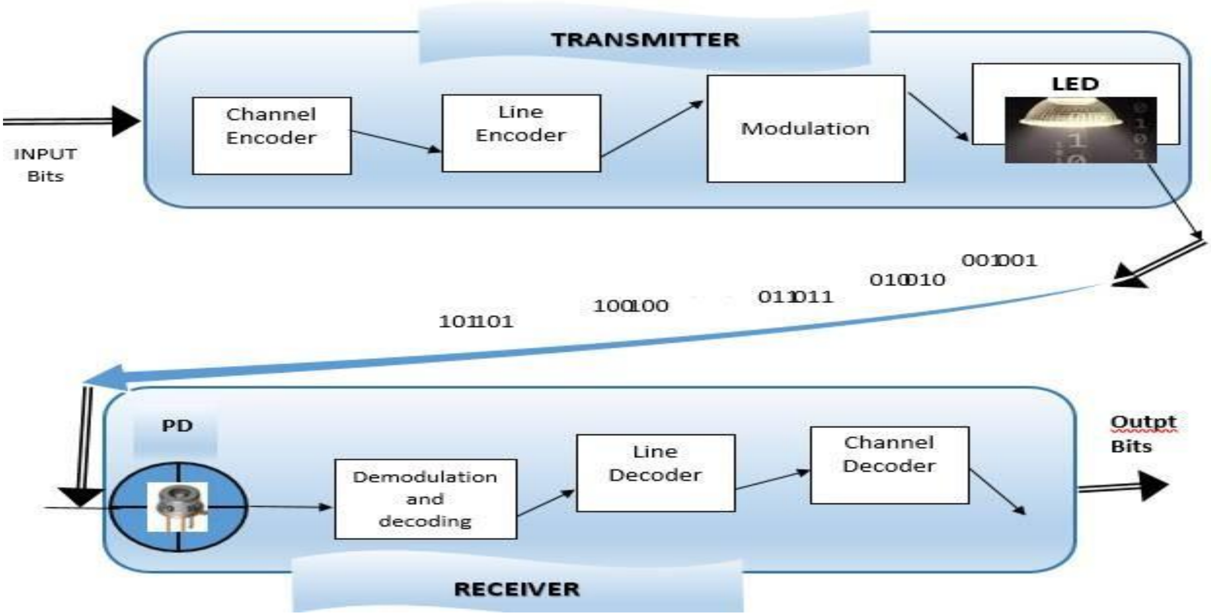

Figure 7. Typical physical layer model of VLC

7. MODULATION TECHNIQUES

Researchers have been working on a novel digital modulation technology for the last ten years that can be used to OWC utilising LEDs. This technique's fundamental premise is intensity modulation direct detection (IM/DD). Depending on changes in light intensity, the information varies. This means that the signal used to modify the LED signal must absolutely be true and positive. We are aware that power cannot be complicated or bad. Bi-polar and complex signals are necessary for the modulation techniques used in RF systems. For data rates to be near to the Shannon capacity limit, higher order modulation methods are required, such as M-level quadrature amplitude modulation (MQAM). The main issue in OWC is how to convert complex and bipolar signals into positive and real-valued signals without degrading bit-error performance [20]. Theoretical solutions for the practical capacity of an IM/DD system using orthogonal frequency division multiplexing (OFDM) and suitable solutions for the effect of non-linearity on the achievable signal-to-noise ratio in real-world OFDM related to VLC systems have been established for some time. OFDM is a frequency-division multiplexing (FDM) strategy used as a digital multi-carrier modulation technique for encoding digital data on multiple carrier frequencies. To maintain overall data speeds comparable to traditional single-carrier modulation techniques in the same bandwidth, each sub-carrier is modulated using a traditional modulation strategy, such as quadrature amplitude modulation (QAM) or phase shift keying (PSK), at a low symbol rate.

The signal from the LiFi source needs an appropriate modulation strategy in order to achieve high bandwidth. Both the switching rate and bit rate are constrained because the real commercial phosphors used in general illumination have comparatively lengthy fluorescence lifetimes of the order of milliseconds. On the other hand, Colloidal Quantum Dots QDs [36] offer substantially quicker switching rates for the LED device due to their much shorter fluorescence lifetimes, of the order of nanoseconds. For data transmission in OWC, single carrier pulse modulation is the best option. With pulse width modulation (PWM) or pulse interval modulation (PIM), information may be stored in the pulse duration.

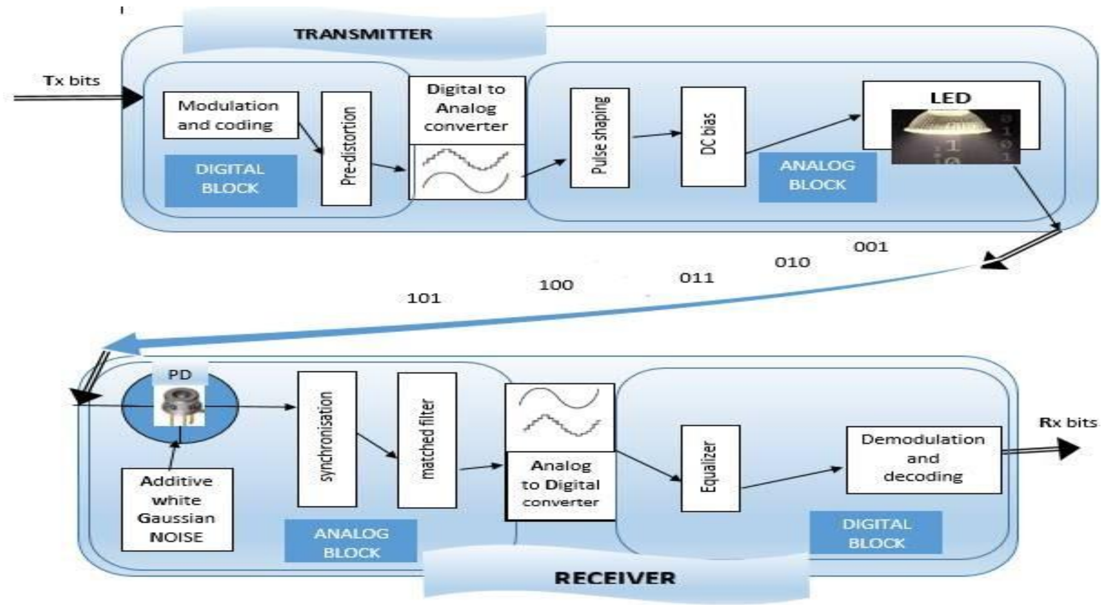

Figure 8. Block diagram of a single carrier modulation communication with pulse modulation

Additionally, information can be encoded in the pulse's location using a multi-level M-PPM or its amplitude using a multi-level M-PAM [20]. Figure 8 displays a block diagram of a single carrier modulation communication using pulse modulation.

The maximum number of bits that may be sent in a modulation method depends on the symbol duration and bandwidth. The Multiple Pulse Position Modulation (MPPM) technology allows for both data stream modulation and brightness adjustment. Both M-PAM and M-PPM can meet the transmitter's minimum, average, and maximum optical power constraints without significantly introducing non-linear clipping distortion. The Hadamard Coded Modulation (HCM) was created by the researchers to achieve low error probability in LED-based VLC systems that demand high average optical powers. As an alternative to OFDM, this method modulates the data using a quick Walsh-Hadamard transform (FWHT). The smaller peak to average power ratio (PAPR) of HCM allows for greater performance under high light levels. By lowering the DC portion of the sent signals, the power efficiency of HCM may be increased without sacrificing any information. Because it transmits signals with lower peak amplitudes compared to HCM and is hence more resistant to nonlinear distortion, the resultant so-called DC-reduced HCM is ideally suited to situations needing dim illumination. To increase the signals' resistance to inter-symbol interference (ISI) in dispersive VLC connections, interleaving can be applied to HCM [37].

8. CONCLUSIONS

A quicker, safer, greener, better, and healthier future for wireless communication systems is promised by LiFi technology as the electromagnetic spectrum continues to become saturated. Each light source may be utilised as a LiFi access point once the system is completely established, thus wherever an LED light bulb is present, we can anticipate the presence of a data connection facility as well. We anticipate LiFi will be combined with other wireless complementary technologies to build a new ubiquitous computing platform within a few years. Every item big enough to attach an LED and a light sensor can connect to LiFi and get power under this next integration. This article highlights the state-of-the-art development of LiFi, the technology's advantages and disadvantages, as well as the difficulties still facing the fully formed LiFi network. Given the widespread interest in LiFi as a viable alternative to Wi-Fi in some settings and circumstances, the VLC standard now needs to be improved to encompass the most recent LiFi advancements. Since the current focus of research is on the creation of appropriate modulation methods utilised in LiFi systems, we felt it was vital to highlight in this study a few of the most competitive ones created thus far.

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