The Technology of LiFi: A Brief Introduction

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Abstract. Light Fidelity (LiFi) is a Visible Light Communication (VLC) based technology that making a light as a media of communication replacing the cable wire communication. LiFi is evolve to overcome the rate speed in WiFi, while using LiFi the rate speed can reach until 14 Gbps. This paper presents an introduction of the LiFi technology including the architecture, modulation, performance, and the challenges. The result of this paper can be used as a reference and knowledge to develop some of the LiFi technology.

1. Introduction

LiFi known as light fidelity was introduced first time by Prof. Harald Haas on July 2011 at TED Global Talk. LiFi is based on Visual Light Communication (VLC) that using light emitting diodes (LEDs) to fully networked wireless system [1]. LiFi enables the electronic device to connect to the internet with no wire. In order to make a communication line between node, a LiFi will need a transceiver to transmit and receive the data. This transceiver will have a modulation technique to make the LED enable to carry the data using the light. The emergence of LiFi is to overcome the shortage of the current technology. We all know that right now WiFi is the most used technology to connect many devices to the internet. As time comes by, the use of internet based devices is increased. This increasing made the capacity of WiFi is reduced due the limitation of radio frequency resources.

According to [2], LiFi and WiFi has the difference related to the congestion, density, security, safety, and speed. The more WiFi enabled device is exist, the congestion may occur. In the technology of WiFi we can’t add more routers if the user is increased, while we can add the light in LiFi. Efficiency and safety of the internet are the dominating issues right now. The performance of LiFi is claimed that more better than the performance of WiFi. The rate speed of LiFi is 1000 times faster than WiFi [2]. For safety of the internet, LiFi is more secure than the WiFi based on the spread of the signal. LiFi has a light characteristic that light cannot go through the wall. It is different from the signal of WiFi can go through anywhere. Based on those two technologies, in a simple conclusion is LiFi has more secure communication rather than the WiFi. The vulnerability exists if there are leakage in the wall while having an indoor communication. Security threat that may exist is an intruder can spoof the data using the leakage wall.

This paper provides an explanation of the newly developed technology that is LiFi. The paper will discuss about the architecture, modulation, performance, and the challenges. The structure of this paper is as follows: in the remaining part of this section we will discuss the LiFi concept based on VLC. In section 3 we discuss the architecture of LiFi. In section 4 we further analyze the performance of LiFi based on the rate speed and security comparing with the WiFi. In section 5 we discuss about the challenge in LiFi technology, it includes a future research based on the security issue. All the result of
this paper is summarized in section 6. The result of this paper can be used as a reference and knowledge when developing a LiFi technology.

2. What is LiFi
According to figure 1, LiFi technology consist of LED Lamp as the media transmission and photo detector as a receiver of transmitted data. Lamp driver is needed to make LED working properly. While amplification and processing are responsible to manage the signal that comes from the photo detector.

![Figure 1. Basic Concept Diagram LiFi](image1)

Figure 1. Basic Concept Diagram LiFi

![Figure 2. Transceiver LiFi based on VLC](image2)

Figure 2. Transceiver LiFi based on VLC

Basic concept for working principle in LiFi Technology are pointing into: Transceiver and Light as a media transmission. Figure 2 is a basic concept block diagram for LiFi. This basic concept indicates as a duplex communication. The rates of LiFi is 14Gbps using three off-the-shelf laser diodes (red, green, and blue) and predict the rate until 100Gbps when the whole visible spectrum is used.

According to [3] LiFi and VLC used a similar medium as a data communication that is light. The difference between LiFi and VLC is VLC has a unidirectional, point-to-point light communication at low data rates. While the LiFi technology is fully networked, bidirectional, and high-speed wireless communication. Others said LiFi is the incorporation of WiFi and VLC[2].

2.1. Transceiver
Transceiver is a block that act as a transmitter and receiver at the same time. This transceiver consists of LED to transmit the light and photodiode to receive the light. Amplifier is embedded to strength the power of light received from the photodiode. The modem is used to modulate and demodulate the signal. The signal that comes from the photodiode is analog and it converts into digital in the modem. While the signal that ready to transmit, the digital signal convert into analog signal in the modem and sent by LED. The driver before the LED operates to drive the current of the LED in order to get the flickering. The flickering is functioning the LED for data transmission, if LED is ON then it transmits digital ‘1’ and if OFF, it transmits digital ‘0’[4][5].
2.2. Modulation

The modulation signals is used to switch LED at desired frequencies that contains information to be transmitted. According to [6] there are several technique of modulation in LiFi. Modulation techniques is needed in order the communication is still available even the illumination is not required. Because of that, a modulation technique may support a dimmable illumination. The variation in intensity of light corresponding to the information in the message signal. There are many typical of modulation in LiFi i.e. Single Carrier Modulation (SCM), Multiple Carrier Modulation (MCM), and Colour Modulation.

2.2.1. Single Carrier Modulation (SCM)

SCM is a modulation multiplexed any number of signal, then modulated individually with different frequency[7]. SCM using a microwave as a subcarrier and an optical carrier. Modulation technique in SCM are on-off keying (OOK), pulse-position modulation (PPM), and pulse-amplitude modulation (PAM). SCM is suitable for low-to- moderate data rates applications.

2.2.2. Multiple Carrier Modulation (MCM)

Because of the performance of SCM degrades as their spectral efficiency increase. SCM also require complex equalization process when employed at high data rates. MCM is developed to replace the disadvantage of SCM. There are several kinds of MCM i.e. OFDM. The difference between SCM and MCM summarised in table 1.

| Modulation | Characteristic |
|------------|----------------|
| SCM        | Transmit data by sequentially turning on and off the LED, the reliable communication range would decrease at low dimming levels, and increasing and decreasing the brightness of the LED would cause the data rate to decrease |
| PPM        | Provide efficient and dimming support in variable pulse position modulation (VPPM) |
| PAM        | Sensitive to signal distortion[8], combination with other modulation technique to get a better performance |
| MCM        | OFDM Excellent for situations where multiple transmitters are used simultaneously, avoid shadowing effects, the interference can be mitigated by shifting the system bandwidth to higher frequency[9] |
| DCO-OFDM   | The substantial energy dissipation due to the biasing [10] |
| ACO-OFDM   | Efficient in term of optical power for lower SNR value for IM/DD channel [11] |
| PAM-DMT    | Better optical power efficiency compared to DCO-OFDM [12] |
| AHO-OFDM   | Support various dimming targets to achieve system performance [12] |
| Flip-OFDM  | Equivalent with the ACO-OFDM in term of spectral efficiency and error performance[13] |
| U-OFDM     | Equivalent with the ACO-OFDM in term of spectral efficiency and error performance[13] |
3. The Architecture of LiFi

According to [14] the paper categorized the architecture based on layered. Figure 3 is the layered architecture of LiFi. In layered architecture, LiFi consist of 3 stages i.e. application layer, MAC layer, and Physical Layer. IEEE 802.15.7 defines only two standard i.e. PHY and MAC layer.

![Layered architecture VLC](image)

**Figure 3.** Layered architecture VLC [14]

### 3.1. IEEE 802.15.7 Layered Architecture

#### 3.1.1. PHY Layer

PHY layer responsible in transmission and reception, activation and deactivation of optical transceiver, and detection of state of transmission channel, is it idle or busy state. There are 3 operation modes in PHY layer. The differences of each operation modes are show in table 2.

| Operation Modes | Usage       | Categories | Rate           |
|-----------------|-------------|------------|----------------|
| PHY I           | Outdoor     | Low        | 11.6 Kpbs – 266.6 Kbps |
| PHY II          | Indoor      | Moderate   | 1.25 Mbps – 96 Mbps   |
| PHY III         | Multiple optical transceiver | CSK Modulation | 12 Mbps – 96 Mbps |

#### 3.1.2. MAC Layer

Three network topologies are defined in MAC layer: Peer to peer, star, and broadcast [14].

a) Peer to peer
   There are two device that communicate. One of them is act as a coordinator.

b) Star
   Communication happens in several devices. One of them is act as a coordinator and it’s used as a illumination infrastructure.

c) Broadcast
   One device i.e., a coordinator sends data to a several devices. The communication is unidirectional way.

### 3.2. Propagation Channel

Propagation channel in LiFi is not different from VLC. According to [16] indoor environment characterized by six different link configuration refers to IR links. Transmitter and receiver communicate in two criterions, i.e. direct or indirect line-of-sight (LOS) that required in the propagation channel. These two criterions are based on degree of directionality of the transmitter and receiver (LOS) others is based on the reflection of the light (non-LOS). In the LOS the links between the transmitter and receiver is pointing or directed each other. While in the non-LOS the light is spreading by the
reflection of the ceiling or diffusely reflecting surface. The characteristic of each criterion summarized on table 3.

Table 3. Characteristic of IR Link

| Line of Sight          | Directed                                    | Hybrid                                     | Nondirected                                |
|------------------------|---------------------------------------------|--------------------------------------------|--------------------------------------------|
|                        | • Maximizes power efficiency                | Combine transmitter and receiver having    | • Wide-angle transmitter and receivers    |
|                        | • Minimize path loss and reception of       | different degrees of direcionality         |                                            |
|                        | ambient light noise                         |                                            |                                            |
| Non Line of Sight      | • Rely upon reflection of the light from    | • Increase link robustness and ease of use  |                                            |
|                        | ceiling or some other diffusely reflecting | • Allowing the link to operate even when   |                                            |
|                        | surface                                     | barriers                                   |                                            |
|                        |                                            | • Referred to as a Diffuse link             |                                            |

The important parameter to get the high data rates is the availability of line-of-sight (LOS) optical link [17]. A non-directed LOS transmission is like to limit the achievable data rates. While the lighting scenario may vary, it is important to adaptation a dynamic rate to achieve a robust VLC link. According to [17] LOS is maybe no longer needed. K.D. Langer built rate-adaptive visible light communication at 500Mbps arrives at plug and play. He developed a bidirectional high-speed real time VLC system.

3.3. The topologies of LiFi

According to [2], the paper experiencing build a proof-of-concept prototype VLC HetNet. This prototype is a concept that using a diverse spectrum to provide high quality-of service in indoor environment. There is an additional tier in the wireless HetNet using indoor gigabit small-cells to offer additional wireless capacity. The prof-of-concept experiment has two model such as hybrid model and aggregated model. In hybrid model, the system is used WiFi to connect to the internet but the downlink of a user is connected through a LiFi link. While the aggregated system is user connected on WiFi and LiFi in parallel. Unidirectional LiFi link is used in hybrid system to supplement the WiFi downlink. In aggregated system both WiFi and LiFi using bi-directional communication to improve the throughput and achieve a robust connectivity.

![Figure 4](image)

Figure 4. (a) Hybrid system and (b) aggregated system [2]

The goal of this concept is to achieve a good performance. In the hybrid system the throughput depends only on the capacity of the LiFi downlink while degrading as the distance increase. Therefore,
in the aggregation system enhances the available reliable network communication. Hybrid system also can be a solution for LiFi channel blockage when implementing a mobile device.

4. Performance of LiFi

Efficiency and safety of the internet are the dominating issues now. Lifi was found in 2011 by Scientist Harold Haas from UK. The design is to overcome the disadvantage of WiFi. The speed of Wifi is up to 1500mbps and it’s not sufficient to accommodate a huge user.

| Table 4. Speed and Standards of WiFi |
|-------------------------------------|
| Standard   | Release Date | Max Speed  |
| 802.11b    | 1999         | 11 Mbps    |
| 802.11a    | 1999         | 54 Mbps    |
| 802.11g    | 2002         | 54 Mbps    |
| 802.11n    | 2007         | 72-600 Mbps|
| 802.11ac   | 2013         | 433 Mbps – 1.3 Gbps |

| Table 5. Speed of LiFi |
|------------------------|
| No | Reference | Modulation | Data Rate |
| 1  | [18] OOK  | 803 Mbps   |
| 2  | [19] OFDM | 2.1 Gbps   |
| 3  | [20] DMT  | 3.4 Gbps   |
| 4  | [16] PPM  | 30 Mbps    |
| 5  | [21] PAM  | 20Mbps     |
| 6  | [22] CAP  | 1.1 Gbps   |

LiFi enabling the system using fully networked wireless communication and could provide a connection that’s 100 times faster than WiFi. It can reach speeds up to 3Gbps by using DMT modulation [20]. The other speed of LiFi with the different modulation also shown in the table 5. M.D Renzo et all using Spatial Modulation for MIMO Wireless System in LiFi, the transmit speed is up to 10Gbps. The rate speed of LiFi can be higher than 3Gbps while the technology is on research and developing. The rate speed of LiFi is based on the using of the modulation. Dr. P. Kuppusamy et.all doing a survey of Lifi and comparing it with Wifi, there are several characteristics that used for comparing. The difference of LiFi and WiFi is showed in table 6.

For security, LiFi is more tought than a WiFi. It is because the coverage area of LiFi is only on their illuminate area. The signal of LiFi cannot go through the wall. While the signal of WiFi can go through the wall, it can cause the vulnerabilities in data loss and data leakage. According to [25] security issues in VLC focus on aspect of basic physical characteristics of the communication channel. The paper also analyzes the risk of signal jamming, data snooping, modification, and MAC-level security. The result is VLC infrastructure is particularly prone to data-security risk. According to [26] one of the security issue in LiFi is eavesdropping, an attack happen by obtaining the signal that come from the gap between the floor and door, crack inside the flooring or from partially shielded windows.
### Table 6. The difference of LiFi and WiFi [23][5][24]

| Parameter                      | LiFi                                | WiFi                                |
|--------------------------------|-------------------------------------|-------------------------------------|
| Transmitter                    | LED                                 | Antenna                             |
| Receiver                       | LED                                 | Antenna                             |
| Inbuilt Device                 | Under research and development      | WiFi Card/Chip                      |
| Average Operation Speed        | Greater than 10Gbps (under research)| 150-600 Mbps                        |
| Frequency band                 | 1000 times of THz                   | 2.4 GHz                             |
| Standard                       | IEEE 802.15.xx                      | IEEE 802.11xx                       |
| No of users                    | All over under the lamp.            | Depend on access point.             |
| Data Transmission              | Bits                                | Radio waves                         |
| Coverage Area                  | 10 meters                           | 20 – 100 meters varies              |
|                                |                                     | based on type of transmission power and antenna |
| Interference                   | No interference issues with RF waves| Interference with neighbor AP routers |
| Topology                       | Point to Point                      | Point to Multipoint                 |
| Communication                  | Based on Visible Light Communication| Based on Radio Frequency Communication |
| Efficiency                     | More, LEDs consume less energy and highly efficient | Less, Radio Base Stations consume high amount of energy |
| Availability                   | Anywhere, available in airplanes and underwater | Limited |
| Secure                         | More secure because light waves cannot penetrate through walls and cannot be intercept by anyone outside the illumination of LED | Less secure because of high penetrating power of radio waves, anyone can intercept |
| Network topology               | Point-to-point                      | Point-to-multipoint                 |
| Suitability                    | Suitable for high data rates and secure communication | Suitable for Aps with high coverage regions |
| Signal-to-Noise Ratio          | Very high                           | Maybe more                          |
| Power consumption              | Less                                | More                                |
| Environment Impact             | Low                                 | Medium                              |
5. The Challenges
The challenge in LiFi is based on point that has been discussed in literature and the infrastructure that already available. Including the real users of LiFi technology is how to response.

5.1. Modulation
The key of LiFi communication is the using of modulation. A modulation in LiFi is to carry a binary data by turning the LED on and off quickly. There are many aspects in LiFi related to modulation, illumination and dimming scheme is the first concern. Illumination is the spread of the light that making the LEDs can be as a media in data communication. The challenge is how the modulation is enabling the illumination of LEDs in order can send the data while the illumination is low. While the dimming process is to proportional of LEDs brightness. The challenge in dimming technology is how the LiFi can fulfill the user satisfaction in order the dimming of LED can stay safe for the user [27].

5.2. Interference
In optical illumination based on data communication, the hard part is to provide the optical uplink service. It is because the uplink service can interfere the downlink signal. These problem is one of the challenge in the interference signal issue. In LiFi, the transmitter should be able to maintain a directional link during the transmission [27] [28].

5.3. Infrastructure
The basic infrastructure in LiFi is indoor and outdoor. Same as in the optical characteristic, a LiFi also has an effect shadowing while transmission. This shadowing effect off course will give an effect in the process of sending and receiving the data. There is a few research about the effect of shadowing in the LiFi communication [29].

5.4. Security
According to [26] a threat like eavesdropping can happen in LiFi. It happens when there is gap between the floor and the door, the light may spread out between them. The crack from inside floor and shielded windows also can be a leakage.

5.5. Coverage
LiFi is a technology that has a good perform in an indoor infrastructure while it’s not happen in the outdoor area. The coverage in outdoor area for LiFi needs to be set up in order the quality of connection can give a good performance. According to [2], LiFi is integrated with the WiFi to get a good performance in an outdoor or in a mobile infrastructure.

6. Summary and Future Scope
In this paper, we outlined the working of LiFi, the modulation that its used, the architecture, the performance, and at last the challenges. The purpose of LiFi technology is to provide a high-speed data communication using visible light spectrum. Now LiFi is on-going of research, it has a potential advantage that can make a supplement RF communication and can be used to improve wireless network performance. Although LiFi has a good performance in the transfer rate, LiFi is not good enough when deploy in an outdoor in sunlight or other condition. LiFi will probably not completely replace WiFi, these two technologies can be used together to achieve more efficient and secure network.

Paris is one place that has been implemented the LiFi technology. There are offices, hospitals, retail stores, public street lighting as well as metro station at L Defense, and Curtius museum in Liege in 2012. The four key criteria that is used are: the LiFi can operate within a complex physical environment, the system can provide the bi-directional communication, traffic and security information can be pushed to smartphones, system of audio-messaging is developed to enable tourist and people to be guided.
In future, the work can be done for analyzing the security threats based on the architecture, communication, and implementation of LiFi according to CIA triad concept. It is also can be done by doing research based on the challenge in the LiFi technology.

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