A small step in VLC systems – a big step in Li-Fi implementation

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Abstract. Light is part of our sustainable environmental life so, using it would be the handiest and cheapest way for wireless communication. Since ever, light has been used to send messages in different ways and now, due to the high technological improvements, bits through light, at high speed on multiple paths, allow humans to communicate. Using the lighting system both for illumination and communication represents lately one of the worldwide main research issues with several implementations with real benefits. This paper presents a viable VLC system, that proves its sustainability for sending by light information not only few millimetres but meters away. This system has multiple potential applications in different areas where other communication systems are bottlenecked, too expensive, unavailable or even forbidden. Since a Li-Fi fully developed system requires bidirectional, multiple access communication, there are still some challenges towards a functional Li-Fi wireless network. Although important steps have been made, Li-Fi is still under experimental stage.

1. Introduction to VLC and Li-Fi Technologies

Into the electromagnetic spectrum, the optical frequency range starts from 300 GHz and reaches 30 PHz (Peta Hertz). The optical wireless communication (OWC) refers to infrared (Ir), visible and ultraviolet (UV) bands. This is an enormous spectral range, comparable to the 300 GHz that the radio frequency (RF) band represents.

Visual Light Communication (VLC), as part of OWC, uses the visible light medium between a frequency of 430 THz and 800 THz and distance from 750 nm to 380 nm as optical carrier both for data transmission and illumination, fast pulses of light transmitting data wirelessly [1].

Light Fidelity Li-Fi refers to a VLC system of wireless data communication that uses the conventional light emitting diode (LED) bulbs and is meant to be wireless, full-duplex (bidirectional), Multiple-Input-Multiple-Output (MIMO) network that uses the visible light medium for communication [2].

The Li-Fi technology is expected to rise significantly because of the request through different areas due to its harmless nature to human health. The market is also expected to increase significantly from the massive growth in usage of LED lights as a cleaner technology, economical and energy-efficient, over the other conventional lighting options such as high-intensity discharge (HID) and fluorescent bulbs. Some of the leading vendors operating in the global Li-Fi market are Oledcomm, LVX, PureLifi, GE, and Philips [3].
2. How Li-Fi Works

Although the VLC technology’s first demonstrations began in early 1990’s in countries like Japan, Germany, Korea the first implementation has been done by a Japan company, on 2003 [4]. Later, Li-Fi has been coined by Harald Haas, professor at the University of Edinburgh, UK, who demonstrated in July 2011 at Global TED Talk, its practical functionality. He explained and demonstrated” Very simple, if the LED is on, you transmit a digital 1, if it’s off you transmit a 0. The LEDs can be switched on and off very quickly, which gives nice opportunities for transmitting data. So what you require at all are some LEDs and a controller that code data into those LEDs” [5]. Other researcher was able to prove that LED's could be retrofitted to send information and Haas envisioned light bulbs that could act as wireless routers. "My big idea is to turn light bulbs into broadband communication devices, so that they not only provide illumination, but an essential utility" [6].

In order to communicate data, instead of RF, Li-Fi uses visible light by sending data through a LED light bulb that fluctuates intensity faster than human eye can perceive. A LED light bulb is a semi-conductor light source. It means that the constant current of electricity supplied to an LED light bulb can be dimmed and dipped, up and down at exceptionally high speeds, without being perceptible to the human eye. To receive the light signals, Li-Fi as VLC system, has a photo-detector and a signal processing element in order to convert the data into a content that is able to receive streams. Data is send into an LED light bulb that has incorporated the signal processing technology and is able to send data embedded in its beam to the photodiode at high speeds [2].

All these the tiny changes in the fast LED’s dimming is going to be converted into electrical signal by the receiver module (Rx). This signal is then converted back into a binary data stream that is recognised as web, video and audio applications that run on internet enabled devices [7], [8].

3. Challenges for a Fully Developed Li-Fi Wireless Network

There have been lots of obstacles in front of the Li-Fi technology development and implementation, some of them have already been overcome, others are still in front of a fully developed Li-Fi network.

There are three main components of the Li-Fi’s system that have to be taken into consideration: transmitter module (Tx), communication channel (CC) and receiver module Rx.

Regarding the Tx: LED types, as well as the control and modulation techniques of the lighting device are about to be improved to pass the line-of-sight (LoS) limitation, LED bandwidth, control the flickering as well as dimming level [1].

There are few type of LEDs that are suitable for a Li-Fi wireless network that use different technologies to create white light by mixing some colours: there is the phosphorescent LED emitting blue light embedded in a layer of yellow phosphor that turns some of the light into longer wavelengths, yellow and red. The human eye sees in this case a white light.

Another type is the RGB trichromatic LEDs that are merged into a distinct device to emit white light. This kind of LED enables easy color interpretation by adjusting each color individually.

Although the phosphorescent LEDs are cheaper than trichromatic LEDs, RGB LEDs are preferred for dual-use because they have a faster rise-time (high bandwidths) and the total throughput can be tripled when each of the three colors can be modulated separately. High-speed communications require either high bandwidths and/or the use of spectrally-efficient modulation schemes [9].

High bandwidths can be achieved when the signal from the LED can have the right modulation scheme. Most of the commercial phosphors LED used for lighting have rather long fluorescence lifetimes (of the order of milliseconds) and therefore, both the on-off switching and bit rate are limited.

The Colloidal Quantum Dots QDs [10], have much shorter fluorescence lifetimes, of the order of nanoseconds, and therefore, much faster switching rates for the LED device are enabled. But, long-term exposure to CdTe (cadmium telluride) quantum dots causes functional impairments in live cells [11].

Therefore, each and every one of the above mentioned LED types has its advantages and disadvantages in different scenarios and situations, for a suitable Tx transmitter data and lighting device.
As for the communication channel, the interferences from external light sources like sun light, normal bulbs, and opaque materials in the path of transmission will cause interruption in the communication or partial loss of data. On the other hand, the emitting LED light bulb can be dimmed at a level that still keep the communication available but is not disturbing during night, for example. The same situation is meet when the fog curtain becomes thick on streets, data communication can still be accessible between car bulbs and street lights [12].

The receiver must have specific properties, dedicated filters, control and synchronization. Avalanche photodiode APS, silicon photodiode PIN diode and solar cells are used for Li-Fi systems. APS has a higher performance than a PIN but is more expensive. The Li-Fi is susceptible to interference from sunlight and indoor lights, that is why, optical filters should be designed to diminish the DC noise components present in the received signal. It is better to use a photodiode in the case of a stationary receiver; still, in case of mobility the imaging sensor is preferred instead of a photodiode because of the larger field of view FOV. Operating imaging sensors has a high energy intake and is slow. Hence, a suitable balance between the cost, speed and complexity, should be done while considering the suitable photoreceptor [13].

Another challenge facing Li-Fi’s development is how the receiving device will transmit back to transmitter. There are already few implementations for this situation using IR or RF.

![Figure 1. Tx, ICC, Rx - components of a Li-Fi system, their specific boundaries and challenges](image-url)

4. Applications of Li-Fi
Any lightings device is possible to be change in such a way to be able to performed as a hotspot. It means that any LED bulb acting like an illumination device is possible to become a data communication device, as well. We refer here at ceiling lights, car lights, street lamps and so on. All of these and many others are able to spread internet connectivity using VLC, allowing in this way low cost architecture for hotspot. Hotspot covers a limited region where some devices are able to access internet connectivity.

Street lamps, for example, can act as free access points (AP) for high speed communication being able to transmit data in real time.

Traffic lights can communicate to the car and with each other. Cars have LED-based headlights, LED-based side lights, and therefore cars can communicate with each other and prevent accidents by fast exchanging of information. Industrial equipment, machines, or automobiles can be paired with light nodes to provide real-time information about the operational and functional performances, issues or any other metrics. Vehicular communication seems to be so simplified now, considering that the
rear and front lights in vehicles can be used for data transfer for effective crash avoidance technologies.

Wi-Fi and many other radiation types are forbidden in many areas that are sensitive to the electromagnetic fog. On the other hand, Li-Fi communication is safe, abundant with low power consumption for all areas of these sensitive locations. These areas are power plants, petrochemical industry, nuclear plants and so on. But power plants, for example, need fast, inter-connected data systems to monitor things like demand, grid integrity and in nuclear plants core temperature need to be constantly monitored and controlled. The savings resulting from proper monitoring at a single power plant can add up to hundreds of thousands of dollars.

Other domain where the Li-Fi technology is possible to be successfully implemented is the aircrafts industry. Velmenni, which is a high-tech hardware startup based out of Delhi and Tartu, Estonia creates VLC links that can broadcast data at high speed, up to 20 meters and also work on applications in aviation. Their project is about to be applied to the Australian Airbus’ BizLab innovation accelerator hubs. This would allow Airbus company to remove the looms of wiring connecting each passenger’s screens to the digital content server containing all the movies, TV shows and music that are enjoyed during a flight. That wiring not only adds cost and complexity to aircraft, it adds weight which results in less fuel efficiency. It doesn’t seem to mean much, but in the domain of aircraft design, every little bit of help is high valued [14].

Offices, schools, museums, metro, commercial places, hospitals in fact any indoor space can be a beneficiary of this new technology. Actually, in France for example, it has already been implemented by an important developer Oledcomm, who deployed Li-Fi products in the market, equipping in 2012 a museum in Europe (displaying a multimedia content in order to improve the visual experience of each artwork and guide the visitor in the museum according to his/her wishes/interest) and deployed in retail and Paris Metro. Carrefour with the support of Philips, installed on May 2015, in a hypermarket in Lille an indoor positioning system (IPS) based on Li-Fi technology, which allow its customers to locate the products in promotion. Philips offers a complete ISP technology. The Lille deployment is using Philips luminaires targeted at supermarket applications. The VLC implementation provides location accuracy to less than 1m. Philips offers a cloud-based location database capability and a software development kit that retailers can use to create a mobile interactive platform [15].

Another project of IPS has been presented on 2016 by the USA’s company, Qualcomm [16]. Their implemented technology named Lumicast, uses LED light fixtures to broadcast positioning signals via amplitude modulation of light in a way that does not impact the fixtures’ primary function of providing illumination. A mobile application that incorporates the Lumicast software framework can decode these VLC signals using those to determine the position of the mobile device. Due to its compatibility with smartphones and LED lighting infrastructure, this technology is able to support a broad range of IPS applications in commercial, office and industrial settings, and has been adopted by leading players in the LED lighting ecosystem such as Acuity Brands [17], [18] and GE Lighting [19].

As Professor Russel Griggs, the pureLiFi Chairman said on July 2016, an extension of standard Wi-Fi is coming and it’s called Wi-Fi HaLow. While using less power, this new project aims to double the range of connectivity. Due to this, Wi-Fi HaLow is reportedly perfect for battery powered devices such as smartwatches, smartphones and lends itself to Internet of Things (IoT) devices such as sensors and smart applications [20].

Due to its high speed, this technology can have a big impact on the IoT too, with data transferred at much higher levels with even more devices able to connect to each other. pureLiFi company succeeded to launch on 2014 the device Li-Flame consisting of two units: Li-Flame Ceiling Unit (CU) (Figure 2) and Li-Flame Desktop Unit (DU) (Figure 3). Li-Flame technology delivered half duplex communication with a 10Mbps downlink and 10Mbps uplink up to 3 meters with standard LEDs, full mobility (portable, battery-powered desktop unit) with high data rate due to dense installation of Li-Fi access points(APs), multiple users per Li-Fi AP, supported through multiple access, while retaining high bandwidth for each user [21].
The state-of-the-art device launched by pureLIFi company, named Li-Fi-X, (Figure 4) that has been publicly demonstrated along with the Li-Fi integrated Luminaire at Mobile World Congress in Barcelona on March 2017. The dongle USB-powered station has turn some of the Li-Fi’s weaknesses in strengths allowing a full duplex communication with a 40Mbps downlink with a photodetector as receiver and 40Mbps uplink with infrared transmitter. The device allows full mobility being portable and is a multiple users device per Li-Fi Access Point, supported through multiple access [22].

Apple is also set to add Li-Fi capabilities to its future iPhones [23]. All the well-known strengths of the Li-Fi technology are supported, such as the secure wireless communications constrained by walls, eliminating the risk of signal leakage to external eyedroppers, safe wireless communication in locations where RF is forbidden and a cost-effective delivery of data as the piggyback of light on the same infrastructure [24].

There are many reasons why we should use Li-Fi in many areas nowadays. Some of these reasons are listed below:

- Safe for human eye/body;
- High security because light does not penetrate walls;
- Can provide high-speed connection;
- No interference on RF signals;
- Environmentally “green”;
- Provide accurate (~1 mm) IPS;
- Both Gamma Rays and X-Rays are dangerous and have health issues;
- Ultraviolet can be used only were humans are not present;
- Infrared has heat radiation issues and using high power causes health problems.
5. The Present Scenario of RF. Comparison Between Wi-Fi and Li-Fi

Li-Fi can be thought of as a light-based Wi-Fi. It uses light instead of radio waves to transmit information. Instead of Wi-Fi modems, Li-Fi technology would use transceiver-fitted LED bulbs that can light a room as well as transmit and receive information.

Wi-Fi is great for general wireless coverage within buildings, and Li-Fi is ideal for high density wireless data coverage in restricted areas and for relieving radio interference issues. So the two technologies can be considered complimentary.

As we are all aware, the radio spectrum is congested and the demand doubles every year resulting in bandwidth shortage. Wireless transmission through RF is limited and expensive, insufficient spectrum for increasing data capacity. 1.8 million cellular radio stations, consume massive energy, most energy used for cooling base stations have only 5% efficiency efficiency [24]. Wi-Fi is available within the range of base stations limited, being unavailable in some aircrafts and it is less secure that Li-Fi since passes through walls. Due to VLC, the node or any terminal attach to the Li-Fi network is not visible to the host of network, thus increase communication safeness.

Li-Fi supports the broadcasting of network, it helps to share multiple thing at a single instance called broadcasting being multi user communication system.

Li-fi is a communication media in the form of light, so no matter about the frequency bandwidth problem. It does not require the any bandwidth spectrum i.e. we don’t need to pay any amount for communication and license.

Although Li-Fi is not intended to replace other existing wireless communication technologies, it can be a great complement in certain places and situations. For example, nowadays, “total radio frequency (RF) wireless data traffic exceeds 11 Exabyte per month, creating a 97% gap between the traffic demands per device and the available data traffic per device in the mobile networks. This is the reason why RF wireless communication bottleneck is closely expected. Optical wireless communication (OWC), as a future reliable alternative, meets unprecedented spread in the last decade, new and interesting implementations bringing hopes for its bright future” [25].

Table 1 presents some characteristics of both technologies, Wi-Fi and Li-Fi, by comparing them.

| Characteristics          | Wi-Fi          | Li-Fi (VLC)            |
|-------------------------|----------------|------------------------|
| Standard                | IEEE 802.11    | IEEE 802.15            |
| Frequency               | 2.4; 5 GHz     | Hundreds of Tera Hz    |
| Power consumption       | Medium         | Low                    |
| Medium of transfer      | RF             | Visible light          |
| Range                   | 100 meters     | Depends on LEDs        |
| Spectrum Range          | 300 Ghz        | VL spectrum is 10.000 larger than RF |
| Data rate transfer      | 800 kbps – 11 Mbps | >1Gbps                |
| Cost                    | Medium         | High                   |
| Network topology        | Point to point | Point to point         |
| Security                | Medium secure  | High secure            |

6. VLC system with Tx and Rx PCBs

A block diagram of the VLC communication system that we have made is shown on Figure 5.

The main components of our communication system are:

- Tx - transmission circuit made by a sound device and a led driver circuit with a high brightness cold white LED has been switched on and off to a very high rate, that acts as a communication source;
- Rx - Reception circuit made by a silicon photodiode which shows good response to visible wavelength region serving as the receiving element with a photodiode.

The tests have been conducted indoor both with a regular amount of ceiling illumination and daylight as well.

![Image of Rx circuit](image-url)

**Figure 5.** The block diagram of the VLC communication system made

### 6.1. Tx – Using 1 Watt Cold White LED

The LED driver circuit uses a 1 Watt Cold white LEDs bulb with a signal input of 10 Hz to 30 MHz and an electrical power supply of 12 V.

![Image of Tx circuit](image-url)

**Figure 6.** Tx circuit with 1 W cold white LED

**TDS-P001L4Z11 Characteristics:**
- Highest flux per LED family: 140-150lm/W;
- Led chip from Epistar and Bridgelux;
- Long lifespan (up to 100k hours) White: 6500K;
- Lambertian radiation pattern;
- Cool beam, safe to the touch (90-120-140degree);
- Fully dimmable;
- No UV radition.
Table 2. LED Chip TDS-P001L4Z11

| Parameter                         | Rating | Unit |
|----------------------------------|--------|------|
| Power Dissipation                | 1365   | mW   |
| LED Junction Temperature         | 120    | °C   |
| Reverse Voltage                  | 5      | V    |
| D.C. Forward Current             | 350    | mA   |
| Pulsed Forward Current; tp ≤ 100μs, Duty Cycle = 0.005)*1 | 700    | mA   |
| Operating Temperature Range      | -40 to +75 | °C  |

Electrical & Optical Characteristics:

| Parameter                     | Rating | Unit |
|-------------------------------|--------|------|
| Luminous Flux, IF = 350 mA    | 120    | lm   |
| Forward Voltage, IF = 350 mA  | 3.3    | V    |
| Reverse Current, VR = 5 V     | 5      | µA   |
| View Angle                    | 130    | deg  |

6.2. Rx module
We have used as the receiver module in two different scenarios. In the first scenario we used a photodiode and in the second one, a solar cell.

6.2.1. Rx – Using Photodiode - First scenario. BPV10 is a PIN photodiode with high speed and high radiant sensitivity in clear, T-1¾ plastic package. It is sensitive to visible and near infrared radiation. BPV10 Photodiode characteristics are shown on Table 3.

Table 3. BPV10 Photodiode’s basic characteristics

| PARAMETER                        | TEST CONDITION | SYMBOL | TYP. | MAX. | UNIT |
|----------------------------------|----------------|--------|------|------|------|
| Forward voltage                  | I_F = 50 mA    | V_F   | 1.0  | 1.3  | V    |
| Reverse dark current             | V_R = 0 V, E = | I_Ro  | 1    | 5    | nA   |
| Diode capacitance                | V_R = 0 V, f = 1 | C_D  | 11   |      | pF   |
| Absolute spectral sensitivity    | V_R = 5 V, f = 1 | s(λ) | 0.55 |      | A/W  |
| Angle of half sensitivity         | φ              | ± 20   |      |      | deg  |
| Wavelength of peak sensitivity   | λ_p            | 920    |      |      | nm   |
| Range of spectral bandwidth      | λ_0.1          | 380 to 1100 |      |      | nm   |
| Detectivity                      | VR = 20 V, λ = 950 nm | D | 3 x 1012 |  | cm√ Hz/W |
Figure 7. Rx circuit with photodiode

6.2.2. Rx – Using Solar Cell - Second scenario. And, in the second scenario, the receiver circuit contains a solar cell. The solar cell’s specification are shown in Table 4.

Table 4. The solar cell’s specification

| Type              | 1 Watt                  |
|-------------------|-------------------------|
| Silicon           | Mono-Crystalline Silicon|
| Parameters        | Rating/Unit             |
| Maximum Power     | 1 W                     |
| Maximum Power voltage | 9 V                   |
| Maximum Power current | 0.11A               |
| Open circuit voltage | 10.4V                 |
| Short circuit current | 0.12A              |
| Cells thickness   | 0.18mm±20µm             |
| Number of cells   | 18                      |

The best improvement in this scenario consists in higher distance communication achievement due to non-Line of Sight (NLOS) high capacity of the receiver.
Figure 9 represents a picture of the VLC system made by us both for data stream and sound communication, using the LED light bulb and one photo detector.

![Figure 9. Our VLC system](image)

The VLC system for data transmission stream has a transmission circuit designed to send data through illumination as piggyback.

![Figure 10. VLC System with the receive wave displayed on oscilloscope](image)

The single carrier binary optical transmission is displayed on oscilloscope.

VLC system for SOUND transmission.

In case of the VLC system for sound transmission, the wave forms similarity of the two channels are displayed on oscilloscope.
Figure 11. VLC System with the send and receive waves displayed on oscilloscope

Wave forms similarity of the two channels displayed on oscilloscope for different distances between LED and Photodiode.

We have captured the signal form of the two waves and their similarity in case that LED bulb is at 1 meter away from Rx Photodiode LoS scenario.

Figure 12. Tx module LED is 1.0 meter away from Rx Photodiode LoS scenario

Figure 13. Tx module LED is 0.5 meter away from Rx Photodiode LoS scenario

7. Conclusions

We can every day see that more and more Wi-Fi able communication devices are hungry for data, thus the RF domain of the electromagnetic spectrum becomes overcrowded. On the other hand, the Li-Fi technology already demonstrated to provide brighter future for wireless networks, especially where the radio frequencies are limited or even forbidden. As most of the latest developments and improvements of the technology shows, when the Li-Fi wireless network system will be fully developed, each light source can be used as a Li-Fi access point (AP), meaning where will be a LED illumination available, data communication is expected to be present, too.

This paper presents shortly the Li-Fi’s state-of-the-art development as well as world wide implementations realized so far. A short balance between the two technologies (Wi-Fi and Li-Fi) has been done, too.

We have made a first application of the VLC technology using as transmitter a 1 Watt cold white LED and as the receiver one photodiode in a fist scenario and a solar cell in the second one. When the photodiode has been used, we have conducted indoor tests for sound communication. In a LoS scenario, Rx and Tx were placed at various distances (up to 1 meter) and both the transmitted wave and the received one were displayed on the oscilloscope’s screen. The higher distance between the Tx and Rx, the lower sound level percept but the accuracy of music seemed to be the same.
We plan to improve and develop the system presented so far in order to make specific working implementation in different areas.

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