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Performance Evaluation and Comparison on LiFi, WiFi and Ethernet Networks in Real Environments

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Abstract. Light Fidelity (LIFI) is an emerging technology in the communications and networks fields that uses lighting RF specter as a medium to link data transmissions. In the first instance, this work presents the characterization and operation of two prototypes of LIFI luminaires. Furthermore, this paper shows different approaches, including the creation of a physical layer for LiFi luminaires, demonstrating each of the stages for transmission and acquisition of the signal, the bridges created to achieve the data link, and even the integration of all before phases and factors to result in a whole LiFi communication system ready to be implemented in the real world.Although to guarantee the quality of service in those communication networks, there are many factors to be considered. Therefore, the performance of a LiFi network could be obtained and predicted if an analysis model can consider specific metrics to adjust the network performance to the user's needs. For the specific case of this work, a set of metrics [21], such as packet loss, delay (latency), jitter, and throughput, was experimentally calculated, presenting the graphical results for LiFi metrics performance facing WiFi and Ethernet technologies. Finally, this work shows the importance of data density for LiFi networks by analyzing the results from distance and speed variation.

Keywords: LiFi, VLC, data-link, wireless communication, optical communication, wiFi, ethernet.

1 Introduction

The study and creativity to combine two quotidian human needs, such as lighting and communication in a single solution, have achieved the development of optical devices through researching fields in optoelectronics and computing. Optical technologies, nowadays, represent a solution to current communication problems. Even though these technologies, just a few decades ago, have been studied is surprising that the first experiments with visible light have an antiquity of at least 3000 years [15].

Light-Fidelity(LiFi) emerges as one of the technologies that will shape the future of communication systems. In the last decade, LiFi technology has grown considerably, having as main strengths the range of frequencies in which it works (380 nm to 750

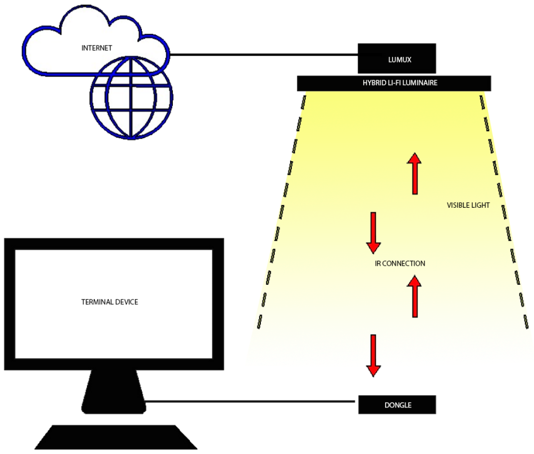

Fig. 1. LiFi connection, through a prototype luminaire, to the Internet.

nm [1]), and the fact of having an infrastructure almost ready for its implementation, making possible the development of new technological perspectives.

Each year the number of users with Internet access is doubled, and the amount of data transmitted each month (estimated at 77 exabytes just for Mobile Data Traffic for the year 2022 [10]) grows in an accelerated way. Therefore, the current networks tend to present congestion and low performance. For this reason, LiFi is presented as a technology not only capable of solving the problems in congestion or performance but as a technological environment capable of interacting and complementing existing technologies such as WiFi or Ethernet.

Human beings have developed lighting systems in any place necessary, and homes were not the exception. For this last reason, the indoor LiFi systems are easy to implement and low cost considering the change of LiFi lamps instead of those currently used. In a typical LiFi network, such as *Figure 1* shows, luminary cells transmit and receive from an access point placed inside a room. Lighting to any point on the receiving surface includes the Line of Sight (LOS) and reflections of objects and walls [16]. LiFi indoors could represent the largest field of action to this technology in the following decades because it represents a potential solution for the Internet of things [12] through experimentation in modulation, color, and power to use this technology in urban environments. In the future, it would be applicable within marine environments or in outer space. Also, it is possible to restructure the lighting in public areas to implement LiFi where necessary.

Although IEEE 802.7.15 and IEEE 802.11 protocols in LiFi sections do not finish yet, this article presents patented prototypes (previously developed by this working group [7, 8]) and finds its main contribution in the methodological, electronic, mechanical, and computational description of LiFi systems. In literature, several models of theoretical operation exist of these systems [5, 19, 20]. So, another essential contribution for this paper is to experimentally demonstrate the performance of current LiFi networks, comparing them concerning similar WiFi and Ethernet environments

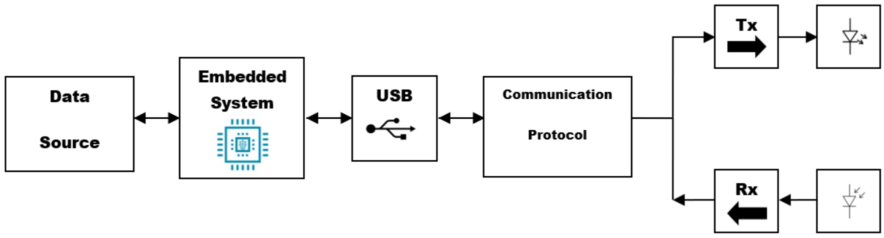

Fig. 2. General LiFi system.

(since these last two technologies are well known, their technical and functional characteristics are not emphasized in this work).

2 LiFi System

Light Fidelity (LiFi) is an emerging technology in the communications and networks fields that uses lighting RF specter as a medium to link data transmissions. Therefore, it uses light radiation, such as emitted light from a Light Emitting Diode (LED), to transfer and receive data and even connect to the Internet. This paper presents the stages of design, implementation, and analysis of two LiFi prototypes. Thus, the activities presented in this work are also thought to give the reader a comparison of this technology against the popular ones that nowadays domain the IT communication technologies like WiFi and Ethernet. The importance of researching in the LiFi field was discussed in Harald Haas and et al. [11] work. They explain the need for a new spectrum for current and future wireless networks. Furthermore, they argue that wireless networks based on light waves are at a very mature state to begin implementing in the industry as an opportunity area. Thus, this work will show the phases and diagrams implemented, during the design and analysis stages, to finally compare these couple of LiFi prototypes against the before mentioned technologies, showing their capability to establish an Internet connection, and giving the user the connectivity experience such as standard communication protocols are.

The diagram shown in *Figure 2* represents the implemented overall system on the LiFi transmitters and receivers. Below is a description of each of the system stages:

– In the first stage, a signal conditioned by the 802.3 protocol is received, which may contain a Manchester or MLT-3 encoding. The MLT-3 coding is specifically used in high-speed communications, due to the fact that MLT-3 has three voltage levels in the signal (-1,0,1) the frequency of the transmitted signal decreases by half, unlike a coding *Manchester no return to zero*. The *Ethernet* signal is isolated by security through a transformer, to be interpreted by a *transceiver*, which will be responsible for encoding and decoding the information provided in *Data Link Layer* to subsequently receive and transmit it to a system embedded.

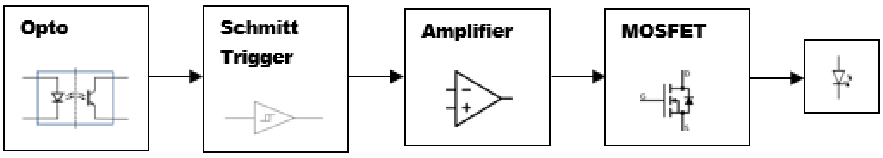

Fig. 3. Transmitter system.

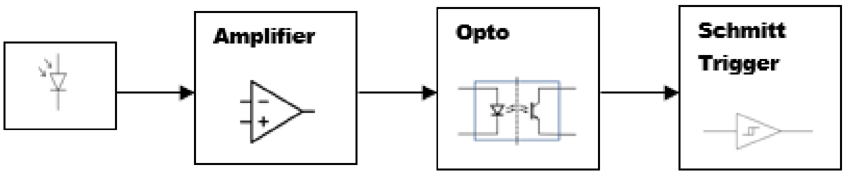

Fig. 4. Receiver system.

- The embedded system is responsible to establishing an information bridge between an *Ethernet port* and a *USB port* through a layer 2 communication protocol.

- Subsequently, the information received in the USB port is converted to a communication protocol, which takes data bytes and transmits them sequentially in a certain format. For establish communication, it is necessary to pair the two devices with the same communication parameters.

- In *Figure 3*, the transmitter system is presented. In this part, the signal is optoisolated to the next stage and is processed by a *Schmitt trigger* gate. In order to transmit this signal, it is necessary to condition it with an operational amplifier, which has as a characteristic a higher bandwidth than the bandwidth of the signal to be transmitted (at least ten times greater). At the same time, this amplifier is used as a drive to switch a *MOSFET* device that will turn on and off the *IR* information transmitter.
- In the reception stage, there is a photodiode, which receives the signal to be processed. This current signal passes through a transconductance amplifier and delivers a voltage signal for being amplified to have compatible levels with *TTL* and *CMOS* signals. Once conditioned, the transmission signal is optoisolated to a serial-USB conversion circuit for being reprocessed by the embedded system and returned to the *Ethernet* network. *Figure 4* shows this set of stages.

The sources used in hybrid white LED luminaires systems are Lambertian sources of visible and infrared light [9]. When radiating in all directions, the DC gain through the i-th LOS communications channel(H_{LOS}) [4] corresponds to *Equation 1*:

$$H_{i,LOS} = \begin{cases} \frac{A(m+1)}{2\pi r_i^2} \cos^m \theta_i \cos \psi_i & \psi_i \leq \psi_{max} \\ 0 & otherwise \end{cases}, \tag{1}$$

where,
A: receiver area
m: Lambert index
θ_i: irradiance angle with respect to the transmitter axis
ψ_i: incidence angel with respect to the receiver angle
ψ_{max}: field-of-view (FOV) semiangle of the receiver
r_i: distance between i-th transmitter and i-th optical detector

3 Design of LiFi Luminaires

3.1 General Modifications to Luminaires

The LiFi hybrid(Visible and Non-Visible light) luminaires were designed in two main parts:
The first one is the luminaire (Lumux): it is a case in which the electronic board (required to send and receive the information) is mounted. This information is suitable for transmission by infrared LEDs; even when the visible lights are turned off in the room where this technology is being used, this fact allows to continue with the transmission.

LiFi luminaires used in this work are a hybrid version between visible light and infrared light (*Figure 5*). This luminaire has a variable and adjustable transmission speed, in the direct link, of 1 Mbps, 3 Mbps, 6Mbps, 12Mbps, or 24Mbps. The speed of transmission is due to the adaptation, positioning, and study of the optics of the LEDs. These factors will represent an essential part of the study of the luminaries that transmit data only in visible light.

The second part for a LiFi luminaire is the Dongle(receptor). Unlike Lumux, Dongle is the device that interacts directly with the end-user, so it needs to cover its electronic board completely. Another important difference is that Dongle contains a single receiver and a single transmitter, representing a considerable reduction in its size (compared to the Lumux size). The Dongles presented in this paper, such as in *Figure 6*, are connected to the electronic devices through a male USB type A connector.

3.2 Communication System

Once the signal has been acquired in the electronic devices of the *Physical Layer* and converted into bits, the system uses a protocol of the *Data Link Layer* to encapsulate the frames with IP headers to the *Network Layer*.

The above process will make possible internet connections through the LiFi luminaires. In this work, a *Single-Board Computer* was used in which the necessary

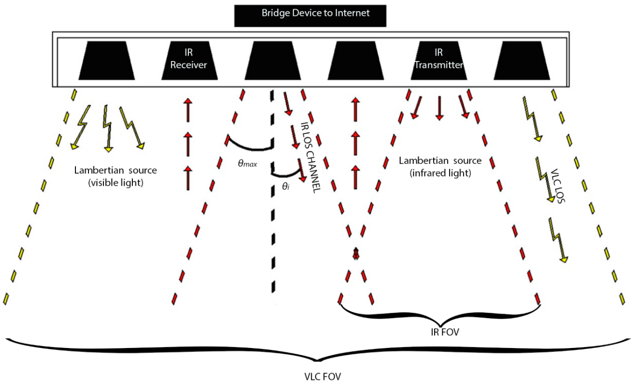

Fig. 5. LiFi Lumux luminaire.

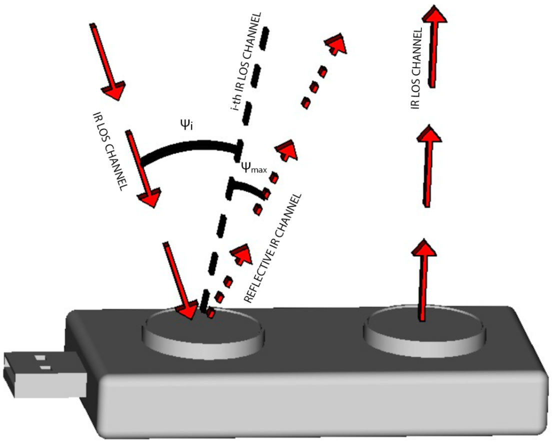

Fig. 6. LiFi receiver scenario, Dongle.

files were created for Lumux and Dongle configurations. The procedure to achieve the communication between Lumux and Dongle is described by *Algorithm 1*.

In addition to the entire functionality process in Lumux and Dongle devices, there are some characteristics in the operation of the LiFi communication prototypes used for this work, these characteristics are described below:

– ***Roaming:*** As we have seen in several wireless communications technologies, mobility is an essential factor that makes more comfortable and easy communications among multiple users or even a per of them; meanwhile, data exchanges occur for each station.
  There are two types of roaming for mobile terminals [3]. The first one is called Intrasystem (intradomain), and another one is called Intersystem (interdomain) roaming. Therefore, we define our proposed roaming as a type of Intrasystem mobility management because it uses network interfaces and protocols similar

Algorithm 1 Internet connection through LiFi luminaires

```
Input ← Internet request
Output → Internet connection
Initialization
Settings of communication parameters
Settings of proxy connection
IP forwarding activation
NAT deployment
Allowing of Layer two protocols
active_communication ← true
while active_communication do
    Send_Data
    Receive_Data
    Check active_communication
end
```

among all stations for communicating with each other. Unlike before the roaming type, Intersystems refers to moving between different backbones, protocols, technologies, or service providers. Also, a mechanism that works internally on the OS was created, such as a software service. This mechanism is continuously looking for a connection request from a client station. Once that request is recognized, this service connects from layer two to upper layers' protocols to give the client station an Internet connection.

In the beginning, roaming mechanism activates IP forwarding to apply NAT between upper layers protocols to layer two, converting data into frames ready to be sent to the physical layer of our Li-Fi prototype and vice-versa. Thus, the roaming mechanism needs to define some properties such as physical port, speed, network parameters, and others to initialize this service. Next, the roaming service checks if communication is active; in this case, the bridge starts sending and receiving data and continuously checks if the connection is online. In another case, the bridge gets close to waiting for another connection request, as is shown in *Algorithm 2*.

- ***Multiple users per LiFi luminaire:*** LiFi communications are characterized by providing dedicated links to the clients that connect to them. However, a single LiFi luminaire can provide connectivity to several terminal devices depending on the dimensions of the Lumux and the scope of its Field of View (FOV) [22]. The LiFi prototypes presented in this work can provide from 4 to 16 users per luminaire, considering the aspects mentioned earlier.

- ***Operating systems compatibility:*** The integration and compatibility between the technological diversity that exists today is one of the most important challenges of new technologies. The luminaire prototypes used for testing offer compatibility across Windows, Linux, and Mac OS operating systems.

Algorithm 2 Bridge to the Internet connection

```
Input ← Internet request
Output → Internet connection
Start roaming service
r_service ← true
while r_service do
    Check Internet_request
    if Internet_request = true then
        Initialization
        Settings of communication parameters
        Settings of proxy connection
        IP forwarding activation
        NAT deployment
        Allowing of Layer two protocols
        active_communication ← true
        while active_communication do
            Send_Data
            Receive_Data
            Check active_communication
        end
    end
    if roaming service is not Alive then
        r_service ← false
    end
end
```

– **Data density, bandwidth, and speed:** Two factors define LiFi technology: high data density and bandwidth. Both factors result in the theoretical speed being up to 10Gbps [2], an extremely high speed compared to conventional speeds for WiFi (150 Mbps). It is important to mention that LiFi provides a higher *Data Density* than WiFi since the density of this data is approximately 1000 times greater than in WiFi [18]. This is due to the lower interference that light presents on radio waves; that is why a LiFi system could have the same performance for certain data traffic than a 144.4 Mbps WiFi connection (as will be shown in section III).

3.3 LiFi Prototype Functionality

In order to show the operation of the LiFi prototypes, an Internet connection will be made through a LIFI luminaire, and the Packet Loss metric will be measured. The link will be adequate at a speed of 1 Mbps to make the frequencies easier to observe on the oscilloscope. The hybrid luminaire used has a field of view of $r = 20cm$; this allows mobility in the device's line of sight without losing the connection (LiFi communication was used for 4 hours for this experiment without setbacks). On the other hand, internet connection speed meters were used to measure downlink and uplink. This fact showed that data downlink and uplink speeds were symmetric (an unusual feature in ISP connections since speeds in the downlink are almost always provided lower than the uplink).

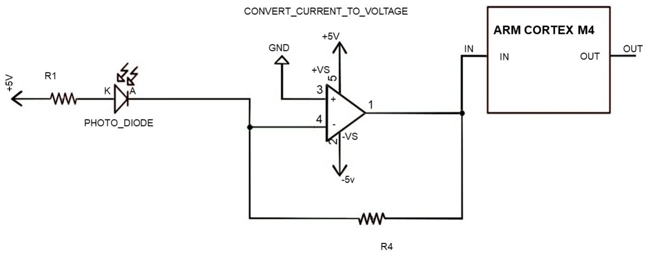

Fig. 7. LiFi receiver circuit.

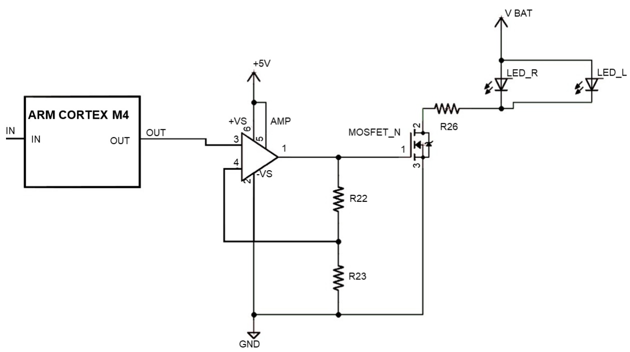

Fig. 8. LiFi transmitter circuit.

The distance between receiver and transmitter was *1.53m*. In these conditions, the noise did not represent a problem. In these LiFi prototypes, noise reduction and speed adjustment are implemented. Another important detail in the measurements is the $1\mu s$ period of the signal, which according to the relationship:

$$T = 1/f, \tag{2}$$

where:
T: period of the signal
f: frequency of the signal
It shows that the frequency of the signal is $1Mhz$.

LiFi prototypes implemented in subsequent sections base their operation on the circuits shown in *Figures 7 and 8* [14].

As an additional test of the system, it is proposed to send 10,000 ICMP packets with 64-byte size to a server to the Internet while the connection is also used to explore other

Table 1. ICMP packages' statistics through distance variation in the Li-Fi luminaire.

Distance (m)	Latency (ms)	Packet Loss
1.55	93	0.04%
1.40	121	0.21%
1.25	109	0.24%
1.10	167	0.15%
0.95	112	0.05%
0.80	116	0.05%
0.60	107	0.33%

websites. For this test, the distances between the receiver and the transmitter varied in a δd = 15 cm. *Table 1* shows the experimental calculation of the *Packet Loss* metric.

4 Performance Comparison (LiFi, WiFi and Ethernet)

This section presents the measurement performance results from *LiFi 1* (3 Mbps), *LiFi 2* (6 Mbps), *WiFi* (144.4 Mbps), and *Ethernet* (1 Gbps) technologies. As is well known, networks generally measure their performance through certain metrics. Below are the used metrics in this document; a summary of each of them is shown next:

– ***Latency:*** The time that a packet stays across a network, latency is also related to various delays in packets, transmission queue, propagation, or processes present in a communications network.

– ***Throughput:*** The sent/received packets by the unit time are linked up with the bandwidth used in a specific unit of time. This parameter is essential to know if a network is in congestion or wasting resources.

– ***Jitter:*** This metric is the delay variation that emerge in a network, that is, the delay that appears between each packet and is related to variations in traffic load and the number of collisions between packets.

– ***Packet Loss:*** The packets loss on a certain number of transmissions. This metric encompasses the memory of nodes, congestion, and control policies in a network.

The metrics shown above can be calculated experimentally through network protocols. There are a lot of protocols that can be measured, the most common are those that belong to the layer 4 on the OSI model (TCP, UDP, ICMP). Next, the main characteristics of these protocols are presented:

– ***ICMP:*** The Internet Control Message Protocol often is used for control and diagnostic purposes, furthermore this protocol is used to find delay and throughput in networking.

Table 2. ICMP metrics.

Technology	Wired	Link Speed (Mbps)	Packet Loss (%)	Latency (ms)
LiFi 1	No	3	0	55
LiFi 2	No	6	0	46
Ethernet	Yes	1000	0	47
WiFi	No	144.4	1	108

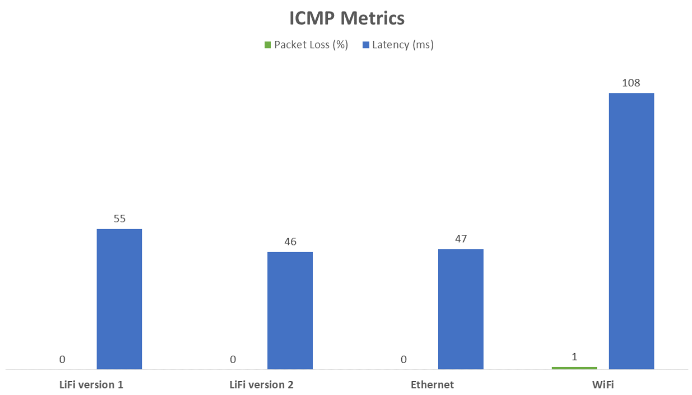

Fig. 9. ICMP latency and packet loss (LiFi,WiFi, Ethernet).

– ***UDP:***The User Datagram Protocol is a protocol that establishes a low-latency link, considered as a connectionless protocol, often used to obtain Jitter in a network.

– ***TCP:*** The Transmission Control Protocol establishes and maintains a network link. This protocol is impacted by latency, then also, the throughput is impacted by this factor.

Specialized BSD software tools were used to measure each metric in every protocol for all the results shown in this work.

4.1 ICMP Results

Meanwhile, the round trip was used to get the latency and packet loss, throughput was calculated in terms of the bits transmitted and the latency. The results of developed experiments are shown in *Table 2* and *Figure 9*. The test was done with 100 packets of 32 bytes size through PING software.

4.2 UDP Results

The results obtained for Throughput and Jitter through UDP protocol are shown in *Table 3* and *Figure 10*.

Table 3. UDP metrics (LiFi, WiFi, Ethernet).

Technology	Wired	Link Speed (Mbps)	Packet Loss (%)	Jitter (ms)
LiFi 1	No	3	0	29.18
LiFi 2	No	6	0	17.08
Ethernet	Yes	1000	0	0.03
WiFi	No	144.4	0.63	2.9

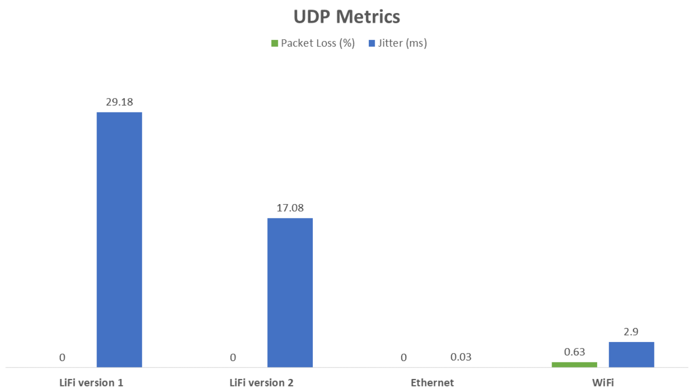

Fig. 10. UDP jitter and packet loss (LiFi,WiFi, Ethernet).

Table 4. TCP downlink and uplink throughput (LiFi, WiFi, Ethernet).

Technology	Wired	Link Speed (Mbps)	Download Throughput (Mbps)	Upload Throughput (Mbps)
LiFi 1	No	3	2.50	2.36
LiFi 2	No	6	4.90	4.75
Ethernet	Yes	1000	95.1	94.6
WiFi	No	144.4	21.1	21.0

4.3 TCP Results

These tests were executed to get the Throughput in downlink and uplink through TCP protocol with a window size of 65 KB. Results are shown in *Figure 11*, and *Table 4*.

4.4 Internet Connection Results

These experiments show the link connection reports about bytes received and transmitted, thus allowing to know the data downloaded and uploaded (*Table 5*, *Figure 12*) for a certain period of time (30 minutes).

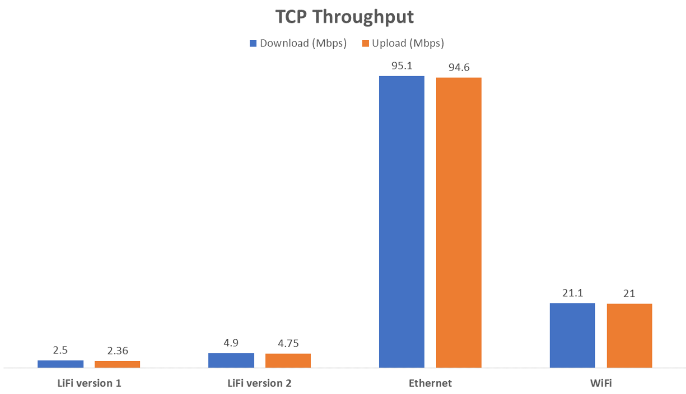

Fig. 11. TCP throughput comparison (LiFi,WiFi, Ethernet).

Table 5. Data transmitted and received (LiFi, WiFi, Ethernet).

Technology	Wired	Link Speed (Mbps)	Download (Bytes)	Upload (Bytes)
LiFi 1	No	3	694,961.18	25,930.75
LiFi 2	No	6	824,726.00	21,483.78
Ethernet	Yes	1000	1,024,507.57	34,504.57
WiFi	No	144.4	951,436.36	63,909.49

5 LiFi Performance through Distance and Speed Variation on LiFi Prototypes

As a final part of this work, the general performance comparison in LiFi prototypes at two different speeds (3 Mbps, 6Mbps) was shown through the methods described in the previous section. These experiments were carried out with the variation of distance between emitter and receiver.

Although distance also affects WiFi and Ethernet technologies, this factor is not considered because its impact is significantly less in short distances (considering 100 meters for Gigabit Ethernet 1000Base-T [13], 100 meters for indoor WiFi, and up to 300 meters outdoor [17]). Such results are demonstrated in Tables 6, 7 and 8, and Figures 13, 14 and 15.

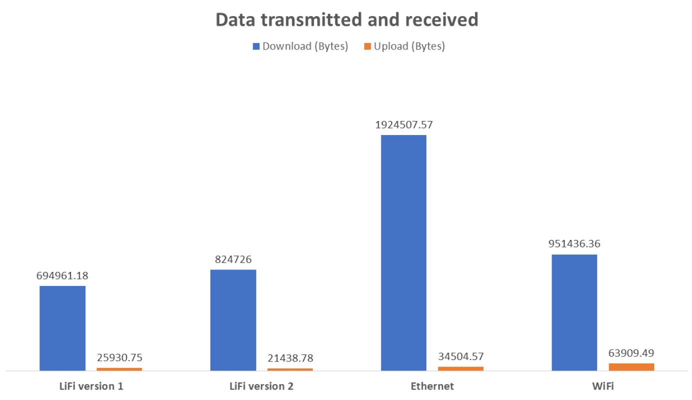

Fig. 12. Data transmitted and received comparison (LiFi,WiFi, Ethernet).

Table 6. LiFi ICMP latency (100 packets, 32 bytes).

Speed Link (Mbps)	Distance (m)	Latency (ms)
3	0.75	49
3	1.0	51
3	1.25	58
3	1.50	64
3	1.75	44
6	0.75	45
6	1.0	52
6	1.25	53
6	1.50	51
6	1.75	46

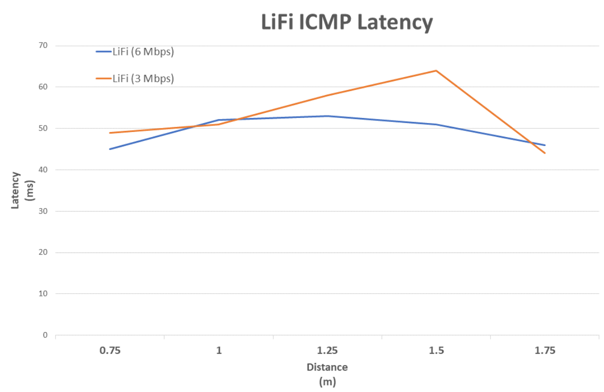

Fig. 13. LiFi ICMP latency at different distances.

Table 7. LiFi UDP Jitter.

Speed Link (Mbps)	Distance (m)	Jitter (ms)
3	0.75	23.38
3	1.0	25.74
3	1.25	28.31
3	1.50	30.69
3	1.75	28.01
6	0.75	20.65
6	1.0	20.48
6	1.25	20.45
6	1.50	19.03
6	1.75	19.69

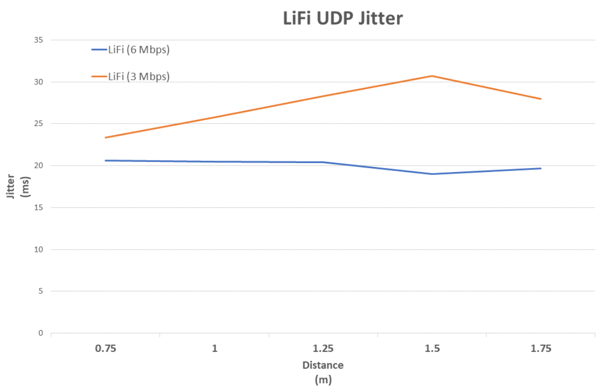

Fig. 14. LiFi UDP Jitter at different distances.

For the last case, it can see in *Figure 15* that the throughput tends to be smaller for long and short distances compared to medium distances. The above is because TCP establishes virtual circuits that require retransmissions, unlike the UDP protocol, which is a connectionless protocol. In addition, for very close distances, the LiFi sensors are easier to align, but sensors could be affected by power saturation; analogously, at very long distances, the sensors may require more energy to amplify the signal, and alignment becomes more complex to find the Line of Sight.

6 Conclusion

The first part of the work was focused on VLC communications and, specifically, on creating LiFi prototypes that can be implemented simply in typical luminaires. The paper presents the electronic blocks for transmission and reception stages, the

Table 8. LiFi TCP (throughput).

Speed Link (Mbps)	Distance (m)	Download Throughput (Mbps)	Upload Throughput (Mbps)
3	0.75	2.50	2.37
3	1.0	2.55	2.41
3	1.25	2.50	2.36
3	1.50	2.55	2.40
3	1.75	1.54	1.41
6	0.75	4.84	4.74
6	1.0	4.89	4.74
6	1.25	4.90	4.75
6	1.50	4.47	4.36
6	1.75	2.1	1.4

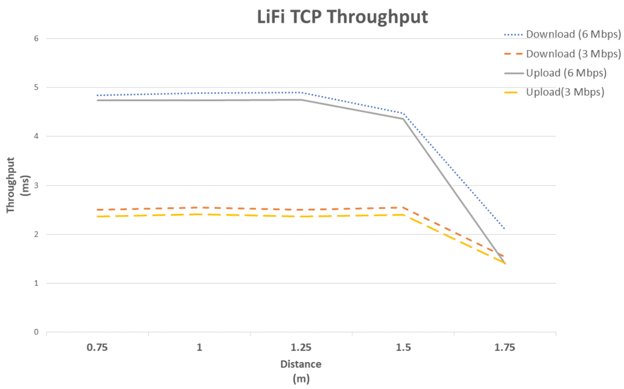

Fig. 15. LiFi TCP throughput at different distances.

mechanical process for LiFi luminaires (Lumux) and LiFi receivers (dongles), and the communications tests between these two devices. It is also shown that the latency times presented in LIFI prototypes are at an acceptable average, and it permits users to surf on the internet in a dedicated link.

The correct implementation of the physical and data-link layers makes it possible to obtain correct communication with the upper layers. In addition to the above, the coverage radios are attached, and the experiment conditions are specified. The manner that humanity communicates is growing accelerated, and it looks for new alternatives to achieve its purpose efficiently. The prototypes presented in this article are an essential starting point for developing LiFi technology and infrastructure that allows an improvement in current communications.

Table 9. QoS metrics.

	Jitter (ms)	**Latency (ms)**	**Packet Loss (%)**	**Throughput (%)**
Excellent / Good	*0-20*	*0-150*	*0-3*	*75-100*
Medium	*21-50*	*151-400*	*4-15*	*25-74*
Poor	*>50*	*>400*	*>15*	*<25*

Another important point of this project was the tests applied to different communication technologies (LiFi, WiFi, Ethernet). In order to compare its performance through certain metrics utilizing specific protocols from the transport layer. After observing the results obtained, we can justify the following premises concerning the proposed experiments and environments:

– Ethernet presented a lower latency and jitter in the ICMP and UDP protocols since cabled technologies have better energy conduction, low loss rate, and no interference. In addition, the PoE in the ICMP packets was 0%. It is important to emphasize that, although the data rates were very similar to the other technologies, Ethernet could support higher data loads through its connection. It is well known that Ethernet is suitable for any protocol of the transport layer, and it was demonstrated in the results of the network performance

– WiFi obtained a Jitter greater than Ethernet but lower than LiFi. Meanwhile, its latency was irregular and therefore obtained the worst values in this test. High latency is a sign of high interference and weak signals, which caused a packet loss of 1%. The data throughput was similar to the other two technologies because the use of the network was similar.

– LiFi presented a latency very close to Ethernet, which indicates that packets within environments that add LiFi present small round trips. With little interference and high data density, the LiFi packet loss was 0%. Meanwhile, the transmitted and received data was very similar to that presented by Ethernet and Wifi. The tests in which LiFi presented the lowest performance were those in which the TCP protocol was used, obtaining a lower data transfer, the previous due to the window sizes, the low bandwidth, and the LiFi network processes.

In general terms, the technologies presented an acceptable performance in Quality of Service (QoS). According to ITU G.114 and TIPHON TR 101 328 standards [6] as is summarized in *Table 9*.

As it can be observed in *Table 10* a denomination EXCELLENT/GOOD was obtained in the three technologies for the case of latency. Jitter metric was categorized as GOOD in all cases, except for LiFi 1 prototype with a MEDIUM score. On the other hand, packet loss was found in a range of EXCELLENT/GOOD range. Although the overall performance was apparently EXCELLENT/GOOD for the throughput test, the test varied by window sizes and packets sent; the experiments showed that although the environments can have a variety of factors that affect a network, in the end, the

Table 10. Summary results.

	Jitter (ms)	**Latency (ms)**	**Packet Loss (%)**	**Throughput (%)**
LiFi 1	*29.18*	*55*	*0*	*78.66*
LiFi 2	*17.08*	*46*	*0*	*79.16*
Ethernet	*0.03*	*47*	*0*	*94.6*
WiFi	2.9	108	1	84

interference in WiFi, the lower LiFi bandwidth and the difficulty for Ethernet cabling are determining factors to find a complement between these technologies.

In the last part of this work, it was showed a comparison of the performance of metrics. These experiments demonstrated that performance was very similar in all cases despite varying distances and speed in LiFi prototypes; this is because of the density of the data found in LiFi transmissions, which allows greater wireless transmission capacity for specific areas.

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