Implementation of a Visible Light Communication Link: Li-Fi with Smartphone Detection

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Abstract: The average bandwidth per user increases daily, being necessary to present solutions that can satisfy this growth. One possible solution is to explore the light emitting diodes (LED) features. Visible Light Communications (VLC) is an emerging technology that presents several advantages comparing to other alternatives that currently exist on the market. This solution can be use simultaneously for illumination and data transmission, being an economical alternative to wi-fi. In this work we proposed the use of a mobile phone camera combined with an application to attain a bitrate up to 1 kbit/s with BER lower that 10^{-3}. The concept of colour shift multiplexing/modulation was explored showing the capacity to successfully increase the aggregate bitrate in a 3 time fold.

1 INTRODUCTION

In the last decade, the world has seen a huge growth in the data traffic transmitted by the telecommunication networks. The increase of devices accessing mobile networks and the high demand for internet services that require high transmission rates (social networks, video calls, cloud-based services, mobile applications, etc.) has increase the research and development of new technologies with high transmission rates (Ghassemlooy, 2017). According to CISCO, in 2021 the mobile traffic will be around seven times higher, when compared to 2016 (Cisco, 2015).

Radiofrequency based communication systems suffer from multipath propagation effects in dense urban environments. This situation can reduce the performance and number of available connections. The limited bandwidth of these systems combined with spectrum congestion implies only a few high definition channels can be use. Therefore, to increase the system capacity and have a greater bandwidth a new spectral region must be utilized or the spectral efficiency must be improved. However, these two solutions imposes very high costs and higher complexity in the design and management of the emitters and the receivers (Ghassemlooy, 2017). .Depending on the frequency used, radio-based communications may also result in safety problems, in human health effects and can cause interference in different systems, as aircrafts communication and navigation system (Khan, 2017).

One possible solution is based in the use of the visible band in the 380 nm and 750 nm spectral range, named as Visible Light Communications (VLC). Since this communication type has an extremely high frequency can provide a high degree of spatial confinement, making reuse of frequency almost unlimited and providing high modulation bandwidth. This characteristic reduces licensing costs and increases security in data transmission (Ghassemlooy, 2017).

The optical signal can be generated by using light-emitting diodes or laser diodes (Ball, 2012), allowing simultaneously the illumination and data transmission. This application is usually called as Li-fi, that is a sustainable and ecological technology of VLC, allowing the transmission of information by modulating the light. In the future, it is expected that Li-Fi become complement to the Wi-Fi.

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2 STATE OF THE ART

The state-of-the-art in Visible Light Communications, can be divided into two main categories: indoor and outdoor communications. The studies related with Li-Fi, the current experiences are mainly base on the indoor environments.

In (Haas, 2015) is presented an alternative to Wi-Fi, based on the Color Shift Keying (CSK), that has the advantage of ensuring a constant illumination flow. In the emitter, they used a chip developed for ultra-parallel visible light communication design and the receiver was based on an avalanche photodiode. By combining the LED light with wireless data networks, it was possible to achieve a considerable reduction in the size of the cells and consequently an increase in the transmission rate, in the number of users served and in the total traffic. Thus, the authors showed that is possible to achieve transmission rates in the order of 1 Gb/s. In this study, a comparison is made between Wi-Fi and Li-Fi, concluding that the performance is higher when both techniques are used simultaneously, in a balanced way.

In 2017 PureLiFi (PureLiFi, 2018) launched the Li-Fi-XC, a device that allows wireless communications at very high transmission rates, in a safely way using LEDs. The Li-Fi-XC is a certified USB plug and play device. Because of its small size, it can be integrated into computers, tablets or smart devices. Allows transmission up to 43 Mbps from each LED, enabling two-way communication in Full Duplex mode. This system also allows the user to walk between different LEDs, maintaining the connection.

In 2018 Philips launched two models of LED luminaires ready to illuminate and transmit information simultaneously, the LuxSpace PoE (Philips, 2018) and the PowerBalance gen2 (Philips, 2018b). Both have a Power-over-Ethernet (PoE) technology that allows to transmit electric energy and data through a single standard Ethernet cable. These devices allow a transmission rate up to 30 Mb/s in a connection that can be bidirectional. Depending on the chosen model, for an input power varying from 9.2 W and 16.2 W, a luminous flux of 1200 lm and 2200 lm can be obtained, allowing a reduction up to 80% in the electric consumption (Lux, 2018).

MyLifi was introduced in 2018 and is another example of LED lighting prepared for Li-Fi use (Oledcomm, 2018), release by Oledcomm, it can reach transmission rates up to 23 Mbps in download and 10 Mbps upload, being used simultaneously for illumination. This device is also considered more efficient, since the lamp with 800 lumens requires 13.5 W, less than the 20 W of conventional Wi-Fi router (Takahashi, 2018). In a Li-Fi system, it is necessary for the receiver to capture the emitted light. In this way Oledcomm also as a USB device that allows any device with this interface to stablish the connection (Oledcomm, 2018).

3 SYSTEM DESIGN

The proposed VLC system is composed by a transmitter based in white emitting LED + RGB LEDs, with an individual electrical power consumption of ~ 1W (Cree XLamp MC-E Colour (Cree, 2018)), a smartphone camera is used as receiver, as illustrated in Figure 1. A DAC board, with a sampling rate of 100 kHZ, (Adalm100) and a LED driver (model T-Cube LEDD18 ThorLabs) allows to drive the LED current accordingly with the digital signal synthetized in Matlab. The capture in the mobile is done using an application (Luximeter) that measure the camera light intensity with a maximum acquisition rate of 10 samples per second.

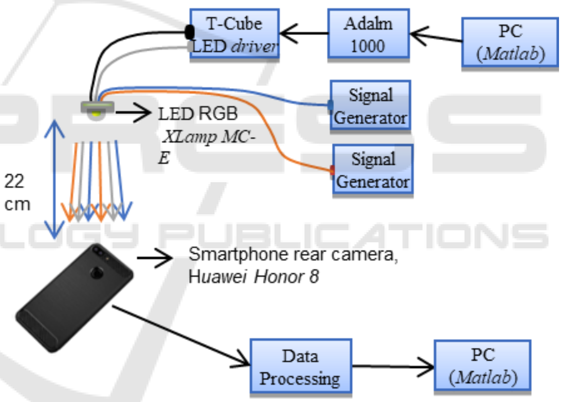

Figure 1: Circuit diagram for the implemented Li-Fi system.

The considered modulation used was On - Off Keying and the detection was made with a minimum distance rule, in this situation considering an equal bit probability, the decision level is in the middle distance between the ‘1’ and ‘0’ intensity levels.

This solution allows to use the smartphone as a Li-Fi receiver, without requiring additional hardware. On the other hand, the camera used has some limitations, like a typical frame rate of 60 fps, making the transmission rate lower. As the Li-Fi system can be used for illumination and data transmission. Is essential that intensity variations ascribed to the information cannot be perceptible by the human eye, therefore, the extinction ratio must be reduced.

Using the white LED the detection is made with the absolute intensity level. By exploring the RGB orthogonal colour space is possible to implement a colour multiplexing system. In this case the detection if made by the intensity on those 3 axes of the colour space.

However, by analysing independently the signals ascribed with blue, green and red colours, the presence of cross interference effects are observed. This is due to the mismatch between the colour primaries and the LED emission wavelengths. The RGB components can be described by:

$$S_B = b_1\hat{B} + r_1\hat{R} + g_1\hat{G} \quad (1)$$

$$S_R = b_2\hat{B} + r_2\hat{R} + g_2\hat{G} \quad (2)$$

$$S_G = b_3\hat{B} + r_3\hat{R} + g_3\hat{G} \quad (3)$$

Using those equations it is possible to construct a matrix model (matrix S) that allows to correct the cross-interference effects. In these equations, b_x, r_x and g_x are the percentage of blue, red and green colour present in each of the individually studied LEDs. The parameters $\hat{B}$, $\hat{R}$ and $\hat{G}$ are the intensity measured in each channel.

To obtain the parameters of matrix S, assigning to each LED the same intensity value and measuring the intensity for the three colours is possible obtain the matrix coefficients, show in table 1.

Table 1: Normalized coefficients for the S matrix.

LED	b_x	r_x	g_x
Blue	0.98	0.01	0.01
Red	0.09	0.82	0.09
Green	0.14	0.12	0.74

It must be referred that these values are only valid for a specific combination of emitter-receiver.

4 EXPERIMENTAL RESULTS

Using the application *Luximetro* (developed by Crunchy ByteBox, available for Android devices on Google Play) and the front camera was possible to implement a direct detection receiver. A sample function of the signal transmitted is presented in Figure 2 top, corresponding to s test 9-bit NRZ sequence 100100101. Each bit has a duration T_b = 2s with 10^5 samples per second and an extinction ratio of 1.1. Due to the limitation imposed by the smartphone camera, the capture is limited to 100 samples per second. The samples received over the time, for a transmission distance of 22 cm, are presented in Figure 2 bottom. This value is in the range of the typical distance between a desk lamp and the table.

To analyse in detail the implemented solution and overcome the limitations imposed by the smartphone camera, was used a photodiode (ThorLabs PbS PDA30G) as reference receiver. The optical power was measure with an optical power meter (IF-PM200) with a detection area of 1 cm^2.

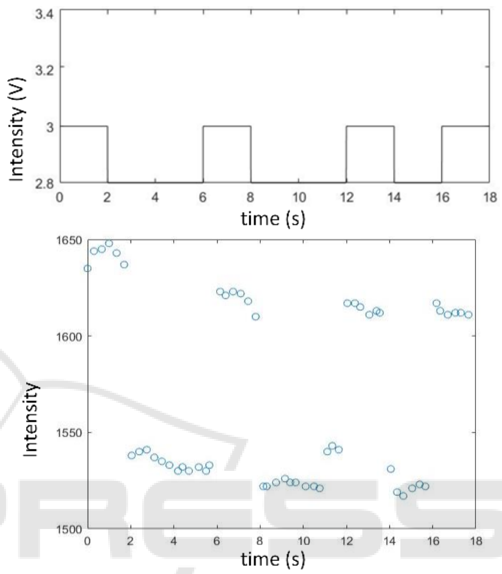

Figure 2: Sample function of the signal. Top) transmitted; Bottom) captured samples using the camera.

The bit error rate evolution as function of the transmission rate is shown in Figure 3. For transmission rates up to 1200 bit/s it is possible to obtain a BER of less than <10^{-3}, that corresponds to the FECs limit.

The BER evolution with the received optical power, for a transmission rate of 2 kbit/s is displayed in figure 4.

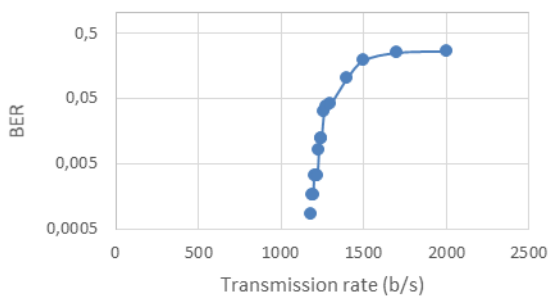

Figure 3: BER evolution as function of the transmission rate.

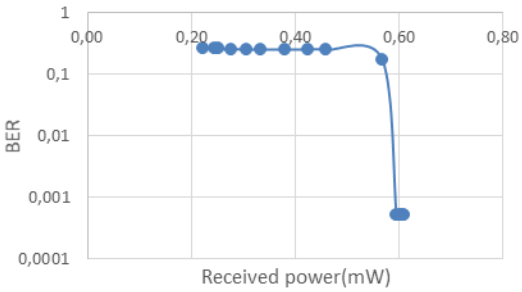

Figure 4: BER as function of the received optical power.

The minimum optical power required to operation with BER lower than 10^{-3} is 0.6 mW. To qualitatively evaluate the quality of the signal received at 10 kbit/s the eye diagram was obtained and illustrated in Figure 5.

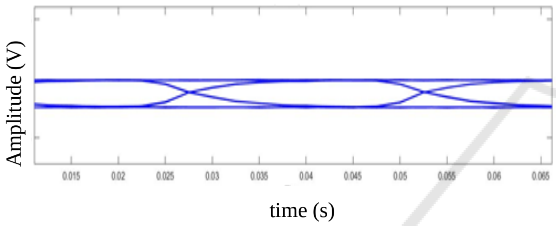

Figure 5: Eye diagram for a 10 kbit/s transmission rate, obtained for a distance of 7 cm.

The result shows low noise and non-significant distortion, verifying the quality of the received signal.

To increase the aggregate transmission rate, it was considered a RGB emitter. The electrical current of the three LEDs here adjusted to obtain a maximum optical power of 7.2 mW, also the influence of the external light sources in this system was considered.

In figure 6 is displayed the raw data for the received signal, with high background intensity levels, due to the presence of environmental light.

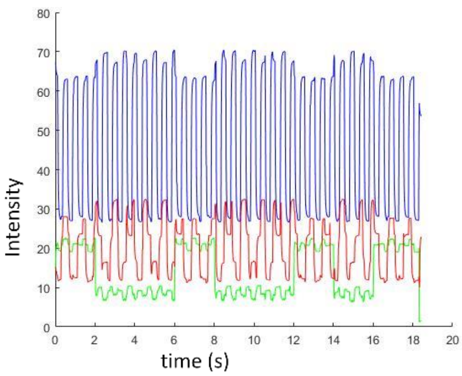

Figure 6: Signal received for the RGB system, considering a natural environment background light.

Combining these values with the matrix S, it is possible to retrieve the original signal, as show in Figure 7.

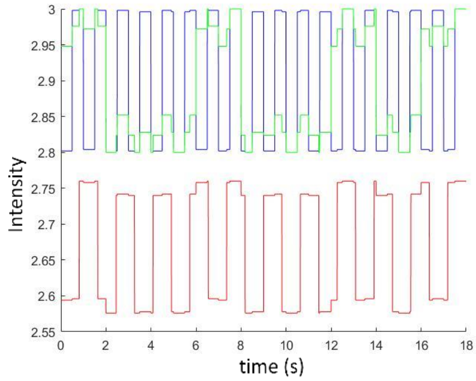

Figure 7: transmitted signals reconstructed from the RGB channel raw data and the matrix S.

5 CONCLUSIONS

VLC systems are an alternative to the technologies that we currently use for transmission. Li-Fi is considered an emerging technology that will help to complement the existing systems such as Wi-Fi.

We demonstrate the possibility to transmit in distance in the order of dozens of centimetres, with a transmission rate up to 1200 b/s, with bit error rate lower than 10^{-3}, the received optical power needs to be higher than 0.6 mW.

By using colour shift modulation /multiplexing is possible to stablish a link with a mobile phone, enabling a Li-Fi solution without extra hardware.

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