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# LED-to-LED Communication on Layer 1 VLC

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## ABSTRACT

Visible Light Communication (VLC) is an up-to-date issue where Light Emitting Diode (LED) is used for lighting and data transmission. Although interest in Visible Light Communication has increased in current academic studies, the devices ready for commercial use are still lacking. In this study, a visible light communication system designed to work in Layer 1 of the IEEE 802.15.7-2011 standard is presented and its performance under different conditions is investigated.

The system design is based on an embedded Linux platform, where a LED is used in the transmitter and another LED is used in the receiver. Application, TCP/IP, and Data Link Layer functions required for communication in the structure are implemented with software.

Payload and distance variables were tested for performance evaluation in the PHY layer on VLC. The effect of variables on the performance of VLC has been analyzed.

## General Terms

Wireless Communication, Communication with Light

## Keywords

VLC, LED, Wireless Communication, Layer, LED-to-LED

## 1. INTRODUCTION

The increasing number of mobile devices in everyday life also increases the need for wireless communication. In addition to mobile devices, embedded connected devices such as the Internet of Things (IoT) and in-vehicle networking have also increased the demand for electromagnetic frequency bands allocated to Wi-Fi. As a result, as the demand for wireless resources increases, there is a problem known as the Wi-Fi spectrum crunch. Visible light communication (VLC) has great potential to address the shortage of Wi-Fi spectrum. VLC is capable of operating at much higher frequencies than Wi-Fi, allowing wireless communication at very high speeds.

Visible light communication is a subset of optical wireless communication (OWC) that uses the visible light spectrum and provides a cost-effective, energy-efficient wireless solution to achieve high data rates.VLC uses modulated optical radiation from light-emitting diodes (LEDs) and laser diodes to convey digital information without appreciable effects on the human eye [4]. Intensity modulation and direct detection (IM/DD) is generally preferred in the physical layer (PHY) of VLC. Therefore, the initial work was based on simple modulation methods such as On-Off Keying (OOK) and Pulse Position Modulation (PPM) [10]. OOK and PPM were chosen as modulation schemes in the IEEE 802.15.7 standard published in 2011 [8].

Today, the white light LED used for VLC consists of a blue LED wrapped in a layer of yellow phosphorus. Figure 1 shows the spectral distribution of an InGaN (indium gallium nitride) LED widely used today to produce white light. Due to the slow temporary response of phosphorus, modulation bandwidth is limited to several MHz [9].

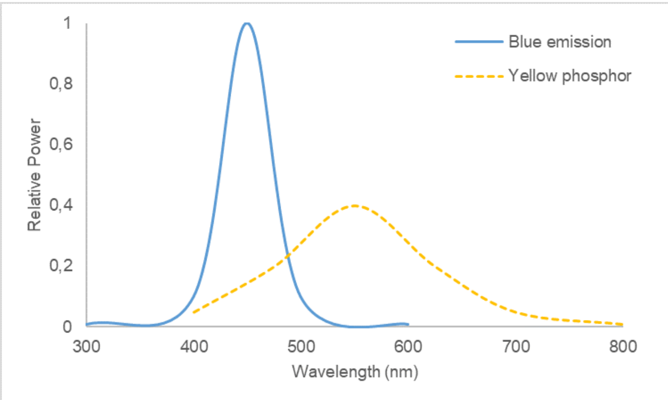


Fig. 1. Spectral distribution of LED

Although the Visible Light Communication structure includes dual-functioning as both lighting and data communication, the communication feature is defined as a secondary function. The characteristics of the space to be used for communication during the system design phase must be compatible with the standards of primary function in VLC systems and the effects of lighting needs [7]. These parameters are key parameters that need to be addressed in the design. This is a problem that is not encountered with other wireless communication systems.

As a spectrum-rich alternative to RF communications, VLC is of interest to both researchers and industry [12] [13]. The increase in the number of devices that will become smart by connecting to the Internet may lead to a new type of infrastructure, the Internet of Lights (IoL), in the future.

This paper aims to analyze the effects of payload and distance conditions on the performance of visible light communication. The study realizes this analysis with a PHY1 layer-based experimental design.

The rest of the paper is organized as follows. In Section II, IEEE 802.15.7 standardization is explained. In Section III, The system model, which includes implementation details and experimental setup based on standardization, is explained. Performance evaluation is given in Section IV.

## 2. IEEE 802.15.7 STANDARDIZATION AND RELATED WORK

The IEEE 802.15.7 physical layer and media access control (MAC) layer were specified in 2011. Three physical layer types (PHY) with different data rates from 11.67 kbps to 96 Mbps were identified and categorized [1]. Table 2 shows the specifications for PHY-I.

Visible light communications describe the short-range optical wireless communication which uses the visible light spectrum from 380 to 780 nm as the carrier. IEEE 802.15.7 standard supports high-data-rate visible light communication up to 96 Mbps. The fast modulation method is applied with visible light sources, and dimming may also be applied. For flicker-free high-data-rate VLC, IEEE 802.15.7 provides dimming adaptable mechanisms.

In recent years, the exponentially growing number of mobile devices and wireless services also caused a great demand for RF-based technologies. The advances in LED light bulb technology have revolutionized the lighting industry. Based on the LEDs, VLC offers a free spectrum and high data rate, which has the potential to serve as a complementary wireless communication technology to radio frequency communication.

## 3. SYSTEM MODEL

The design structure is a development platform for VLC networks consisting mainly of three parts:

—Development platform,
—Pcb with necessary hardware components,
—The software.

BeagleBone Black (BBB) [2] was chosen as the development platform in the system design. Xenomai real-time development framework was integrated into the 3.8 kernel version of on the Debian operating system, which is the official distribution of the platform.

Figure 3, shows the block diagram of the introduced design. In the design, the transmission medium is air, and low-power LEDs are used in transmitters. In the system, PHY I communication is used

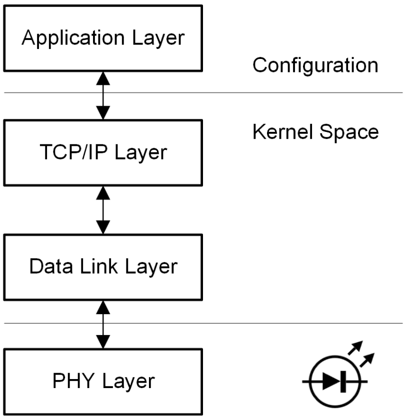


Fig. 2. Implementation of the MAC protocol in the operating system

with On-Off Keying (OOK) Modulations, Manchester RLL code, 200 kHz Optical clock rate, (15,7) outer code (RS), and 1/4 Inner code (CC) FEC codes have been implemented.

The standard framework used as the communication protocol is presented in Table 3.

The study, it was aimed to include VLC in smart lighting with low-power LEDs by integrating cost-effective electronic components. With its basic form, the structure operates at distances of up to 2 meters with a bandwidth of 375 b/s for Layer 1 of the IEEE 802.15.7 protocol. Figure 4 and Figure 5 shows the experimental setup of the system and the transceiver unit, respectively. Hardware components of the units are presented in Table 3.

### 3.1 LED as Optical Sensor

Photodiode, photo transistor-like optical sensor circuit elements can detect in a wide radiation spectrum [6]. This situation causes both increased inputs and decreases in sensor sensitivity. In another adverse situation, it consists of excess circuit elements to be used during the filtering of the desired part in the data flow of the sensor. The use of tape-passing filters, mechanical filters, and similar development requirements increase the complexity of the structure.

In order for the LEDs used as transmitters to be used as receivers, it is enough to know/measure the internal capacity phenomenon in each circuit element instead of going deep into the physical properties of the circuit element. When the potential difference on the circuit elements is removed, they begin to discharge due to the internal capacitive effect. The LED, which emits light in its radiation band under the correct polarized, also begins to discharge when the potential difference on it is removed and continues until there is enough potential difference to polarize/beam correctly again. This situation occurs quite quickly in the structure where LED is used as a communication tool. For example, physical layer 1 also has a 200 kHz optical clock. If we can measure the discharge voltage of the LED in the closed position by measuring the potential difference in the LED at sufficient speed.

In the studies conducted by Mims in 1992 and Acharya in 2005, it was mentioned that if special LEDs are used as sensors, there is no need for an additional optical filter for communication and it is emphasized that they are more resistant to sunlight interference

Table 1. PHY I in IEEE 802.15.7 standard [1]

| **Modulation** | **RLL Code** | **Optical Clock Rate** | **FEC** | | **DataRate** |
|---|---|---|---|---|---|
| | | | **Outer Code (RS)** | **Inner Code (CC)** | |
| **OOK** | **Manchester** | **200 kHz** | **(15,7)** | **1/4** | **11.67 kb/s** |
| | | | (15,11) | 1/3 | 24.44 kb/s |
| | | | (15,11) | 2/3 | 48.89 kb/s |
| | | | (15,11) | none | 73.3 kb/s |
| | | | none | none | 100 kb/s |
| VPPM | 4B6B | 400 kHz | (15,2) | none | 35.56 kb/s |
| | | | (15,4) | none | 71.11 kb/s |
| | | | (15,7) | none | 124.4 kb/s |
| | | | none | none | 266.6 kb/s |

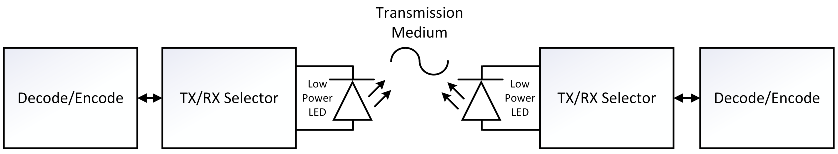


Fig. 3. Transmitter Design

Table 2. Frame Format

| Frame | Length (byte) |
|---|---|
| Preamble | 3 |
| SFD | 1 |
| Frame Length | 2 |
| Destination Address | 4 |
| Source Address | 4 |
| Protocol | 2 |
| Payload | 0-255 |
| CRC | 2 |

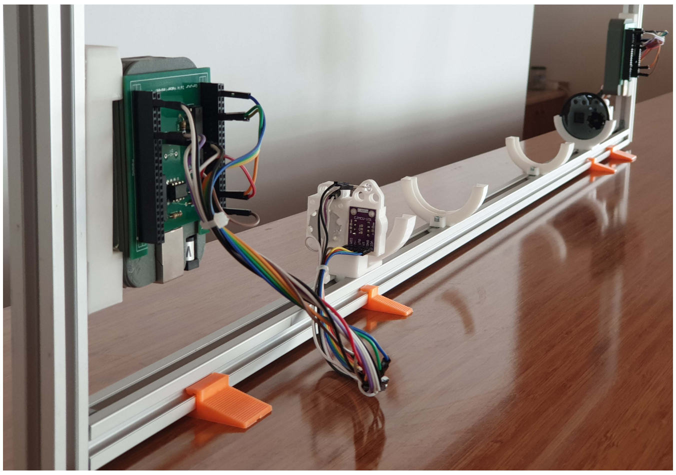

Fig. 4. Experimental setup of the system

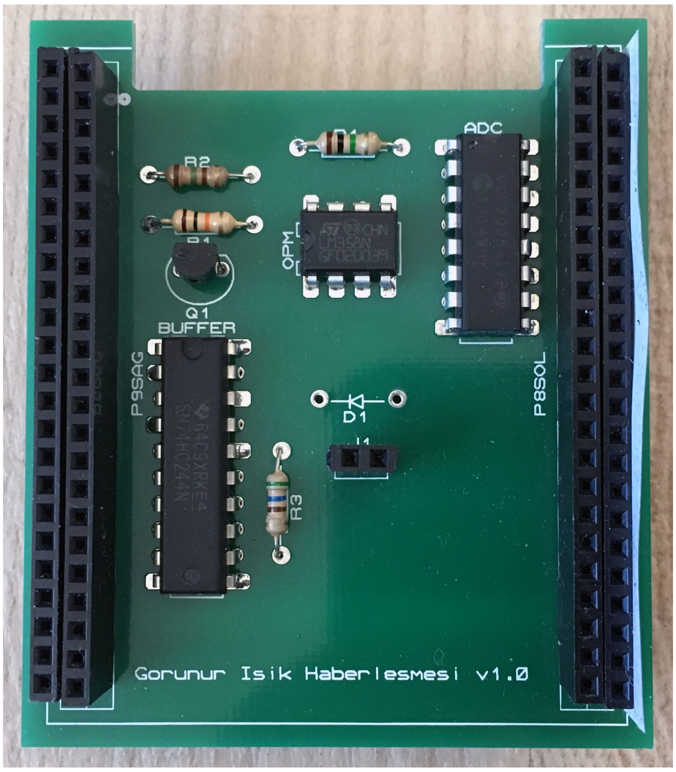


Fig. 5. Transceiver design

[3]. In the study to be done, when LEDs are used as receivers, their ability to detect in a slightly wider spectrum than the light spectrum they emit will be tested. In case the structure works as designed, there will be no need to use band and light filters, which are needed in circuits using optical sensors.

The idea of using LED as a receiver and transmitter emerged from the necessity of direct detection in optical communication. As with on-off keying, the presence of the signal (light) symbolizes ”1”, and its absence represents ”0”.

Table 3. Hardware components

| | |
|---|---|
| 74HCT244N | 8-bit buffer with tri-state outputs |
| 2N3904 | Transresistance amplifier |
| LM358N | Transimpedance operational amplifier |
| MCP3008 | 10-bit analog-to-digital converter |

The intensity of the incoming light is converted into current or voltage value if a photodiode and similar circuit elements are used as a receiver; LED can be analyzed in different ways if it is desired to be used as a receiver.

For example, the small value capacitor to be connected in parallel with the LED can be charged just before the period when the LED is intended to be used as a receiver and the amount of voltage on the capacitor can be measured according to the presence and absence of incoming light. The discharge time of the capacitor parallel to the LED under reverse polarization can be shortened by the amount of light falling on the LED. Even if the measured value varies according to the selected capacity value, the voltage value below the threshold (threshold) to be determined indicates the presence of light, i.e. the signal ”1”; the voltage value above the threshold value indicates that there is no incoming signal, that is, the ”0” signal. Thus, LED can be forced to work photo diode-like operation and, as previously mentioned, can do this work between a much narrower light spectrous 6.

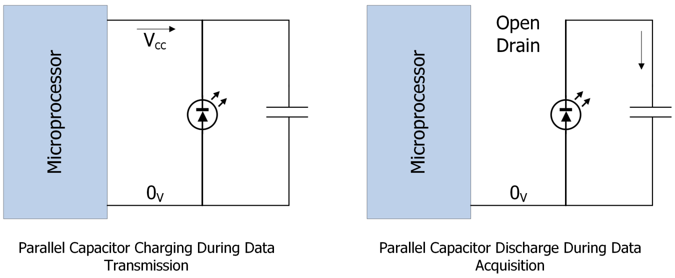


Fig. 6. Usage as Receiver with LED Parallel Capacitor

Like any electronic circuit element, it has an internal capacitive effect on LEDs, which can be observed in the reverse polarization of diodes, albeit in a few nanoseconds. If the LED is reverse polarized quickly enough and the potential difference between the ends can be observed, the effect of the light falling on the LED on the led’s discharge can be observed 7.

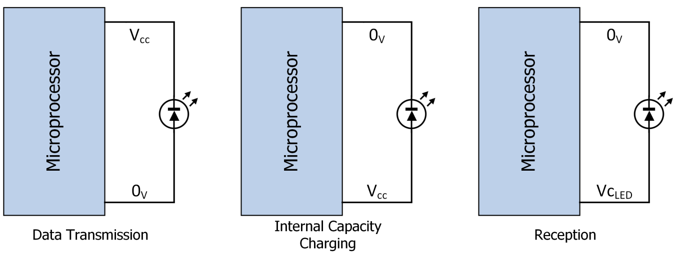


Fig. 7. Using the LED as a Receiver

The internal capacity of each circuit element can be used as a measurement tool, provided that measurements can be made fast enough one step further. Thus, a parallel capacitor is not needed. As described above, the LED charged with reverse polarization creates an internal light flux with the internal capacity falling on top of it and forces the internal capacity to discharge. Thus, the signal value can be measured with the amount of voltage read at the end of the specified period.

$$V_{C_{LED}}(t) > V_{threshold} \rightarrow signal = 0$$

$$V_{C_{LED}}(t) < V_{threshold} \rightarrow signal = 1$$

Low-power LEDs will be used as receivers and transmitters in the first test assembly. The structure; The circuit contains the return signal tip that detects transmitter ends for receiver, transmitter, and buffer signals and signals coming through the LED at the log level via the analog-digital converter 8.

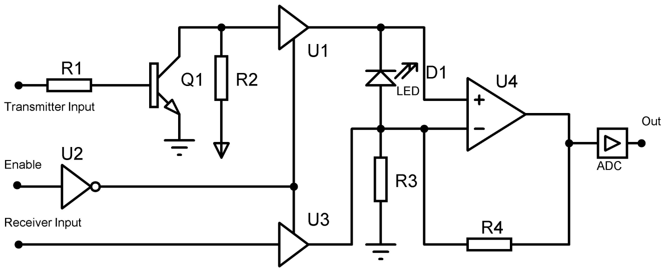


Fig. 8. LED-and-LED Circuit Board Logic Design

## 4. PERFORMANCE EVALUATION

The variables used in the application scenarios are presented in Table 4. For performance evaluation, parameters such as payload to be transported and low power LEDs were used.

Table 4. Experiments

| Variable | |
|---|---|
| **Dİstance (m)** | **Payload (b)** |
| 0.2 | 10 |
| 0.4 | 40 |
| 0.6 | 80 |
| 0.8 | 120 |
| 1 | 160 |
| 1.2 | 200 |
| 1.4 | |
| 1.6 | |
| 1.8 | |

The data are collected under conditions where the payload is 200 bytes. Figure 9 shows the throughput with the effect of distance on the data transfer rate. In the analysis, low-power LEDs are used with communication distances between 0.2m to 1.8m.

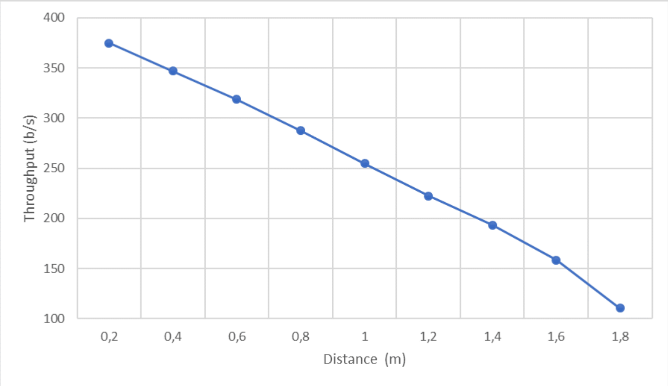


Fig. 9. Throughput with different LED types

For example, while the data transfer rate is 110,32 bytes with the low-power LED on 1.8m, it reaches the data transfer rate of 374,83 bytes on 0.2m.

As expected, the data transfer rate increases with the communication distance.

Figure 10 shows the throughput with data rates for the payload of 10, 40, 80, 120, 160 and 200 byte, and the distances of 0.2, 0.4, 0.6, 0.8, 1, 1.2, 1.4, 1.6 and 1.8m.

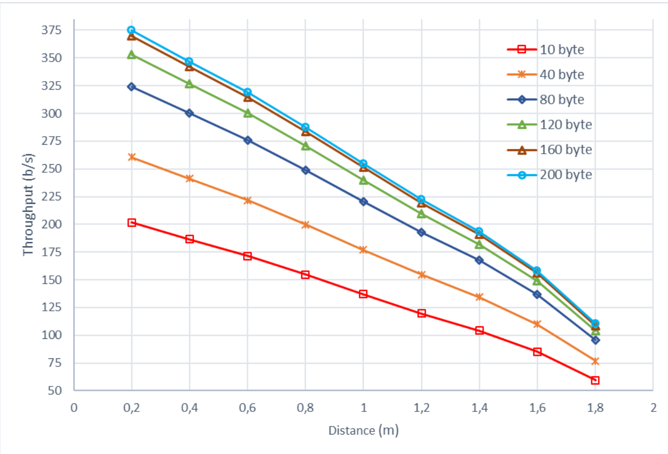


Fig. 10. Throughput with different payloads

As expected in the system, the data transfer rate increases when the payload increases and decreases with the increase of communication distance.

Figure 11 shows the standard deviation of data rates, and the distances of 0.2, 0.4, 0.6, 0.8, 1, 1.2, 1.4, 1.6, and 1.8m.

As expected in the system, the standard deviation in the data transfer rate increases as the communication distance increases.

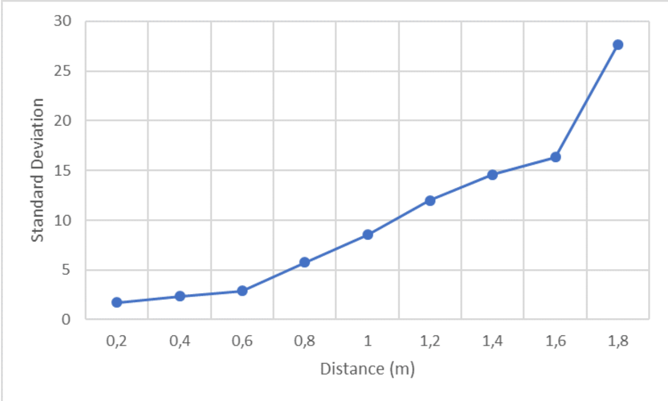


Fig. 11. Standard Deviation with distance

## 5. CONCLUSION

This paper presents the design, implementation, and performance evaluation of a platform developed for VLC exploration in the field of network-based embedded systems at the Layer 1 level. The structure in the study shows that it is sufficient as a starter kit for VLC research. In the future, the structure can be easily extended and various functions can be added. Likewise, it can be used with the development of network protocols to support the use of existing networks.

Among similar studies, although the transceiver designed by Pornchanok Namonta et al. for Layer 1 can reach performance values of 100 kb/s at 2.5 meters (5.9 meters by using a repeater), the structure requires complicated ready-made parts and a computer connection for processing power [14]. The main difference between the study is its low cost and self-study.

More efficient and faster-LED drivers can be suggested for the improvement suggestions of the study. A more efficient structure for high power LED can be created by referring to the LED driver recommendations submitted by Fengyu Che et al. [5] in 2016 and by Yu-Chen Lee et al. [11] in 2016. Similarly, it is possible to replace the BBB circuit that forms the system infrastructure with a more powerful, new generation SoC.

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