

# **Journal of Digital Science**



**ISSN 2686-8296**

**Volume 2 Issue 2**

**December 2020**

**© Institute of Certified Specialists**

## CONTENTS

<b>Design and Evaluation of Visible Light Wireless Data Communication Models ..</b>	<b>3</b>
Simona Riurean	
<b>Predicting the Signs of the Links in a Network .....</b>	<b>14</b>
Quang-Vinh Dang	
<b>The origins of severe software defects method .....</b>	<b>23</b>
Nico Hillah	
<b>The development of a classification model of accounting in the digital economy .....</b>	<b>31</b>
Aleksei Kovalev	
<b>Development principles for preparing financial reporting in the context of digitalization .....</b>	<b>44</b>
Elena Dombrovskaya	

# Design and Evaluation of Visible Light Wireless Data Communication Models

Simona Riurean [0000-0002-5283-6374]

University of Petroșani, Petroșani 332006, Romania

[https://doi.org/10.33847/2686-8296.2.2\\_1](https://doi.org/10.33847/2686-8296.2.2_1)

Received 30.09.2020/Revised 01.12.2020/Accepted 21.12.2020/Published 29.12.2020

**Abstract.** The technologies based on the radio frequency used for wireless transmission indoor are more congested than ever these days, therefore several wireless communication alternatives are intensively searched. Some most promising technologies are based on the optical part of the electromagnetic spectrum. The benefits and drawbacks in optical wireless data communication models design are presented in this work. The key characteristics of the VLC systems are briefly discussed, as well. Some models developed for wireless data transfer in visible light communication and infrared are presented, and their operation related to the data rate and the length of the optical link, are briefly compared.

**Keywords:** Visible Light Communication, LED and PD key characteristics, Optical link, prototypes.

## 1. OWC Technologies and Applications

This article is an extension of the paper [1] presented at the ICCS 2020 conference.

The wireless transmission has gone through many paradigm changes after the advent of electromagnetic (EM) waves, remote communication such as telegraphy and the invention of radio [2, 3]. EM waves consists of radio, infrared (IR), visible, ultraviolet, etc. [2]. Today, the RF part, among these all, is the most used for communication purposes.

The RF communication does not require a Line of Sight (LoS) architecture between the transmitter (Tx) and receiver (Rx). The RF signal can travel long distances from Tx to Rx and also reach high data rates [3], however, faces some challenges such as interference, security issues as they can easily penetrate through solid objects, bandwidth and power limitations resulting in power inefficiency, lots of vulnerabilities in the respect of data security, and also affects the health and human wellbeing. Most important, the RF space has become increasingly crowded lately because of the many smart devices (desktops, laptops, tablets, smart phones and so on) connected simultaneously, especially indoor where the most data traffic occurs [4]. Therefore, developing alternative solutions to wireless RF transmissions especially indoor but also outdoor is imperious necessary to solve these congestions. The various optical wireless communication (OWC) technologies and applications developed so far (Infrared communication - IR, Visible Light Communication - VLC, Optical Camera Communication - OCC, Light Fidelity LiFi and Free Space Optics - FSO), emerge as a potential partner to the RF technologies (Wi-Fi, Bluetooth Low Energy, Cellular Data, ZigBee, 6LoWPAN, WiMax and so on – fig. 1.) and, in some specific scenarios, the major player. The IR Communication, VLC, OCC and LiFi, dedicated to indoor implementations and FSO aiming to transfer remote data outdoor, have been intensively researched lately. Today, these technologies and applications, early used as indoor positioning and tracking systems already tested and installed in

museums, airplanes, schools, underground, retail or medical facilities are about to become ubiquitous [5-8]. The instruments dedicated to human wellbeing and health, as smart watches, IR temperature measurement devices or finger pulse oximeters are these days more necessary than ever. IR wireless communication has been already searched for decades and some of its most used applications worldwide are the TV remote control, robots' control and positioning. The discovery of the white LED (in 1990 by Shuji Nakamura from USA and in 1992 by Isamu Akasaki and Hiroshi Amano from Ja-pan that received in 2014 the Nobel prize for physics [9]) triggered intensive research on VLC technology.

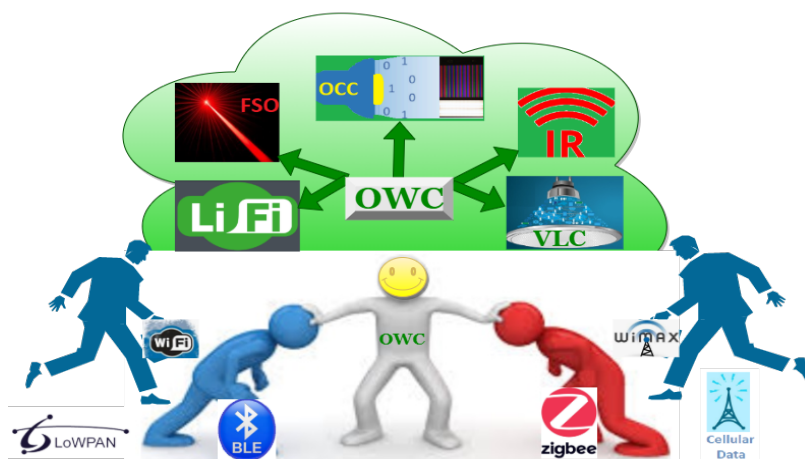


Fig. 1. Optical Wireless Communication versus RF technologies

OCC considered in IEEE 802.15.7m standardization along with VLC, covers the transmission between light sources and cameras for low rate communication and localization [10]. LiFi (coined by Harald Haas during a Ted conference in 2011) is a networked, MIMO, full duplex (VLC download and IR upload) wireless communication technology using access points embedded into the lighting fixtures [11].

The automotive applications such as Vehicle to Vehicle (V2V) communication, Vehicle to Infrastructure (V2I), Infrastructure to Vehicle (I2V) or Infrastructure to Infrastructure (I2I) and many other applications are more investigated than ever and aim to improve transport security, the human comfort, and become energy efficient [12]. V2V wireless communication is one of the most intense researched and advanced findings in FSO area [13].

### 1.1. Standardization of VLC

A significant step towards the widespread commercialization of VLC networks was the advent of the IEEE 802.15.7 standard in 2011. It defines three physical layers (PHY) (from PHY I to PHY III) and the Media Access Control (MAC) layer. PHY I layer is designed for outdoor scenarios, while PHY II and PHY III layers aims the indoor applications. A typical physical layer model of VLC is presented in figure 2.

There is a total of thirty combinations of modulation and coding schemes defined for VLC. PHY I are specified uses Reed-Solomon (RS) and Convolutional Codes (CC) for Forward Error Correction (FEC), while PHY II and III rely mostly on RS codes for FEC only.

Both PHY I and PHY II use On-Off Keying (OOK) and Variable Pulse Position Modulation (VPPM), while PHY III uses only color shift keying (CSK), thus PHY III is compatible only with Red Green Blue (RGB) LEDs.

Depending on the modulation used, the Run-Length Limited code (RLL), the optical clock rate, the FEC code, the three PHY modes, there are different data rates: 11.67 to 266.6 Kbps, 1.25 to 96 Mbps and 12 to 96 Mbps. The physical network topologies supported by the MAC layer are star, peer-to-peer, and broadcast. Three classes of devices are considered: vehicles, mobile and infrastructure.

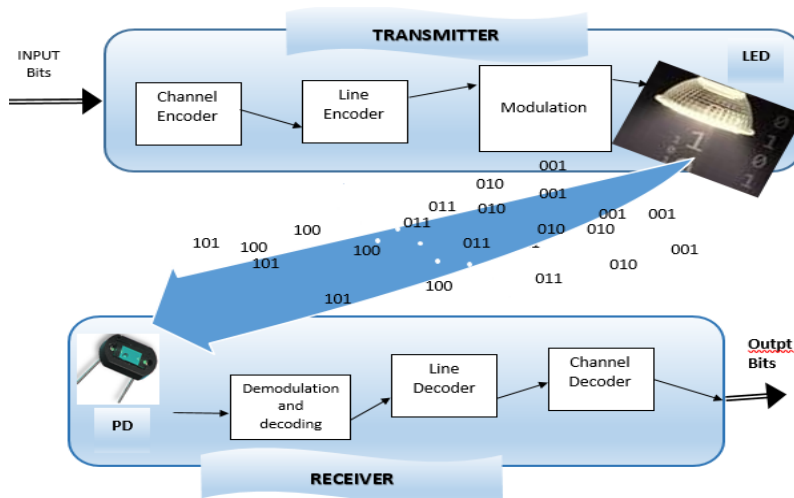


Fig. 2. Typical physical layer model of VLC

The MAC layer addresses characteristics as: support for mobility, dimming, color function and visibility, avoid flicker, support for pairing and disassociation in the VLC Personal Area Network (VPAN), generation of network beacons if the device is a coordinator, and reliability of the connection between MAC entities. Security considerations are applied at the application level. The MAC 802.15.7 layer is very close to the IEEE 802.15.4 MAC Personal Area Network (WPAN) [14].

However, many situations of using VLC technology are not considered in these standards, therefore, the IEEE Task Group 7m, first known as the IEEE 802.17.5r1, was initiated in late 2014 to revise the IEEE 802.15.7-2011 standard [15].

## 2. Key characteristics of oTx and oRx in a VLC setup

### 2.1. A general setup of the VLC system

A VLC system (regardless the topology setup) comprises the optical transmitter (oTx) and optical receiver (oRx), two separate modules responsible for sending/receiving data piggyback by the light.

Possible topologies in optical wireless transmissions (fig. 3) used for communication between transmitter (oTx) and receiver (oRx) can be a directed line of sight (LoS), non-directed LOS (NLoS), diffuse or quasi-diffuse links.



Fig. 3. a. Direct Line of Side (LoS) link, b. NLoS link, c. Diffuse link d. Quasi-diffuse link

The general diagram of a generic VLC system (fig. 4) consists of an oTx, the environment where the optical signal is affected by different noises, and the oRx.

Channel coding and modulation in oTx aim to adapt the signal to the channel and the part responsible for the conversion of the electrical signal into an optical one (E/O circuit in figure 4) is the main part of the oTx, the light source.

Noises into the environment (where the optical beam of light travels) affect the signal due to the ambient light. The ambient light can be the natural light and/or other sources of artificial light (fluorescent, incandescent bulbs or LEDs).

The photodetector (PD), part of the oRx module, is responsible to convert the optical signal into an electrical one (O/E circuit in Fig. 4).

The signal already converted is amplified and then demodulated and decoded to be recovered as accurately as possible.

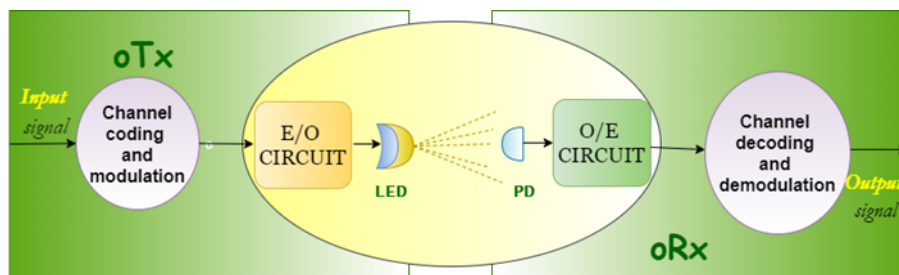


Fig. 4. A general diagram of a VLC system

## 2.2. LED's key characteristics for oTx setups

VLC systems can use different types of light sources such as white LEDs (WLEDs), array or stripe of SMD LEDs,  $\mu$ LEDs, OLEDs, Laser Diodes (LDs), according to the requirements of the application and specific environment. The most challenging characteristics of the LED for stable, mature VLC systems, are their nonlinearity and the limited modulation bandwidth. Numerous factors, such as quantum confined stark effect (QCSE), carrier lifetime, carrier recombination time, crystal orientation, etc. affect the modulation bandwidth of LEDs [16,17].

The modulation bandwidth of the VLC (generally limited to MHz) is directly influenced by the frequency response of the LED, therefore, negatively affects the data rates. It depends on the lifetime ( $\tau$ ) of the carrier recombination on the active region and on the p-n junction capacity. The frequency response of the off-the-shelf white LEDs is fundamental constraint by the slow temporal response of the yellow phosphor layer.

There are a number of proposals in literature for addressing the LEDs' non-linearity drawback in VLC systems. The simplest method is to use binary transmission such as the On-Off Keying (OOK) or Pulse Position Modulation (PPM), when the LED is simply switched on and off at specific current values. To mitigate this effect, higher spectral efficient modulation schemes such as multi-band Carrier-less Amplitude and Phase modulation (m-CAP), Orthogonal Frequency Division Multiplexing (OFDM) or color shift keying (CSK) have been used [18]. On the other hand, using Wiener model, although demonstrated only by simulation, a valid adaptive pre-distortion technique was proposed by Qian et. al. for the VLC systems. It consists of a linear time-invariant and memoryless nonlinear model, but with significant complexity VLC setup [19]. Since then, many other pre-distortion methods are being proposed [20,21].

A different solution is the use of a blue filter in front of the PD, to remove the slow response of the yellow phosphorus. Both the frequency response of the LEDs and the modulation bandwidth are related to the input current level and the junction and parasitic capacity. The LED's cut off frequency is also important. It refers to the maximum frequency at which the LED's light emission decreases to half the initial light intensity. Whether the transmission system is simplex or duplex, it is important to switch the LED between ON and OFF at high speed. The requirements for the signal that determines the output color are usually lower in terms of voltage compared to their power supply

When selecting a LED, for a robust VLC setup, the light intensity, the wavelength of light, the light scattering, the modulation speed and the power requirements must be considered.

For example, in case of using a stripe of Surface Mounted Diodes (SMD) LEDs (such as 3528s, 5050s, 2835s or 5630s) each LED can be addressed independently. Although the signal degradation occurs, the problem can be solved by connecting the LEDs to a series of synchronized controllers.

If the wavelength of LED is matched with that of the PD from the optical receiver (oRx), the noise level produced by the ambient light (natural and artificial) is decreased, therefore the correct reading of the optical signal is ensured. A high optical power requirement may also involve a cooling solution when the prototype is designed for a VLC network working in special scenarios with high ambient light noise.

### **2.3. PD' key characteristics for oRx setups**

Light Dependent Resistors (LDRs), imaging sensors or a photodetectors (PDs) can be used in a VLC systems use as oRx a. PDs can support higher bandwidths for higher downlink speeds than camera-based VLC.

The Positive Intrinsic Negative Photodetectors (PIN PDs), and the avalanche photodiode (APD) are the highest sensitive semiconductor PD used in VLC systems that exploits the photoelectric effect to convert light into electricity. Silicon APDs are de-signed to offer high conversion gain, increased sensitivity and lower noise compared to standard PIN detectors but are more sensitive to extreme temperatures than PIN PDs [22]. On the other hand, APD produce a stronger signal but add more Poisson noise.

As Si PIN PDs have low voltage operation, high tolerance to a wide range of temperature fluctuations and excessive lighting, linear response characteristics, and low costs, are most often used in VLC systems.

PDs can be configured in two modes, photovoltaic and photoconductive. In photovoltaic mode the diode is unpolarized and the relationship between voltage and the amount of light is nonlinear. Usually, the photovoltaic panels operate in this way, being useful in producing electricity but limiting the sensitivity of the diode. Photovoltaic mode is preferable if we want to make accurate measurements since it is less susceptible to noise. The photoconductive mode applies a reverse bias voltage to the PD and the relationship is linear, up to 1mW optical power for a 1mm diameter diode.

The applied voltage produces a lower capacity and a higher speed of the diode to the detriment of heat production. Photoconductive circuits have applicability in bright light environments and where fast readings are needed.

### **2.4. Boards used for VLC development**

The Arduino, Raspberry Pi, BeagleBone Black or STMicroelectronics Nucleo 32L0 are some of the development boards that are affordable for early prototyping and proved to have acceptable performance in different VLC topologies [23-27].

Arduino certainly has several options in the field of prototyping, their specialty being in robotics and small, localized systems. There are many options for compatible modules including sensors, prototyping boards, lighting, motors, and anything else that requires a short program to be controlled.

The reason the Raspberry Pi can be a proper choice for prototyping, is that it has the same behavior as a computer. It can connect to the internet, process text files, is compatible with peripheral devices (keyboard, mouse, screen), processes media files and is generally capable of anything as long as it needs enhanced processing or enhanced graphics capabilities. Last year, the newest Raspberry Pi 4B model was launched with significant improvements as 8Gb of RAM, 2 micro HDMI ports capable of 4k resolutions at 60 frames per second, Bluetooth 5.0, Gigabit Ethernet and a 1.5 GHz ARM v8 64bit processor.

The BeagleBone Black board has Sitara AM3358BZCZ100 processor, a Dual Data Rate RAM memory Micron 512MB DDR3L or Kingston 512mB DDR3 the physical interface to the network through SMSC Ethernet PHY and a high-definition multimedia interface (HDMI) Framer that provides control for an HDMI or DVI-D display with an adapter, as well as with various connectors, LEDs and switches (DC Power, power button, 10/100 Ethernet, serial debug port, four blue LEDs, USB, mini-USB, microSD, microHDMI BOOT switch and reset button).

STM Nucleo 32L0 board is designed around the STM32 microcontrollers in a 64-pin. It provides a high-power efficiency, with dynamic voltage scaling, an ultra-low-power clock oscillator and short wakeup time. The autonomous peripherals (including USART, I<sup>2</sup>C, and touch sense controller) reduce the load of the Arm® Cortex®-M0+ core leading to fewer CPU wakeups and contribute to decreased processing time and power consumption.

However, Raspberry Pi and Arduino are the main PCBs used in VLC prototyping to keep the features high and the cost low of the final product.

### **3. oTx and oRx modules for indoor data transfer**

The challenging journey from idea to testing a prototype has to follow few important steps [28].

The prototypes developed aim to test VLC system for indoor data transfer in a LoS topology under regular ambient light (sunlight and fluorescent light sources embedded into the lighting fixture).

In a more advanced scenario, an additive light source coming from a desk lamp with white LED placed over the VLC system aims to determine the influence of this additional noise on the system performance in terms of distance between oTx and oRx.

#### **3.1. VLC model with Arduino**

The prototype with the Arduino PCBs (Arduino Uno for the oTx and Arduino Mega for oRx) a text message was sent to a 400 mm distance (see fig. 5.). The oTx circuit was built with NPN transistors 2N3904 and 2SC5200, resistors and capacitors

The LED used is VLHW4100 with luminous intensity 90-110 LM, VF min 3.0 V max 3.6V, Max current 350 mA and CCT of 3200 - 3500K. The oRx circuit was built with the NE5532 Op Amp, resistors and capacitors. For the first scenario, a solar panel was used and then a PD type is VTB8440BH with IR filter (Fig. 5).

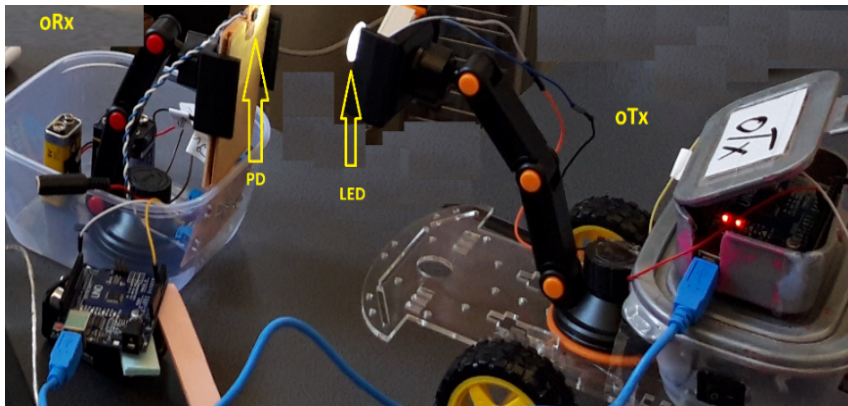


Fig. 5. VLC prototyped with Arduino PCB

### 3.2. VLC model with Raspberry Pi

The prototype with the Raspberry Pi PCB (Fig. 6. and 7.) has the LED type APA102C and a circuit with PNP transistors and resistors.

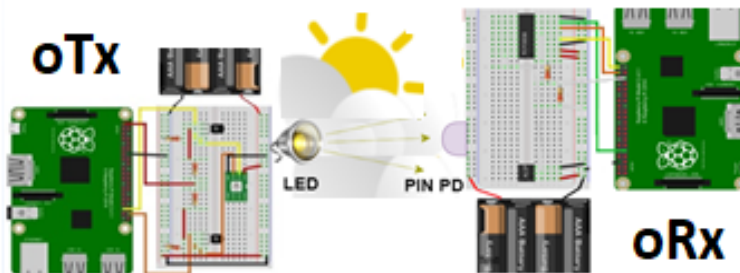


Fig. 6. oTx and oRx simulated with Raspberry Pi

The APA102C is an addressable LEDs that operates on +5V power input, as well as 0-5V logic levels for clock and data. It works on 2-wire communication protocol consisting of a clock line and a data line.

It requires one more wire than standard WS2812B LEDs because the communication with the LEDs becomes timing-independent. This feature allows it to be used directly with a Raspberry Pi, for example. The oRx circuit has the buffer/line driver 74HCT125 that aims to convert the optical signal into an electrical one and ALS-PT19-315C/L177/TR8 as optical detector.

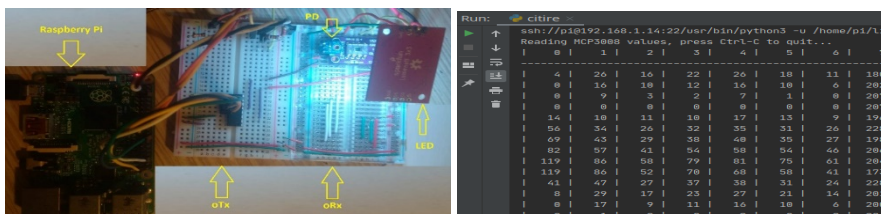


Fig. 7. VLC model with Raspberry Pi PCB and communication results

The ALS-PT19-315C/L177/TR8 is a low cost 2-SMD phototransistor. It has the sensitivity wavelength range ( $\lambda_p$ ) between 390 and 700. It has the peak sensitivity wavelength at 630 nm. The operating temperature is between -40 and +85 0C and the operating voltage 2.2 and 5 V. Its Rise time ( $t_r$ ) is 0.11 ms and the fall time ( $t_f$ ) 0.22 ms.

The output voltage ( $V_{out}$ ) is the product of photocurrent ( $I_{PH}$ ) and loading resistor ( $R_L$ ) (see eq. 1 ad eq. 2.).

$$V_{out(max.)} = I_{PH(max.)} \times R_L \leq V_{out(saturation)} = V_{CC} - 0.4V \tag{1}$$

$$R_L \times C_L \geq 0.5 \tag{2}$$

### 3.3. VLC model with BeagleBone Black

The BeagleBoard BeagleBone® Black (BBB) with ARM Cortex-A8 32bit RISC microprocessor, up to 1GHz. It has on board a HDMI to connect directly to monitors and/or TVs. The Linux Debian distribution can be flashed to the eMMC. It has a USB 2.0 client and host ports, a UART0 serial port access via 6 pin 3.3V TTL header and 10/100 RJ45 Ethernet connector [29].

OpenVLC 3.1 board is an open-source, low-cost and flexible VLC system platform. Research and development is coordinated by the Pervasive Wireless Systems group at IMDEA Networks Institute. It can achieve a throughput of 400 kbps at the Transport Layer at a distance of more than 4 meter, powered BBB. OpenVLC is code based and the use of VLC easy to adjust the behaviour of the platform by modifying the software code, such as introducing new media access control (MAC) protocols. Its interface is designed as a Linux kernel module [30].

OpenVLC's source codes are free: they can be redistributed and/or modified under the terms of the GNU General Public License.

The frame format built has the configuration as in Fig. 8.

Field	PRE	SFD	LT	Dst	Src	Protocol	Payload	CRC
Byte	4	1	2	2	2	2	0 ... 255	2

Fig. 8. The frame formats

The frame consists of 4B for preamble (PRE), 1B for the start of frame delimiter (SFD), 2B for the length (LT), 2B for the destination address, 2B for the source address, 2B protocol, between 0 and 255 B payload and 2B for the Cyclic Redundancy Check (CRC).

The error-correcting codes used are Reed–Solomon codes (RSc) that operate on a block of data treated as a set of finite-field elements called symbols, being able to detect and correct multiple symbol errors. By adding  $t = n - k$  check symbols to the data, a RSc can detect (but not correct) any combination of up to and including  $t$  erroneous symbols, or locate and correct up to and including  $\lfloor t/2 \rfloor$  erroneous symbols at unknown locations. The "reed-solomon.h" file with generic Reed Solomon encoder / decoder library is used for this purpose.

The VLC frame is prepared and then symbol flow is sent to the shared memory from where it is read by the firmware in the PRU. The PRU then controls the GPIOsto modulates the LED light for data transmission.

At the receiver, the light signals are detected by the PD and are sampled by firm-ware from PRUs. Once a valid PR and SFD are detected, the received data is sent to the shared memory and then received and processed by the OpenVLC driver. Finally, the received data is sent to the network layer, where it is processed using the Linux TPC / IP kernel.

The OpenVLC kernel module allows to create a network interface, meaning that any user is able to see the OpenVLC module as if it were just another network device, such as Wi-Fi or Ethernet, and any application to run would be connected via the VLC

network interface. The kernel runs in the BBB processor; its processing power is much higher than that of the PRU microcontroller. For this reason, the most computationally demanding tasks remain at the core level.

The designers used the Manchester line encoding. It encodes one bit into two sym-bols with On-Off-Keying (OOK) modulation (a symbol is either a HIGH or a LOW) ensuring that the average signal power remains constant. To avoid flickering, the Manchester line coding converts a "1" bit into a LOW-HIGH symbol pair and a "0" bit into a HIGH-LOW. Both RSc and Manchester encoding are also used in the 802.15.7-2011 standard.

The software solution is implemented as a Linux driver communicating directly with the OpenVLC cape and the Linux networking stack. Into the cape, the VLC interface is set up as a new communication interface, using a number of Linux tools.

The cape uses the duplex communication, having both the oTx and oRx functions. Once flashing the BBB, setting up the operating system, connecting the VLC cape and setting up the Tx and Rx, the system (OpenVLC cape with the BBB) behaves as a common network interface. With an open source script (online available on GitHub [31]), the interface's IP (IPv4) can be changed. Once the module driver is installed, the built-in microcontroller (PRU) can be boot up with the code necessary to transmit and received data over VLC and IR (Fig. 9).

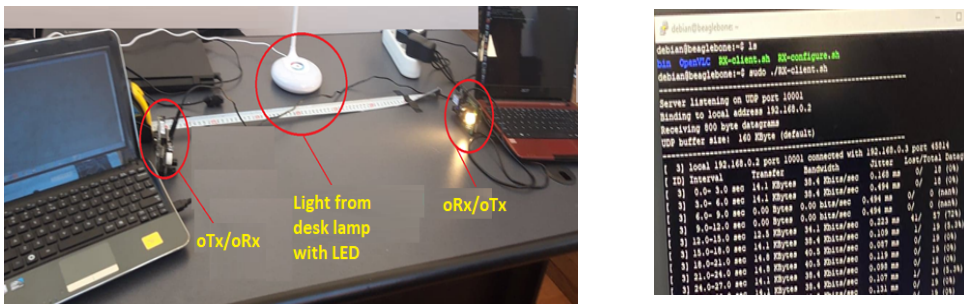


Fig. 9. Setup for data communication with BBB and OpenVLC Cap 1.3. and transmission results.

The most affordable model is the one with Arduino, but the most performant is the one with BBB. The model developed with Raspberry Pi, although more expensive than the model developed with Arduino, has a better throughput and a longer optical achievable link. Both models with Arduino and Raspberry Pi are simplex communication based solely on visible light and the OpenVLC cap with BBB has duplex transmission base both on IR and visible light.

A brief comparison between the three tested models is presented in Table 1.

Table 1. Comparison between the three tested models.

Nr Crt	oTx Board/ oRx Board	LED/PD	oTx PCB/ oRx PCB	Cost	Software/ Application	Optical Length [mm]
1	Arduino Uno/ Arduino Mega	VLHW4100/ VTB8440BH	2N3904; 2SC5200/NE5532	low	Arduino IDE	400
2	Raspberry Pi/ Raspberry Pi	APA102C/ ALS-PT19	74HCT125/MCP3008	moderate	Python	200
3	BeagleBone Black/ BeagleBone Black	XHP35/ SFH206K with TINA10645 lens	OpenVLC 1.3. ADS7883 LTC6269 FQPF30N06L	high	Debian GNU Linux/C PuTTY	1800

## 4. Conclusions

The key characteristics of the parts used for the models are important to be considered when the future manufactured prototype is simulated. There are many benefits, downsides and also challenges to overcome when VLC models are design with the off-the-shelf components especially when the prototype must have a low cost with planned throughputs. The models developed are tested in a LoS scenario under regular indoor ambient light (natural and fluorescent bulbs as artificial light from the lighting fixture), as well as a desk lamp with LED for additional noise, resulting acceptable performance. The link length is not the one targeted, but, as a first solution to keep low the entire budget of the project, and increase the VLC link is to use proper optics such as biconvex lenses in front of the LED and lenses with concentrators in front of PD to increase the optical gain. Although the prototypes tested have their particular benefits and drawbacks, with the current technological boom in this field, new, and improved spare parts are to be expected to become available on the market with low costs.

## References

1. Riurean S.: VLC Prototypes Developed with Off-the-Shelf Components for Wireless Indoor Data Transfer. In: ICCS 2020, LNNS, Vol.186. DOI: 10.1007/978-3-030-66093-2\_30.
2. Rehman, S. U.; Ullah, S.; Chong, P. H.; Yongchareon, S.; Komosny, D., Visible Light Communication: A System Perspective—Overview and Challenges. *Sensors*, 19 (5). (2019).
3. Leba M., Riurean S. and Ionica A., LiFi — The path to a new way of communication, 12th Iberian Conference on Information Systems and Technologies (CISTI), Lisbon, 2017, pp. 1-6, doi: 10.23919/CISTI.2017.7975997, (2017).
4. Marcu A., Dobre R. and Vlădescu M.: Investigation on available bandwidth in visible-light communications, 2016 IEEE 22nd International Symposium for Design and Technology in Electronic Packaging (SIITME), Oradea, 2016, pp. 244-247, doi: 10.1109/SIITME.2016.7777287.
5. Riurean, S., Antipova, T., Rocha, Á., Leba, M., Ionica, A. VLC, OCC, IR and LiFi Reliable Optical Wireless Technologies to be Embedded in Medical Facilities and Medical Devices. *J Med Syst* 43, 308 (2019).
6. Dimitrov S., Haas H.: Principles of LED Light Communications. Towards Networked Li-Fi, Cambridge University Press, (2015).
7. Riurean S., Antipova T., Rocha A., Leba M., Ionica A. (2019) Li-Fi Embedded Wireless Integrated Medical Assistance System. In: Rocha Á., Adeli H., Reis L., Costanzo S. (eds) *New Knowledge in Information Systems and Technologies. WorldCIST'19 2019. Advances in Intelligent Systems and Computing*, vol 931. Springer, Cham. [https://doi.org/10.1007/978-3-030-16184-2\\_34](https://doi.org/10.1007/978-3-030-16184-2_34).
8. Riurean S., Olar M., Leba M., Ionica, A.: Underground positioning system based on visible light communication and augmented reality, 17th International Technical-Scientific Conference on Modern Technologies for the 3rd Millennium, Oradea, ROMANIA, MAR 22-23, 2018, Pages: 345-350, <http://orcid.org/0000-0002-5283-6374>, (2018).
9. Nobelprize Homepage, <https://www.nobelprize.org/prizes/physics/2014/press-release/>, last accessed 2020/08/25.
10. Marcu A. E., Dobre R. A. and Vlădescu M., Flicker Free Optical Camera Communication for Cameras Capturing 30 Frames per Second, 43rd International Conference on Telecommunications and Signal Processing (TSP), Milan, Italy, 2020, pp. 166-169, (2020).
11. Ted Homepage [https://www.ted.com/talks/harald\\_haas\\_wireless\\_data\\_from\\_every\\_light\\_bulb](https://www.ted.com/talks/harald_haas_wireless_data_from_every_light_bulb), last accessed 2020/08/25
12. Avătămăniței, S.A.; Căilean, A.-M.; Beguni, C.; Dimian, M.; Popa, V. Analysis concerning the usage of Visible Light Communications in Automotive Applications: achievable communication distances vs optical noise. *International Conference on Development and Application Systems*, (2020).
13. Căilean, A.M., Dimian, M., Done, A., Enhanced design of visible light communication sensor for automotive 785 applications: Experimental demonstration of a 130meters link. *Global LIFI Congress (GLC), Paris, 2018, 1-4. 786 (2018).*

14. IEEE Computer Society. IEEE Standard for Local and metropolitan area networks - Part 15.7: Short-Range Wireless Optical Communication Using Visible Light. Number September (2011).
15. IEEE 802.15 WPAN 15.7 Amendment Study Group (2015).
16. Huang Y.M., Singh K.J., Liu AC, et.al. Advances in Quantum-Dot-Based Displays. *Nanomaterials* (Basel). Jul 6;10(7):1327. (2020).
17. Liao C. et al., Light-emitting diodes for visible light communication, International Wireless Communications and Mobile Computing Conference (IWCMC), Dubrovnik, 2015, pp. 665-667, (2015).
18. Burton, et. al., Investigation into Using Compensation for the Nonlinear Effects of the Output of LEDs in Visible Light Communication Systems, 2nd West Asian Colloquium on Optical Wireless Communications (WACOWC), Tehran, Iran, 2019, pp. 80-84 (2019).
19. Qian H., Yao S. J., Cai S. Z, and Zhou T., Adaptive Postdistortion for Nonlinear LEDs in Visible Light Communications, *IEEE Photonics Journal*, vol. 6, pp. 1- 8, (2014).
20. Aggarwal P., Ahmad R., Bohara V. A. and Srivastava A., Adaptive predistortion technique for nonlinear LED with dimming control in VLC system, 2017 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS), Bhubaneswar, (2017).
21. Ying Kai, Yu Zhenhua, Baxley Robert j., Qian H., Chang G.-K., and Zhou T. Nonlinear Distortion Mitigation in Visible Light Communications, *IEEE Wireless Communications* 22(2) April (2015).
22. Jie Lian, Zafer Vatanserver, Mohammad Noshad and Maïté Brandt-Pearce, Indoor visible light communications, networking, and applications, *Journal of Physics: Photonics*, Volume 1, Number 1 (2019).
23. Riurean S.M., Nagy A.A, Leba M. and Ionic A. C.: A small step in VLC systems – a big step in Li-Fi implementation, IOP Conference Series: Materials Science and Engineering, Volume 294, International Conference on Applied Sciences (ICAS2017) 10–12 May 2017, Hunedoara, Romania (2017).
24. Swain K.P., Prasad M.V.S.V., Palai G., Sahoo J., Mohanty M.N., Exploiting VLC Technique for Smart Home Automation Using Arduino. In: Dash S., Vijayakumar K., Panigrahi B., Das S. (eds) *Artificial Intelligence and Evolutionary Computations in Engineering Systems. Advances in Intelligent Systems and Computing*, vol 517. Springer, Singapore. (2017).
25. Wang T. and Zhao Z., An implementation of visible light communication based on Raspberry Pi, IEEE Integrated STEM Education Conference (ISEC), Princeton, NJ, 2018, pp. 218-219, (2018)
26. Riurean S., Leba, M. Ionica A. and Nassar Y. Technical Solution for Burnout, the Modern Age Health Issue, IEEE 20th Mediterranean Electrotechnical Conference (MELECON), Palermo, Italy, 2020, pp. 350-353, (2020).
27. Duque A., Bidirectional Visible Light Communications for the Internet of Things. *Networking and Internet Architecture [cs.NI]*. Université de Lyon - INSA Lyon, (2018).
28. Rosca S., Riurean S., Leba M., Ionica A., An Educational Model of Graduation Project for Students at Automation and Computer Engineering, *Journal of Digital Science*, Vol.1, Iss. 1, Dec (2019). DOI: 10.33847/2686-8296.1.1\_4.
29. Nayyar A., Puri V.: Comprehensive Review of BeagleBone Technology: Smart Board Powered by ARM, *International Journal of Smart Home* 10(4):95-108 (2016).
30. Galisteo A., Juara D., Giustiniano D.: Research in Visible Light Communication Systems with OpenVLC1.3, *Networking and Internet Architecture (cs.NI)* arXiv:1812.06788 (2019).
31. [Online] <https://github.com/openvlc/openvlc>, last accessed 10.11.2020.

## **Aims and Objectives**

Published online by ICS two times a year, Journal of Digital Science (JDS) is an international peer-reviewed journal which aims at the latest ideas, innovations, trends, experiences and concerns in the field of digital science covering all areas of the scholarly literature of the sciences, social sciences. The main topics currently covered include: Digital Communications and Network; Digital Economics, Education, Engineering, Finance, Health Care.

The main goal of the journal is the effective dissemination of original incites/results generated by the human brain and presented/reflected in articles using modern information/digital technology.

## **Editorial Board**

**Editor-in-Chief** Tatiana Antipova, ICS,  
<https://orcid.org/0000-0002-0872-4965>

**Associate Editor** Julia Belyasova, Catholic University of Louvain, Louvain-la-Neuve, Belgium;  
<https://orcid.org/0000-0001-6983-2129>

## **Editors**

Abdulsatar Sultan, Catholic University in Erbil, Erbil, Iraq;  
<https://orcid.org/0000-0001-5090-5332>

Jelena Jovanovic, University of Nis, Nis, Serbia;  
<https://orcid.org/0000-0001-7238-6393>

Lucas Tomczyk, Uniwersytet Jagielloński, Krakow, Poland  
<https://orcid.org/0000-0002-5652-1433>

Natalya Sukurova, State University of Telecommunications, Kyiv, Ukraine  
<https://orcid.org/0000-0003-4297-1123>

Olga Khlynova, Russian Academy of Science, Moscow, Russia  
<https://orcid.org/0000-0003-4860-0112>

Omar Leonel Loiza Jara, Universidad Peruana Unión, Lima, Peru  
<https://orcid.org/0000-0002-3262-709X>

Roland Moraru, University of Petrosani, Romania  
<https://orcid.org/0000-0001-8629-8394>

Tjerk Budding, Vrije Universiteit Amsterdam, Netherland  
<https://orcid.org/0000-0002-5343-7535>

Zhanna Mingaleva, National Research Polytechnic University, Perm, Russia  
<https://orcid.org/0000-0001-7674-7846>

Quang Vinh Dang, Industrial University, Ho Chi Minh City, Viet Nam  
<https://orcid.org/0000-0002-3877-8024>

## **Contact information**

**Website:** <https://ics.events>

**Email:** [conf@ics.events](mailto:conf@ics.events)