VLC for Vehicular Communications: A Multiple Input Multiple Output (MIMO) Approach

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***Abstract*—Visible Light Communication (VLC) it's a cheap communication system which uses electromagnetic frequencies from the visible spectrum to fulfil optical communications. It's an active research topic, being used in many research laboratories because of its potential of development. The main contribution of this paper is the development of an adaptive MIMO (Multiple-Input-Multiple-Output) system for VLC using frequency diversity. In this way, a VLC system can use more than one transmitting-receiving frequency, increasing in this way the data rate and the amount of information transmitted. The system is used for ITS (Intelligent Transportation System), where the car headlights can communicate with other LED (Light Emitting Diode) light sources across the road, increasing in this way the road safety. In the last part of the research is related a new approach for a hybrid communication system, integrating VLC with LoRa technology.**

***Keywords*— VLC; MIMO; V2V; LoRa; On-Off Keying**

I. Introduction

Visible Light Communication (VLC) is a top-edge topic being the focus of many research centers. The rapid growth of wireless communications systems has boosted the exponential development of smart technologies while driving a substantial increase in traffic volume [1].

Continuous improvement of wireless communication performance, in terms of speed and bandwidth, has led to the systematic congestion of the RF (Radio Frequency) environment. Thus, the performance level of these systems is limited by other factors such as disturbances, and it becomes imperative to develop new algorithms and techniques that allow the coexistence of these technologies, leading to complicating the degree of complexity of the transmitter and receiver, reflected in price [2-4].

In recent years, to avoid these impediments, we are facing a migration of wireless communications into licensed high frequency bands (millimeter waves in the range 30-60 GHz) [1].

Another possible emerging and promising approach is the use of visible light-lengths (380 to 780 nm) for green environment and human health transmissions [5].

II. Challenges

Currently there is a rapid development in solid state lighting. Concerns about energy consumption lead to the gradual elimination of incandescent sources and there is a rapid increase in the use and development of SSL (Solid State Lighting) sources. Their efficiency increased while the initial cost of the investment decreased. Currently, they are widely used in car applications for indicators and stop lamps [6, 7].

Using of SSL sources provides the possibility of data transfer, in addition to providing lighting. Sources can be modulated at high speed, thus becoming a communication channel [1].

VLC technology can be used successfully in the automotive industry, facilitating vehicle-to-vehicle communication as well as vehicle to traffic light or vehicle to environment illumination systems [8]. The contribution of this technology to vehicle-to-vehicle communications (V2V) is immense if we take into account the potential for reducing casualties, thereby increasing safety [9]. In 2016 nearly 25,624 people died in road accidents at the level of the European Union. Integrated VLC in vehicle communications technology can help increase safety [10].

MIMO concept for VLC has been extensively investigated in many research papers [11, 12] especially for indoor scenarios. Recently, due to the concept of autonomous driving and Advanced Driver Assistance System (ADAS), some research are made for VLC MIMO in vehicular communication, enfacing the safety critical information's such as emergency brake [6].

The main contribution of this paper is the development of a configurable MIMO system that allows the simultaneous transmission of data streams using frequency diversity. The advantage of the proposed architecture also determines the diversity of the total number of receivers. In the same time, a new concept is proposed for the transfer of information within the vehicle networks using LoRa (Long Range) technology. Thus, the system allows the reception of data streams, increasing the network's capacity and in the same time ensuring interference resistance.

From the best knowledge of the authors this is the first paper that proposes this kind of approach by integrating MIMO technology in vehicular networks using also a hybrid technique by adding LoRa capabilities.

Information transmitted from vehicles can be collected, transmitted to a central database and processed to streamline traffic flow or integrate into a more complex IoT system. For this purpose, to increase the communication speed, a hybrid VLC MIMO system can be used, in addition to the frequency diversity implemented at the VLC receiver level, to allow the transfer of information using other wireless transmission technologies to a Cloud, such as for example LoRa technology.

LoRa is a modulation technique patented by Semtech [13] which uses a chirp code to increase the frequency bandwidth of the modulated signal to increase the resistance to interfaces. Thanks to this modulation technique, it is possible to transfer information over ten of kilometers [14, 15]. Thus, this technology is perfect for use in backhaul transfer of data from the VLC modem.

A proposed architecture that will be developed in a further scientific research paper is shown in Fig. 1.

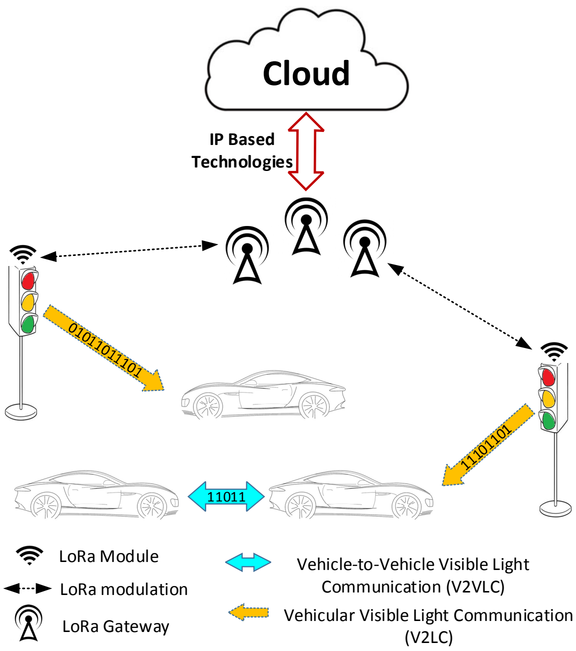


Fig. 1. Vehicle-to-vehicle hybrid communication architecture.

This architecture allows a high degree of flexibility with the possibility to be easily expanded by adding new nodes in the network.

III. VLC MIMO Communication System

In this section a VLC communication system with MIMO capabilities in presented based on the references from [16], where a theoretical approach is related.

In Fig. 2 is the structure of the VLC system that has the transmitter and the receiver parts.

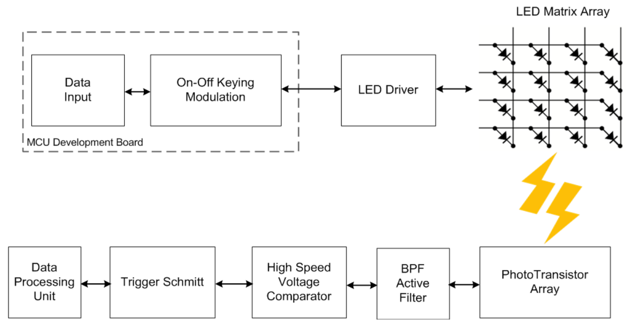


Fig. 2. Visible Light Communication System.

In the block diagram shown in Fig. 2, the operation of the circuit involves the use of a set of input data modulated with OOK modulation. The data sequence is generated by a Development MCU Board, using one of the frequencies used in VLC systems for OOK modulation, namely 11.67 kHz, 24.44 kHz, 44.48 kHz, 73.3 kHz or 100 kHz, according to IEEE 802.15.7 standard [17]. The modulated data sequence is then transmitted to a driver that controls a LED array. The transmitter is designed to transmit 4 different signals at the same time. For proof of the concept, in this paper only 2 of these standardized signals are used, 11.67 kHz and 24.44 kHz respectively.

Fig. 3 shows the VLC transmitter using the LED driver and the LED array. The driver uses standard N-MOS transistors that are gate controlled with a rectangular signal received from the MCU Development Board. Each LED array consists of 9 high brightness 0.5 W Power PLCC-4 SMT red LED’s, with a measured luminance of 14.3 lm.

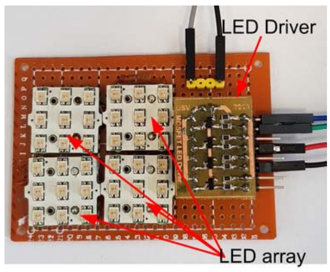
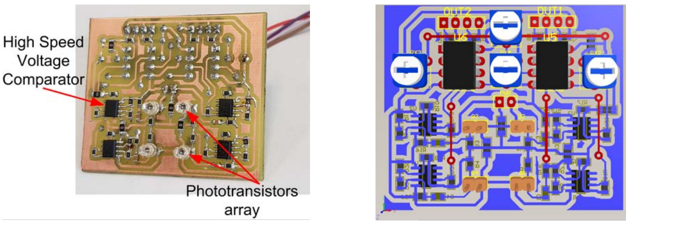


Fig. 3. VLC Transmitter with a LED array.

In the VLC systems, the information is transmitted using a modulated light source to a VLC receiver. The receiver uses photodetectors that will convert the light into electric current. The electric current magnitude depends on the intensity of the incident light on it. The MIMO receiver has a set of phototransistors for detecting the light signal transmitted by the LED array, active band-pass filters, high-speed voltage comparators and a Trigger Schmitt pulse circuit maker.

The phototransistors are used in this design because of their improved sensitivity. The priority for the proposed design isn’t a high data rate transfer because this kind of system is used in vehicle applications. Thus, if it’s used the OOK modulation scheme and Manchester encoding, the maximum data rate can be up to 100 kbps in the mentioned applications and the mentioned approach can fulfil the expectations [18]. Many VLC receivers use trans-impedance amplifier, which will reduce the strong influence from the ambient light. In the proposed design is used instead a high-speed voltage comparator with a variable threshold chosen by the given testing conditions, with the same results. The Trigger Schmitt circuit is used for enhance noise mitigation and to deliver a clear rectangular signal for the Data Processing Unit.

In Fig. 4 it's depicted the implementation of the VLC receiver, representing the PCB and the 3D bottom view of the layout, respectively.



a) Top view of the PCB b) 3D Bottom view of the layout

Fig. 4. Visible Light Communication Receiver.

A standard VLC system has only one transmitter-receiver circuit. In a VLC MIMO system will be more than one transmitter-receiver circuits close to each other. Here, the problem is filtering the signal in such a way that each photodetector will receive the proper value from the transmitter, on the right frequency. In case if a wrong approach is used, the receiver signals will not be received properly, and all the transmitted information will be altered. An example of this is related in Fig. 5, where two signals of 11.67 kHz and 24.44 kHz are received in the same time from two different photodetectors.

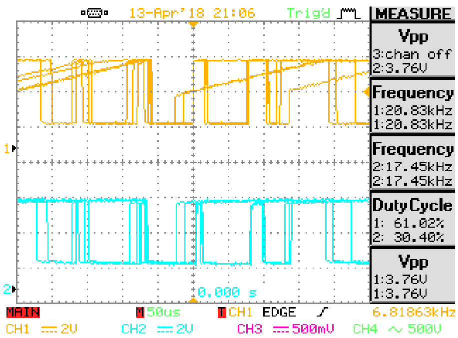


Fig. 5. VLC MIMO system with improper filtering.

In the proposed design, each photodetector element in the group will only identify one single signal sent by the LED arrays via the existing circuits to the receiving module. Thus, after the light signal is captured, its value will pass through a band-pass active filter (BPF) designed for one of the frequencies mentioned for the OOK modulation using the IEEE 802.15.7 standard. Once the signal is filtered for one of the desired frequencies, the filter response is sent to a high-speed voltage comparator to identify the low amplitude signals according to the chosen threshold. In this way, the system can be used successfully for transmitting information at greater distances than existing VLC communications systems, the threshold being set by the hardware component used as a comparator. At the input of the comparator, a capacitor is provided to filter the continuous component from the component comparator circuit received by the photodetector and filtered by the BPF. The signal obtained at the output of the photodetector (marker 2 – CH2) compared to the signal at the output of the receiver circuit (marker 1 – CH1) can be seen in Fig. 6.

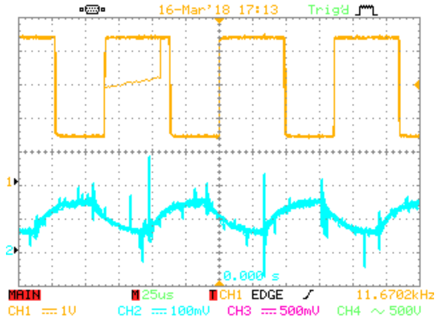


Fig. 6. The phototransistor output signal vs. receiver output signal.

The noise of the signal at the output of the phototransistor is filtered with active BPF, resulting in a signal that can be processed much easier by the comparator, in order to be sent to a Trigger Schmitt rectangular pulse maker. The latter will form the impulses used for the Data Processing Unit, tracking the transmission frequency. This way, multiple data streams can be transmitted at the same time, but using different transmission-reception frequencies, making it possible for various VLC receivers to process only the information they need to avoid capturing all the information from the broadcasting VLC systems.

IV. Results and Discussions

In Fig. 7 the experimental setup is presented.

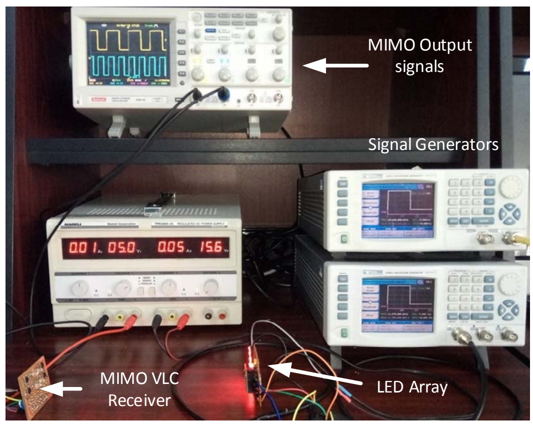


Fig. 7. The experimental VLC MIMO system.

This paper priority is to demonstrate the MIMO approach of a VLC system. Thus, for testing and proof of the concept, two arbitrary rectangular signal generators are used instead of a Manchester scheme for encoding a transmitting-receiving signal delivered by the Development MCU Board. The chosen signals that can simulate OOK are PWM signals, with 50% duty cycle and frequencies of 11.67 kHz and 24.44 kHz respectively. The signal generators will provide the gate command signals for the LED drivers, being connected only 2 LED arrays with a total of 18 LEDs. The distance between the transmitter and receiver circuits is not important in this concept, its optimization being the subject of future scientific research work. In Fig. 8 is depicted the output signals from the MIMO VLC receiver for the two above-mentioned transmitted frequencies.

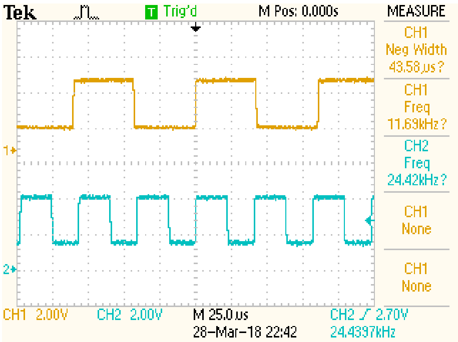


Fig. 8. The MIMO signals at the receiver side.

Both signals are received clearly and correctly, without any interference between them, with frequencies of 11.69 kHz and 24.42 kHz respectively, and a duty cycle of 50%. The measurements confirm the good functionality of the proposed MIMO system, validating the concept described. Using such a system can efficiently transmit multiple data streams using different frequencies, increasing the efficiency of a standard VLC system.

V. Conclusion

Visible Light Communication is an alternative to data transmission in an efficient and low-cost system, using high data-rate infrastructure that can substantially increase wireless capacity. The system proposed in this paper proves efficiency by using multiple standardized VLC transmission frequencies for a high volume of data transmissions. This way, VLC receivers can be configured for customized applications as well as only able to retrieve the required information from a complex VLC transmission system. The use of a hybrid system will extend the scope of VLC classic applications in order to develop a complex IoT system. Thus, LoRa technology is a good candidate for the implementation of such an IoT concept, integrating much more data, increasing in this way the road safety.

Acknowledgement

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