Design of a multi-input-multiple-output visible light communication system for transport infrastructure to vehicle communication

Lucian-Nicolaie COJOCARIU  
Department of Computers, Electronics and Automation  
Stefan cel Mare University  
Suceava, Romania  
lcojocariu@usm.ro

Valentin POPA  
Department of Computers, Electronics and Automation  
Stefan cel Mare University  
Suceava, Romania  
valentin@eed.usv.ro

Abstract—The Visible Light Communication systems have been recently developed based on the advances in lighting semiconductor devices and added 300THz communication bandwidth to the current short-range wireless technologies family. They have a great potential for indoor as well as outdoor applications, the area of interest for our work being the communication between traffic signal infrastructure and vehicle. This paper proposes a novel architecture for a multiple-input-multiple-output visible light communication system that shares information from the traffic center to the vehicles on roads.

Keywords—Infrastructure to Vehicle Communication, Visible Light Communication Systems, Multiple-input-multi-output, Traffic Light.

I. INTRODUCTION

The Visible Light Communication systems (VLC) represent a wireless communication technology based on the remarkable progress made in semiconductor-based lighting devices [1]. Concentrated efforts of numerous research centres have led to the implementation of reliable Light Emitting Diodes (LED) with superior performances compared to the classical light source regarding the energy efficiency and lifetime as well as fabrication costs [2-5]. In the next ten years, the lighting efficiency of a standard LED is expected to increase to 200lm/h [6] and to dominate the light source market.

The use of LED in artificial lighting systems can offer not only the illumination function but also a wireless transmission function due to the LED capability to rapidly switch between the conduction and blocking state. Thus, the VLC technology has already found various applications in networking, intelligent transport systems and medicine [7-10]. In networking, VLC systems are used in conjunction with PLC’s (Power Line Carrier Communication) to provide data services through the lighting system. Localization is another application that can be developed using VLC systems, positioning systems being implemented both inside and outside buildings. In medicine, VLC systems can replace radio communications systems which disturbed some diagnostic medical devices.

Intelligent Transport Systems (ITS) is another application of the VLC systems with a huge potential for development in the near future having the aim of increasing traffic safety and efficiency in the sector of road transportation [11-20]. Equipping the road infrastructure and the vehicles with VLC receivers and transmitters would allow the following communication scenario:

a) I2V (Infrastructure to Vehicle Communication) unidirectional communication between infrastructure and vehicle;

b) V2V (Vehicle to Vehicle Communication) inter-vehicle communication in order to carry out the ad-hoc network found in the technical literature under the acronym VANET (Vehicular Ad-hoc Network);

c) V2I (Vehicle to Infrastructure) unidirectional communication between the vehicle and the infrastructure.

Extensive research have been launched in these areas with the aimed at developing wireless communication systems with high data transfer rates using electromagnetic waves from the visible spectre. A VLC prototype with a transfer rate higher than 500Mbps has been recently implemented and successfully tested in a controlled environment [21]. The interference of the VLC radiation with the ones generated from other artificial or natural light sources represents a major challenge in the large scale implementation of such systems but recent engineering developments in dealing with noise may also contribute to overcome these obstacles [22]. Taking into consideration the recent efforts to improve the switching speed of Organic LED (OLED) [23], the future VLC systems might greatly benefit from the flexibility of organic optoelectronic devices.

In this paper we present the architecture proposed for a multiple-input-multiple-output visible light communication system that shares information from the traffic centre to the vehicles on roads. The functional blocks proposed for the emitter and the receiver of an I2V scenario are discussed in details.
II. VLC MIMO EMITTER DESIGN

In this section we present the hardware and software architecture proposed for the emitter of an I2V system.

A. Emitter hardware architecture

According to the hardware architecture shown in Fig. 1, the message intended to be transmitted by the LED Array located in the traffic light will be entered from the keyboard connected on the processing module based on FPGA. The block Bi-directional Level Shift is necessary because the FPGA Module is working with signal levels of 0 - 3.2V, while the keyboard and the LED Array Driver works with signals having levels between 0-5V. By using the keyboard, the user can select the colour of the light signal used to transmit the information, the sector of the selected colour surface, the encoding method and the speed of data transmission. Based on the specifications made via the keyboard, the FPGA Module will process the received data and activate the selected area through the block called LED Array Driver. Dividing surface was chosen for each colour, meaning each array into 4 sectors, with the aim of implementing a MIMO (Multiple Input Multiple Output) communication system. The Functional blocks will be powered by the power supply block that will provide the following voltages: +3.3V, +5V and +12V.

B. Emitter software architecture

Fig. 2 shows the functional blocks included in the software component implemented on the FPGA to control the hardware architecture of the emitter. These functional blocks will be described in VHDL language. The communication between the keyboard and FPGA Module will be done through the PS2 Interface block. The data contained in the transmitted message will be coded in Manchester or Miller by the Data Encoding block, next being modulated in the Data Modulation block, and the resulted signal will be applied to LED Array Driver block. The PS2 Interface block will also transmit a signal on the carrying signal frequency to Data Modulation block, necessary to the modulation process using OOK technique (On-Off Keying). Depending on the specifications made by the user, the LED Array Driver Control Unit block will command separate each sector from selected active colour of the traffic light.

III. VLC MIMO RECEIVER DESIGN

The VLC receiver will be installed in the car. For the implementation, two version were been taken into account and theirs hardware/software architecture will be presented in this section of the paper.

A. Hardware architecture of the receiver with band-pass filter

Fig. 3 presents the hardware architecture for the receiver with Band-Pass filter that use for photo detection a PIN with Si photodiode, which will generate a photocurrent dependent by the photons arrived on its active surface. The current given by the photosensitive element is converted in voltage by I/U Converter block and the output signal will be applied to the Preamplifier. After a first stage of amplification the signal it’s applied further to the Band-Pass Filter block. The centre frequency of the filter will be dependent from a clock signal given by the FPGA. The signal acquired from the photodetector varies with the distance from the light source, consequently, in order to maintain a signal with constant amplitude at the entrance of Trigger Schmitt block, it was necessary to introduce the Variable Gain Amplifier block. Depending on the signal level read by the ADC (Analogue to Digital Converter), the FPGA Module will process and transmit the necessary command to the Variable Gain Amplifier in order to maintain a constant amplitude for the signal at the entrance of Trigger Schmitt block. The FPGA Module will receive rectangular impulses from the Trigger Schmitt block, impulses that represent the modulated and coded data transmitted by the emitter. After processing, the information will be displayed.

Fig. 1. Emitter hardware architecture

Fig. 2. Emitter software architecture

Fig. 3. Hardware architecture of the receiver with band-pass filter.
B. Software architecture for the receiver with band-pass filter

The software architecture diagram that will be incorporated in the FPGA is presented in Fig. 4. The Variable Gain Control Unit block will receive the data from the ADC block and will control the Variable Gain Amplifier block in order to maintain constant amplitude. The High-Pass Filter Control Unit block will control the High-Pass Filter block in order to adjust the filter on the frequency of the signal transmitted by the emitter. The data will be demodulated and decoded by the Data Demodulation block and the Data Decoding block, and the result of the previous processing will be applied then to the Display Control Unit block which will control the showing of the message on the displaying.

The High-Pass Filter will be implemented with a hybrid integrated circuit, and the centre frequency of the filter will be establish by a clock signal received from the FPGA Module. The hybrid integrated circuit that hosts the Band-Pass Filter has an analogical block and a digital control one. The frequency of the clock signal, given by the High-Pass Filter Control Unit block will be processed by the digital block. Depending on its value, the digital block will select the combination of group for the capacitors that are part of the analogic filter block.

C. Hardware architecture of the receiver with high-pass filter

For the hybrid integrated circuit that hosts the High-Pass filter, the maximum centre frequency is limited at a few kHz, and this fact limits the data rate in the VLC system described. In order to ward of this shortcoming, second receiver hardware architecture it’s taken in the account. Comparing the receiver hardware architecture presented in Fig. 5, with the one in Fig. 3, the Band-Pass block was replaced with the High-Pass filter, and the Trigger Schmitt was eliminated entirely from the architecture. The simplification of the receiver hardware architecture can be observed in the low price of the implementation and in the growth of the software’s architecture complexity. The signal gathered from the photodiode is converted in voltage by the I/U Converter block. The variable signal from the I/U Converter block exit will be applied to the Preamplifier. The High-Pass filter block, feed with pre-amplified signal, will reject the signals component due to other light sources. As in the previous architecture it has kept the maintenance loop in the constant amplitude of the processed signal, block realised with the help of a Variable Gain Amplifier.

D. Software architecture for the receiver with band-pass filter

This time, the software architecture from the FPGA will command the ADC block to create a continuous conversion of the signal. The digitized signal will be stored in a Buffer and then applied to a digital filter which will transmit the data to the Demodulation and Decoding blocks. Even since the design stage, the emitter architecture was provided with the possibility to be used into a MIMO type communication. For the receiver to correspond to a MIMO type communication it is necessary to multiply the following stages of software and hardware architecture: photodiode, I/U Converter, High-Pass Filter, Variable Gain Amplifier, Digital Filter, Data Decoding, Data Demodulation. The implementation of a VLC receiver architectures governed by FPGA has the advantage of using parallel computation and software architecture.

IV. CONCLUSIONS

The Light Emitted Diode became an omnipresent optoelectronic device used in a wide variety of application like: artificial lightning, displays, traffic signals and automotive lightning. Exploiting the switching capability of the LED was opened a unique opportunity for a new low cost short-range wireless communication technology, namely Visible Light Communication Systems (VLC). This new promising wireless technology provides 300THz unlicensed and unused communication bandwidth for indoor, as well outdoor applications.

In our day the majority of the light traffic signals, headlamps and taillights for car are implemented with LED’s array, fact that allow to make them part of VLC systems and variety of communication scenarios can by developed. The ITS is a major application area for VLC wireless optical communication technology. In this article we propose a new approach to implementing of an I2C architecture for ITS.

The receiver with High-Pass Filter has a simplified structure for the electronic circuit and implicit a lower cost for
implementation. The software component has a higher degree of complexity, compared to architecture with Band-Pass filter, since it includes entitled Digital filter block. The receiver with Band-Pass Filter offers the possibility to do measurements with oscilloscope after each level of hardware architecture, and this allows greater control over how the signal containing the data is processed. Among the disadvantages of this type are the highly complex electronic circuits, ie low data rates. The receiver with High-Pass Filter allows a superior data rates, however it has a software architecture that involves rigor in execution. Testing the two proposed type of receivers for implementation will track and determine the optimum size for bits package is intended to be sent, ie using an appropriate coding method following the channels requirements. Because of the fact that the light source for traffic lights is implemented with a LED array, it is possible the implementation of a VLC system based on the MIMO technique (Multiple Input and Multiple Output) through the simple multiplication of a few blocks from the receivers software and hardware architecture.

Acknowledgment

This work was partially funded by the Romanian National Program II, Young Research Team project no. 107/6.8.2010. The authors thank Prof. Mihai Dimian from instructive discussions and support during this work.

REFERENCES


