System Prototype Proposed for Vehicle Communications Based on VLC-RF Technologies Adaptable on Infrastructure

Eduard Zadobrischi
Department of Computers, Electronics and Automation, Stefan cel Mare University of Suceava, Suceava, Romania
Technical University of Cluj-Napoca, Cluj-Napoca, Romania
E-mail: eduard.zadobrischi@usm.ro;

Abstract— **The chaotic increase in the number of vehicles and the population density makes road safety an important topic from all points of view. Urban planning and disorganization in terms of traffic efficiency and fluidization solutions cause massive traffic congestion in most cities around the world. The diversity of mechanisms and devices dedicated to the fluidization of traffic in pedestrian areas or pedestrian crossings does not offer safety to all categories of persons, here referring to the sick, elderly, children. A number of studies that have analyzed and focused on the field, offer solutions whereby a combination of vehicles and automated tools, used in conjunction with an efficient data communication type, can reduce traffic congestion problems and reduce traffic jams. Wireless communications technologies have the possibility of the dynamic and increase the security of the transmission mode. We can say that this article presents an overview of the most important and promising technologies that can be used in the applications dedicated to the road safety sector based on communication between cars. We propose a system prototype based on RF (Radio-Frequency) communications and VLC (Visible Light Communications) technology, thus making a promising alternative in the field. Based on these proposals, analyzes and simulations are performed on a hybrid architecture, offering results on performance evaluation of the solution.**

Keywords—infrastructure-to-vehicle communications, visible light communication system, hybrid networks, inter-vehicle communications, radio-frequency.

I. INTRODUCTION

As millions of people lose their lives and dozens more are injured each year, we can say that road accident is a serious problem in our society [1]. An important factor and an aspect that is not negligible is the economic one, being affected by a percentage of 1% and 3% of all the internal product in terms of damage [1]. The studies carried out are currently presented in about 90% of the number of road accidents are caused. by lack of attention, driving distraction, delayed reactions, fatigue, in main human causes. Therefore, the systems dedicated to road safety have been based on sensors, these can significantly. reduce the number of accidents and automatically the loss of human lives. We can say that at this moment the communications between vehicles V2V (Vehicle-to-Vehicle) and the communications infrastructure-vehicle V2I (Vehicle-to-Infrastructure) can improve with more than 80% of the road accidents, advancing in the matter of the safety of the vehicles[2],[3]. Thus, the systems developed in the direction of the safety of the vehicles based on communications, offer the possibility of the existing infrastructure or of the vehicles that identify problems or situations in traffic with a high potential of danger, to inform the driver and the other participants in the traffic on the detected problem. Therefore, vehicles can exchange information on speed, location, traffic lights, traffic jams, their cooperation increases the degree of safety and speeds up traffic. An impediment is that which refers to the strict standards that are imposed on the safety of vehicles based on communications. Applications of this type need quite small latencies, they can reach up to 20 ms to detect an obstacle or a collision, this ratio where the estimated delivery time of the packages varies up to 300m [3],[4]. In the context of the above mentions, the article presents the visible light communications (VLC) in complementarity with the RF ones, through which a communication platform between vehicles can be created, coming to the aid of the field of active safety systems.

The presented approach stands out the potential to supply a viable solution that offers improved connectivity, adaptive behavior regardless of context, and superior scalability. The research works in which we work are aimed at designing, implementing valid solutions in the field of communications, aimed at developing a hybrid platform using technologies such as VLC, complementing with other network technologies, 4G/5G or LTE (Long-Term Evolution) [5], for in-vehicle or cloud communications.

Toward the local infrastructure level, in order to maintain the connectivity between different types of communication, hardware and software modules should be developed to allow the VLC network to work as well.

II. PRESENTATION OF THE EXISTING SOLUTIONS IN WIRELESS COMMUNICATION AND AUTOMOBILE DOMAIN

The amount of information and devices connected to the internet is producing an increasing demand for wireless communication, raising many challenges for radio frequency (RF) technologies. Although the progress shows that we are at an early stage in the development of the technology of the fifth-generation (5G), according to (the Global Mobile

This work was supported by project DECIDE – Development through entreprenurial education and innovative doctoral and postdoctoral research, project POCU/380/6/13/125031, project co-financed from the European Social Fund through the 2014-2020 Operational Program Human Capital.

978-1-7281-6870-8/20/$31.00 ©2020 IEEE

Furnisors Association), by mid-2019 there were 35 operators launched these services. However, the development of a new 6G technology has begun, thus trying to complement the 5G minuses. On the other hand, in parallel with the development of a new generation of communications, companies work and develop solutions based on Li-Fi. The use of this technology facilitates and removes the shortcomings encountered during the use of Wi-Fi / 4G / 5G communications, thus the medical, aerospace, automotive, approaches Li-FI (Light-Fidelity) solutions, even considering their cooperation for improved speeds and security.

The alternative in the case of Li-Fi technology 5G cellular network technology. A prototype presented by Ericsson in 2019 gave the general public the opportunity to see how a truck is controlled at a distance of 2500 km on the Gothenburg (Sweden) - Barcelona (Spain) route. We can say that this demonstration aims to expose the high transfer rates that 5G services can offer, significantly higher data transport, but also low latencies. Therefore, as mentioned above, the features presented are essential in the process of forging automotive applications and processing real-time data. However, there are no reliable forecasts and information that a similar approach can underpin the whole network of vehicles, providing good reliability under high traffic density.

A. Introduction on the radio frequency communications

According to the notes in the literature, we can say that the radio frequency spectrum was widened from about 3 kHz to later about 300 GHz. This RF spectrum is divided into several multiple bands, which in turn propagate individually in the case of dedicated applications. Thus, the VHF band benefits from a variable bandwidth and can be extended from about 30 MHz to about 300 MHz. This has utility in amateur radio communications, CB stations, TV broadcasting, the bandwidth in the case of UHF (Ultra High Frequency) is appropriate in mobile telephony Wireless LAN and Bluetooth. The multitude of applications in the case of the RF band makes it an important component, but at the same time more and more saturated. The mentioned problem has been studied intensively by the experts in the field, and a solution considered and subsequently applied was to use increasing frequencies, but this long-term solution becomes expensive and requires complex equipment.

The importance of the field and the need to find solutions supported the rising costs, and the financial aspect became secondary. However, the reuse of space was taken into account for the mitigation of this crisis, reaching the "smart cell concept". Gradually the size of the communication cells decreased, reaching up to 35 km for 2G systems, about 5 km for 3 G systems and 100 m for 4 G systems and in the case of 5 G only 25 m, this decrease is expected, and in the case of 6G (future technology). We can say, that cell shrinking has been and is possible, but for this moment it becomes increasingly difficult to obtain due to the high costs and the interference, even the redundancy of the consumers gravitates around this situation. Analysis of the past in the field of wireless communications, the demand for new technologies has led to the development and introduction of standards such as 802.11 (Wi-Fi). Therefore, Wi-Fi in a relatively reduced time has become the most widespread wireless communication network having a common mechanism for both receiving and transmitting data. The researches have led to a high degree of complexity in Wi-Fi technology. Therefore, offering a high degree of flexibility, adaptability but also mobility, the 802.11.b standard was later extended to be useful for the developed industrial environment and IEEE 802.11p became useful and applicable to the automotive field. According to statistics, most services and daily activities are based on an internet connection, more than 90% of them, whether we are talking about bank transfers, online shopping, private and secure applications, industrial parks and logistics developers, all use the internet.

According to this analysis, the main concern is about the reliability and stability of the networks, their variety but also the security offered to the users. The present Wi-Fi offers major advantages, covering important sectors in the field of communications but also extended services. The limited availability of the spectrum affects its performance, making it an unstable candidate in the field of wireless communications.

B. Introduction on the visible light communications

The literature and existing studies provide a viable solution that can address the limited availability of spectrum this solution is represented by wireless optical communications (OWC). The main advantage of the optical spectrum is that it benefits from the visible light spectrum and the infrared (IR) spectrum, which is almost unlimited, has about 800 Thz. bandwidth, compared to the RF spectrum, which is limited to about 300 GHz.

We can say that the IR spectrum has a much older history being tested a long time ago, unlike the visible light spectrum (380-780nm) being something new. Therefore, the concept of this VLC technology is introduced in the late 90s and later in the early 2000s, is already incorporated in various high-performance experimental prototypes presented in the coming years. This technology has become popular since 2010 because it is presented as a technology of the future with transfer rates of over 1Gb/s and soon exceeding this value. The development of the technology continued in the years that followed, and at the present works report transfer rates exceeding 10Gb/s, specifying that in the coming years the values will reach several hundred Gb/s. At the same time with the improvement of transfer rates, the development of VLC technology is also taking shape in other areas, expanding the scope of application, becoming a Mondial business. Technological developments and research have succeeded in transforming an LED (Light Emitting Diode) an ideal component for standardization in the field of optical communications using visible light according to the IEEE. Although the IEEE 802.15.7 standard was not accepted by the developers, it was the starting point for the development of VLC, is the necessary reasons to develop the future elements of standardization of the technology [6]-[8].

A major advantage on which VLC communications are based, across the broad spectrum, is that it can use the distribution of light sources. Thus, any LED-based light a source can easily be transformed into a device that can

transmit data, being a simulated process. In the context presented. The IEEE standard 802.15.7 proposes and requires that the transfer function does not interfere with the illumination process. Thus, the standard sets out the situation in which the power of the light emitted by the user becomes adjustable as needed, so it is possible to increase the light emitted according to the requirements imposed by him. Another analysis addresses the issue of referring to the flashing light standard, but in this situation, it is specified that transmission of data should not provide perceptible flashes. This aspect is treated accordingly based on the techniques by which each bit is modulated and encoded (IE 0 and 1) while maintaining the same light intensity. However, most scenarios in which VLC technology was implemented to reflect the utility and adaptability of the communication, providing reliable communications, both over short distances with remarkable results (50 - 100m) but over longer distances of over 200-300 m where the signal is affected by other light sources [9].

According to the literature and studies, another advantage of VLC technology is the contour of the safety zone, the fact that the visible light does not destabilize the activity of electronic equipment and does not endanger human health, according to recent reports published by the World Health Organization, the accession worrying about for widespread use of radiofrequency and microwaves. This has warned authorities in several large cities, suspending the process of providing 5G wireless access, as the health impact would be harmful. Consequently, VLC can provide a secure way of communication for human health, but also for other systems, these being solid arguments, being supplemented by VLC only in certain situations [9]-[11].

III. Debate ON Setup and Future Perspectives

Past events highlight the increased demand for technologies in the field of communications, a factor that has led to the introduction of standards such as 802.11 (Wi-Fi), which later became the most popular and the widespread wireless network has a common mechanism for data transmission and reception. However, research has achieved from Wi-Fi a complex technology adapted to each environment. Thus, in order to obtain increased flexibility, mobility and increased adaptability, the 802.11b standard has succeeded in being extended to the industrial milieu, and due to its performance and necessity, the automotive field has embraced the initiative, through the IEEE 802.11p standard. At this moment, we can say that over 95% of the activities and services we benefit from are based on an internet connection, regardless of whether we are talking about electronic commerce, industrial parks, state or private companies, multinationals, bank transfers. The current context raises question marks and concerns about the reliability, stability, and security of the network, having variety in terms of customers and their variety, using communications in various activities.

Therefore, the current Wi-Fi technology offers major advantages, covers important areas and sectors of the communications area, serves various services, but there is room for better. Thus, the context in which demand is increasingly exponential for wireless communications, limited availability of spectrum can affect the performance of the technology and make it a vulnerable player in the field of wireless communications [8]. But many aspects can be corrected when using a complementary VLC-RF system, secure in the case of VLC is effective due to LOS (Line of Sight) communication, being a technology that cannot be intercepted, does not interfere with EM (Electro-Magnetically). Thus, in the next section are presented developed or developing elements, based on VLC technology, having prototypes in working order. They aim to integrate the two VLC-RF technologies within a hybrid platform, in order to obtain a complete, efficient, sustainable, flexible product, capable of becoming a solution in the context presented in the previous sections.

A. *Presentation of the experimental RF setup*

Our research group has been developing a VLC system, this uses the configuration of a logarithmic transimpedance circuit, which makes a significant contribution to the process of improving noise resistance. Each block has been designed for the flexibility and extension of its parameters, offering high flexibility and performance under both indoor and outdoor conditions. The evaluations of the current state of the system were presented in [13],[14], and confirmed external communication distances of over 50 m (limited only by the

Fig. 1. V2I indoor outdoor system based on VLC communications, using commercial traffic lights and prototype receiver incorporated into 3D navigation.

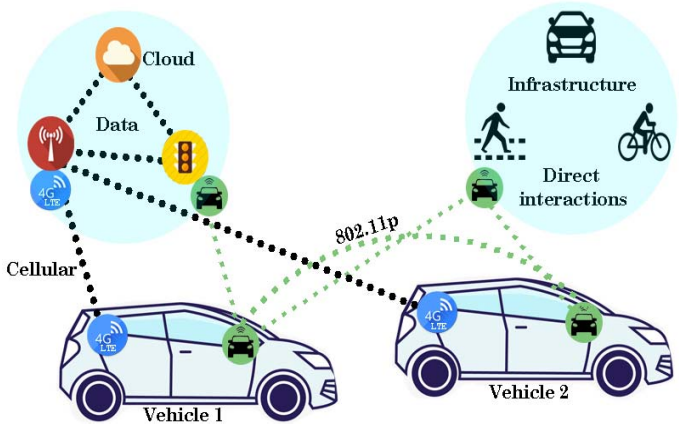

Fig.2. Communication V2V based on the OBD dongle module with 4G.

factor of buildings), resulting in increased resistance in case of disturbances coming from the artificial light area. It can be said that the current system, which is constantly developed, has achieved remarkable results, BER was lower than 10-7 obtained in the scenario of transfer rates between 1.5 kb/s - 50 kb/s. Moreover, our experimental results show that the developed setup allows communication over 50 m distances in extreme conditions. As a result, the VLC system requires adjustments in terms of reducing the incident sunlight, this is possible by adjusting the field of view.

According to this topic, the evaluation of the outdoor configuration is provided in [11],[13]. Improvements in the system and its sustainability have increased communication distances, registering between 130 and 150 m in ideal conditions. As a result, it can be observed that the modifications made to allow the system to be adaptable to the context, and the VLC system benefits from improved performances, radically increasing the compatibility with the applications dedicated to the automotive field [11]-[16].

B. Presentation of the experimental RF setup

We can say that cooperative management assistance systems have a significant rise in the automotive safety sector. In the near future the vehicles they will communicate with other either with the help of V2V communications or with infrastructure elements through V2I, without, intelligent traffic signs, intelligent traffic lights but also the local infrastructure of type RSU-(Road-Side-Units). Vehicles and road infrastructure elements form an ad-hoc vehicle network. In the specialized literature, these directions are included in V2X (V2V and V2I) communication based on 802.11p standard, but also LTE (Long Term Evolution) mobile communications[20]-[24]. The proposal for developing a V2X(Vehicle-to-everything) prototype (V2V and V2I) reflects on the possibilities of interconnecting other systems as well as VLC or IV-AR communications (communications through augmented reality modules [17],[18],[19].

Thus, cooperative management assistance functions are integrated. The presented architecture Figure 2 includes the installation of an OBD dongle capable of interacting with the vehicle providing control over the sensors and the on-board computer and the development of modules intended for acquisition or communication with the existing sensors being made possible directly through the device installed on the

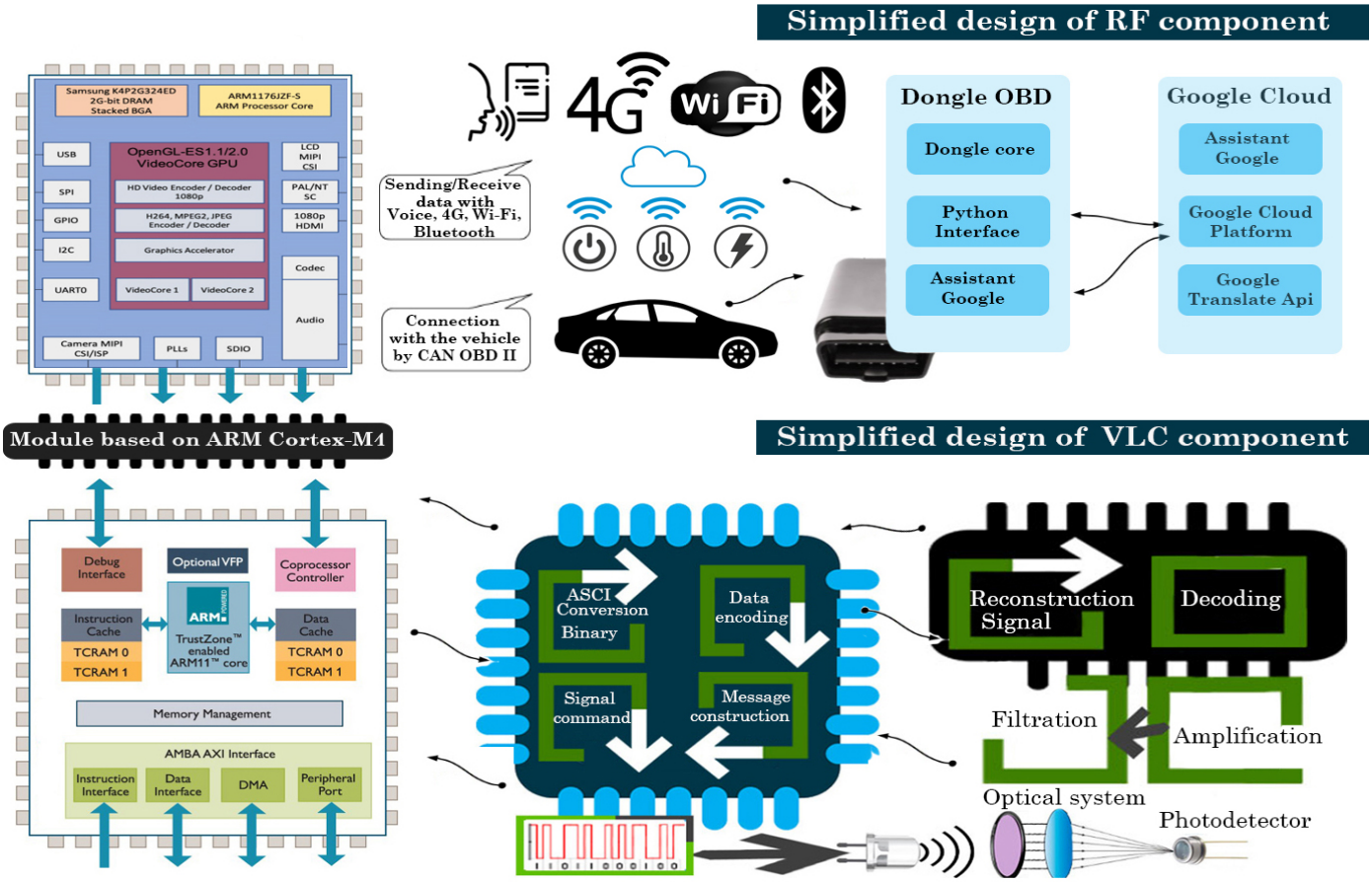

Fig. 3. Simplified designs VLC-RF systems

vehicle. Cloud server, which in turn collects information from other traffic participants, including road infrastructure, pedestrians, but other devices also. The architecture presented is modular, allowing the separate implementation of the other functions, and the information is subsequently transmitted to the server.

C. Discussion on the experimental VLC-RF setup proposed

The development of the VLC system was based on its modularity and interconnectivity with an RF system, meeting the requirements imposed by the automotive field. Therefore, the VLC transmitter uses commercial elements that meet the criteria of a 200mm traffic light with LED. Consequently, the power emitted has approximate value to an ordinary traffic light, the results being comparable and widely reproduced. An improved module based on a microcontroller (ARM Cortex M4) and one digital power switch is added on the commercial traffic light [20]-[23].

Thus, the microcontroller transforms the data and transmits it in a binary message by switching the LEDs, the simplified scheme can be found in Figure 3. The VLC receiver is built using a PIN photodiode, with an angle of half sensitivity of ±55º, connected to a transimpedance circuit, so this configuration improves significantly robustness of the system to noise and extends the range, through the logarithmic configuration[14],[15]. We can say that the possibility of saturation of the photoelement is remissive, under intense lighting conditions, this design automatically reduces the sensitivity. The use of infrared rejection (IR) optical filters but also the optical system that limits the (FoV), and following we reduce of the parasitic light and that of the signal amplitude. Thus, the inclusion of an adaptive Bessel filter is imperative, an automatic circuit (AGC), and a Schmitt trigger all one controlled by the same type of 180 MHz microcontrollers, similar to the VLC transmitter. The decoded information from the message header is identified by the microcontroller based on a developed algorithm that is able to measure pulse width and edge identification[14],[16]. Since the VLC system aims at applicability in the automotive field, while the VLC channel is characterized by unpredictability, the purpose of this architecture is to be provided with a VLC-RF system adapted to any context. As we well know from the literature and published works, the adaptability of a VLC component can be disturbed by several factors such as water droplets, fog, dust particles, or other bodies that can pass through the visual field of the photodiode. Thus we try to use and adapt two components, one VLC another RF for their complementarity and mutual support at certain points.

Thus, the information that requires detailed analysis will be taken over and processed by the RF component based on higher computing power and mobility in the coating of certain elements through image capture and analysis. For better connectivity and increased response times, the development of software architecture is based on analysis and image processing using algorithms, but also an accelerator to develop a neural network, namely Movidius, to communicate with that Cloud server and the whole RF infrastructure outlined around the Raspberry Pi Zero W controller. Thus, the computing power and fast connection provided by this stick can achieve parallel processing to streamline the entire process. The connection between these two components, the RF and the VLC, will be achieved with the help of a microcontroller-based on ARM Cortex-M4, used so far on the developed VLC system, ideal in data packet processing, information transfer, and analysis.

In the case of the RF architecture shown in Figure 3, we have a device based on two microcontrollers (Arm Cortex-A53) for information processing, and for communication between modules a Cortex-M4 microcontroller, interfacing and transmission to other devices. Another device dedicated to direct communication with the car is based on a module dedicated to CAN (Controller Area Network) communication of OBD type, offering the possibility to interact with the vehicle and collect information both from other traffic participants and from vehicles from it is installed. The microcontroller is based on an ARM1176JZF-S- (1GHz) processor capable of 4G / Wi-Fi / Bluetooth communication.

Thus, estimates of current technologies such as 5G are somewhat vague, but the need for high and stable speeds to maintain the stability of data transfer is imperative. Another important feature is that of latency, which is the time required for a network to respond to a request received from users. Ensuring a quality response and perceptible latency must be as low as possible. In the case of 4G used in the RF component dedicated to this system, the latency values reaching approximately 50 milliseconds, given that 5G can have latency even lower than one millisecond [24],[25].

The modular system allows the development and adaptation of new hardware and software elements dedicated to both image processing and the development of components dedicated to vehicle control through the OBD module installed in the car. Thus, we can have information about the car from anywhere but also total control. The customized tests performed led to this first stage and the subsequent development of a product consisting of the two components presented above. According to the previous presentations, observing the advantages and disadvantages of each technology, but also the tests so far in the field, the development of such a system has every reason to continue in the direction presented. The most discouraging factor is the legislative factor in order to install such a system on a commercial car and its approval. Expectations regarding the developing system are in line, wanting to highlight the common features and complementary of the two revolutionary communications technologies and the purpose of an autonomous prototype to be developed with the help of commercial components and at low cost.

In addition to the above, the hybrid system integrates a VLC prototype being supplemented by complementing with a dedicated prototype that includes 4G / Wi-Fi functions to achieve, the mechanism of teaching, processing, analysis, and distribution of information thus optimizing system efficiency. The approach presented offers the possibility to expose the benefits of density and bandwidth offered by VLC with a

totally non-intrusive RF back-channel thus maintaining compatibility with conventional devices, demonstrating excellent scalability. The data received from the VLC transmitter is processed and transmitted using the interconnection module between the two systems automatically reaching the server managed by the module installed on the car, then they are displayed on the developed navigation device. We can say that the heterogeneous nature of the technologies used suggests various ways of applying them, because since 2011 research groups have developed hybrid indoor systems that provide mechanisms to provide internet connections based on RF-VLC technologies.

IV. Conclusion and Further Development

The technological advancement and the interest generated by the users and the industry for wireless communication technology are constantly increasing having the possibility of development in several areas of interest. Therefore, road safety applications and communications-based vehicles are an example and an area of interest. This article provides information on the use of VLC-RF communications in the automotive field. Further, part of the analysis has formed a basis by which the integration of technologies within a vehicle communication platform becomes possible. Therefore, VLC communications prove to be suitable for short-distance V2V connections, while if visible light communication does not have continuity in certain areas, RF communications intervene, completing the system and covering all areas. The constantly developing platform is capable of providing detailed information within the network by providing information on distances, road infrastructure, traffic analysis, sensors. Future work involves each component developed in order to obtain a finished product capable of meeting the requirements, especially for this product to become a real solution in the fight against road accidents and reduce the number of people who lose their lives.

References

[1] Fact Sheet 358—Road Traffic Injuries, World Health Org., Geneva, Switzerland, May 2016.

[2] Global status report on road safety 2018. Geneva: World Health Organization; 2018. Licence: CC BYNC-SA 3.0 IGO.

[3] N. Kumar, N. Lourenço, D. Terra, L. N. Alves and R. L. Aguiar, "Visible light communications in intelligent transportation systems," *IEEE I. V. Symp.*, 2012, pp. 748-753. doi: 10.1109/IVS.2012.6232282

[4] A. Căilean, B. Cagneau, L. Chassagne, M. Dimian and V. Popa, "Novel Receiver Sensor for Visible Light Communications in Automotive Applications," in *IEEE Sensors Journal*, vol. 15, no. 8, pp. 4632-4639, Aug. 2015. doi: 10.1109/JSEN.2015.2425473

[5] M. Y. Abualhoul, O. Shagdar and F. Nashashibi, "Visible Light inter-vehicle Communication for platooning of autonomous vehicles," *2016 IEEE Intelligent Vehicles Symposium (IV)*, Gothenburg, 2016, pp. 508-513. doi: 10.1109/IVS.2016.7535434

[6] W. Shen and H. Tsai, "Testing vehicle-to-vehicle visible light communications in real-world driving scenarios," *IEEE Vehic. Net. Conf.*, 2017, pp. 187-194. doi: 10.1109/VNC.2017.8275596

[7] S. Rajput and Nidhi, "A Study of Vehicular Adhoc Networks," 2019 International Conference on Computing, Communication, and Intelligent Systems (ICCCIS), Greater Noida, India, 2019, pp. 135-138. doi: 10.1109/ICCCIS48478.2019.8974462

[8] I. E. Lee, M. L. Sim and F. W. L. Kung, "Performance enhancement of outdoor visible-light communication system using selective combining receiver," in *IET Optoelectronics*, vol. 3, no. 1, pp. 30-39, 2009.

[9] W. Whyte, J. Petit, V. Kumar, J. Moring and R. Roy, "Threat and Countermeasures Analysis for WAVE Service Advertisement," 2015 IEEE 18th International Conference on Intelligent Transportation Systems,LasPalmas,2015,pp.1061-1068.doi: 10.1109/ITSC.2015.176

[10] S. Rajagopal, R. D. Roberts and S. Lim, "IEEE 802.15.7 visible light communication: modulation schemes and dimming support," in IEEE Communications Magazine, vol. 50, no. 3, pp. 72-82, March 2012. doi: 10.1109/MCOM.2012.6163585

[11] E. Zadobrischi, L. Cosovanu, S. Avătămăniţei and A. Căilean, "Complementary Radiofrequency and Visible Light Systems for Indoor and Vehicular Communications," 2019 23rd International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, Romania, 2019,pp.419-423.doi: 10.1109/ICSTCC.2019.8885570

[12] B. Blaga, M. Deac, R. W. Y. Al-doori, M. Negru and R. Dănescu, "Miniature Autonomous Vehicle Development on Raspberry Pi," 2018 IEEE 14th International Conference on Intelligent Computer Communication and Processing (ICCP), Cluj-Napoca, 2018, pp. 229-236.doi: 10.1109/ICCP.2018.8516589I

[13] A. Cailean, M. Dimian, V. Popa, L. Chassagne and B. Cagneau, "Digital Signal Processing Sensor for Automotive Visible Light Communications Applications," 2017 New Generation of CAS (NGCAS), Genova, 2017, pp. 225-228.doi: 10.1109/NGCAS.2017.53

[14] A. Cailean and M. Dimian, "Impact of IEEE 802.15.7 Standard on Visible Light Communications Usage in Automotive Applications," in *IEEE Communications Magazine*, vol. 55, no. 4, pp. 169-175, April 2017.

[15] P. A. P. Ferraz and I. S. Santos, "Visible Light Communication Applied on Vehicle-to-Vehicle Networks," *2015 International Conference on Mechatronics, Electronics and Automotive Engineering (ICMEAE)*, Prague, 2015, pp. 231-235.

[16] R. Roberts, P. Gopalakrishnan and S. Rathi, "Visible light positioning: Automotive use case," *2010 IEEE Vehicular Networking Conference*, Jersey City, NJ, 2010, pp. 309-314.

[17] M. Kinoshita *et al*., "Motion modeling of mobile transmitter for image sensor based I2V-VLC, V2I-VLC, and V2V-VLC," *2014 IEEE Globecom Workshops (GC Wkshps)*, Austin, TX, 2014, pp. 450-455.

[18] D. Aguirre, R. Navarrete, I. Soto and S. Gutierrez, "Implementation of an emitting LED circuit in a Visible Light communications positioning system," *2017 First South American Colloquium on Visible Light Communications (SACVLC)*, Santiago, 2017, pp. 1-4.

[19] J. Huang *et al*., "V2X-communication assisted interference minimization for automotive radars," in *China Communications*, vol. 16, no. 10, pp. 100-111, Oct. 2019.

[20] Ashritha M and Sridhar C S, "RSU based efficient vehicle authentication mechanism for VANETs," *2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO)*, Coimbatore, 2015, pp. 1-5.

[21] L. Yang, W. Zhang, Y. Zhang and J. Zhang, "Hybrid Optical Wireless Network Based on Visible Light Communications (VLC)-WiFi Heterogeneous Interconnection," *2019 2nd International Conference on Communication Engineering and Technology (ICCET)*, Nagoya, Japan, 2019, pp. 35-38.

[22] M. B. Rahaim and T. D. C. Little, "Toward practical integration of dual-use VLC within 5G networks," in *IEEE Wireless Communications*, vol. 22, no. 4, pp. 97-103, August 2015.

[23] S. Ucar, S. C. Ergen and O. Ozkasap, "Security vulnerabilities of IEEE 802.11p and visible light communication based platoon," *2016 IEEE Vehicular Networking Conference (VNC)*, Columbus, OH, 2016, pp. 1-4.

[24] S. Ucar, S. C. Ergen and O. Ozkasap, "Visible light communication assisted safety message dissemination in multiplatoon," *2017 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom)*, Istanbul, 2017, pp. 1-5.

[25] C. Wang, P. Zou, J. Chen, G. Li and N. Chi, "Internet of Vehicle System Based on Automotive Headlight utilizing Probabilistic Shaping," *2019 11th International Conference on Wireless Communications and Signal Processing(WCSP)*,Xi'an,China,2019,pp.1-4.