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# A survey on the usage of DSRC and VLC in communication-based vehicle safety applications

Alin-Mihai Cailean<sup>1,2,\*</sup>, Barthélemy Cagneau<sup>1</sup>, Luc Chassagne<sup>1</sup>

<sup>1</sup>Université de Versailles,  
Laboratoire d'ingénierie des systèmes de Versailles  
Vélizy-Villacoublay, France  
\*alinc@eed.usv.ro

Valentin Popa<sup>2</sup> and Mihai Dimian<sup>2</sup>

<sup>2</sup>Stefan cel Mare University, Department of Computers,  
Electronics and Automation  
Suceava, Romania

**Abstract**— This paper addresses the issues related with the employment of wireless communication in vehicle safety applications. It focuses on the usage of the 5.9 GHz dedicated short range communications (DSRC) under the 802.11p standard. By analyzing the theoretical and experimental literature, the paper highlights the vulnerabilities associated with the DSRC usage. Besides the radio frequency DSRC, the usage of visible light communication is discussed as well. It was found out that the two are complementary technologies, each of them being suitable in the scenario in which the other one is vulnerable. Under these circumstances, the junction of the two has the potential to ensure a reliable link even in challenging conditions.

**Keywords**— IEEE 802.11p; IEEE 802.15.7; inter-vehicle communications; vehicle safety; visible light communications.

## I. INTRODUCTION

Traffic safety represents one of the major preoccupations not just for the automotive industry but also for governmental and non-governmental agencies. Until few years, the concern in this field had as central point the idea of helping people surviving accidents. Nowadays, with the development of the active safety systems, the target is to help people avoid accidents. In spite of all the tremendous efforts made towards the improvement of the current active safety systems, such ESP or ABS, more and more people are injured or die because of traffic events [1], [2]. This proves that the next generations of vehicle safety systems require more than individual measures but should involve full cooperation between the traffic participants. One of the most efficient ways to reduce the number of crashes and the associated victims is increasing the vehicle awareness. Embedded sensors can feel the environment and assist the driver in dangerous situations. Such systems include ultrasounds sensors that are used for park assistance, cameras that are used for traffic lane, traffic sing or pedestrian detection, Radar or Lidar technology used in long-range obstacle detection and distance measurements. However, sensors have their limitations, and in these conditions, wireless communications can take the driver assistance at the next level. As illustrated in Fig. 1, wireless communications enable vehicles to communicate with each other, by transmitting “Here I am!” messages and also to share the information collected by the sensors. By using the collected data, the

system is able to take actions in risky situations. However, it will not act against the driver but more like as a “safety net”. In most of the cases, the activity of the vehicle ends before the driver can react. Beside safety, the communication can be used to increase the efficiency of the transportation system by providing locations services and optimized alternative routes.

The Intelligent Transportation System (ITS) [3] aims to integrate state-of-the-art cooperative technologies with the purpose of increasing the safety and efficiency of the transportation system and also to reduce the CO<sub>2</sub> emissions. In ITS, wireless communications are required to enable vehicle-to-vehicle (V2V) and infrastructure-to-vehicle (I2V or V2I) communications, which represent the basis for the so called communication-based active safety applications. It is considered that enabling I2V and V2V communications the number of accidents can be substantially reduced. The combination of the two has the potential to address up to 81% of all vehicle crashes [4]. Wireless communication allows vehicles to share traffic safety information (e.g. velocity, brake, direction, mechanical state, etc.) that can substantially increase the traffic safety. The efforts towards the development of Dedicated Short Range Communications (DSRC) for vehicular safety applications and also the huge interest in this direction have been confirmed with the allocation of a 75 MHz bandwidth in the 5.9 GHz spectral region and with the publication of the IEEE 802.11p [5] standard for wireless access in vehicular environments.

Communication-based safety applications require high reliability and low delays. However, the wireless cooperation between vehicles is a challenging problem due to the large amount of dynamic data. In a Vehicle Ad-hoc Network (VANET), the problem becomes more stringent due to the mutual interferences.

For many years, the wireless communications were dominated by Radio Frequency (RF) communications with no perspective for a strong contra candidate. However, the progress in the solid state lighting technology, high performances Light Emitting Diodes (LEDs), capable of rapid switching, enabled Visible Light Communications (VLC). Compared with the classical lighting sources, LEDs offer multiple advantages like energy efficiency, long life expectancy, low maintenance cost and so on. Due to these

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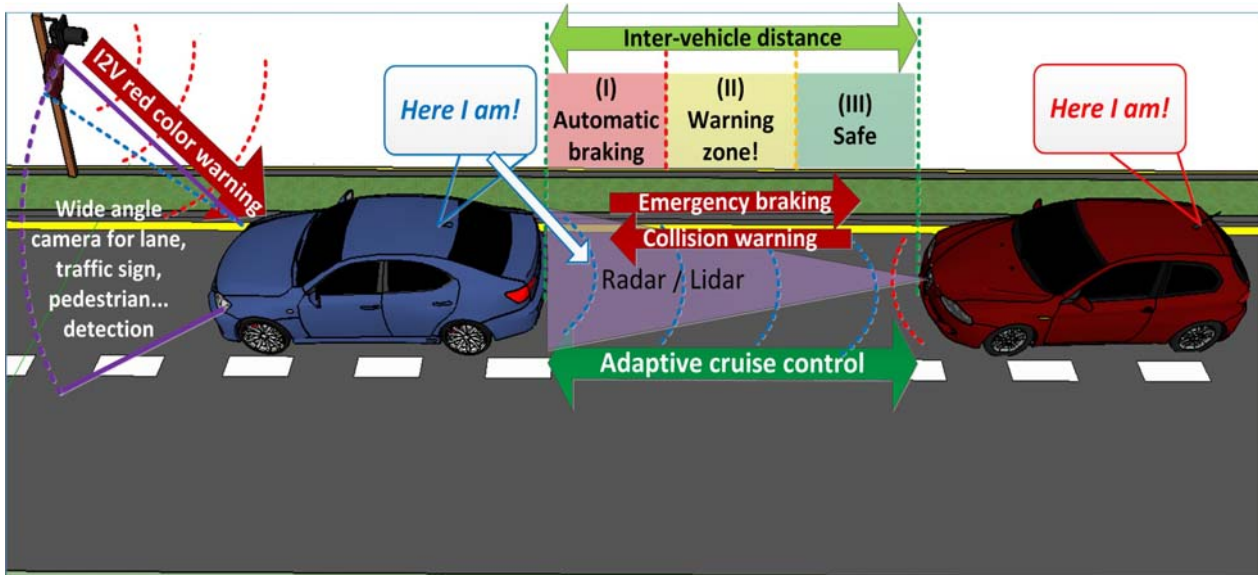


Fig. 1. Sensors and wireless communication fusion for traffic safety applications.

advantages, LED lighting systems began to be used in numerous applications, both indoor and outdoor. In the transportation area, LEDs began to be used for traffic lights, street lighting or traffic signaling. The automotive industry had also begun to replace the halogen lighting with LEDs lighting systems. In the light of the upper mentioned context it is obvious that LED lighting is omnipresent in the transportation domain and its usage for wireless communications seems appropriate. Furthermore, the potential of VLC potential has been confirmed with its standardization by the IEEE 802.11.7 standard [6]. Within the standard, the PHY I is intended for outdoor, long-range, low data rate applications such as I2V and V2V communication.

This paper provides an overview over the area of communication-based vehicle safety applications, pointing out some of the requirements imposed in the field. By analyzing and putting together the some of the most relevant works in the field, the paper highlights some of the issues related with the usage of the RF DSRC. It has been found that an important number of papers reported safety issues related with it. Furthermore, this paper highlights some of the advantages of enhancing the vehicular communications with a second wireless technology, namely VLC. The usage of VLC in vehicular applications is also discussed, presenting its advantages and limitations. It has been showed that the two are complementary technologies that can be used for different scenarios.

## II. REQUIREMENTS IMPOSED IN VEHICULAR COMMUNICATIONS

The main vehicle safety applications are identified by analyzing the occurring frequency and the impact of different classes of accidents [4]. The Vehicle Safety Communication Project [7] has defined the most representative safety applications and out of them, eight were considered of high-priority. As summarized in Table I, these high priority applications impose very strict limits concerning the latencies. Except for the curve speed warning, all of them require

latencies below 100 ms, with a 20 ms limit for the pre-crash sensing. Concerning the maximum required communication range, it varies between 50 and 300 m. This points out that in vehicular applications, up to a certain limit, the connectivity, the robustness and the latencies are prior to communication distances. The reason for this is that as the inter-vehicle distances increase, the driver has sufficient time to react on his own or the potential dangerous situation is no longer dangerous. If we take lane changing as example (but the same logic is true for most of the situations), it is obvious that the action is risky only when other vehicles are in vicinity.

TABLE I. THE HIGH PRIORITY SAFETY APPLICATIONS

Application	Max. Range [m]	Rate [Hz]	Max. Latency [ms]	Message Length [bits]	Type
Traffic Signal Violation Warning	250	10	100	528	I2V
Curve Speed Warning	200	1	1000	235	I2V
Emergency Electronic Brake Light	300	10	100	288	V2V
Pre-Crash Sensing for Cooperative Collision Mitigation	50	-	20	435	V2V
Cooperative Forward Collision Warning	150	10	100	419	V2V
Left Turn Assistant	300	10	100	904 208	I2V and V2I
Lane Change Warning	150	10	100	288	V2V
Stop Sign Movement Assistant	300	10	100	208 416	V2V and I2V

As for the message generation rate and the length, relatively short messages are generated up to 10 times per second. Table II presents an overview on the inter-vehicle distances under different traffic conditions.

TABLE II. INTER-VEHICLE DISTANCE IN DIFFERENT TRAFFIC CONDITIONS

Conditions	Inter-vehicle distance [m]
Traffic jam	<35
Roadway in urban areas	35 – 49
Urban highways rush hours	50 – 66
Urban highway	67 – 100
Rural highway	101 – 159
Rural areas	>160

### III. ON THE ABILITY OF THE 802.11P TO SUPPORT COMMUNICATION-BASED VEHICLE APPLICATIONS

Several technologies were proposed and investigated for communications between vehicles and infrastructures such as Infra-red [8], Bluetooth [9], 3G [10], [11] LTE [12] or even combinations of these technologies [13]. However, the strongest focus is on the RF DSRC. DSRC is regulated by the IEEE 802.11p standard for Wireless Access in Vehicular Environments (WAVE).

The IEEE 802.11p standard was developed based on the IEEE 802.11a standard but with the improvement of the PHY and MAC layers. The enhancements performed on the standard aim to provide higher robustness and to adapt to the fast movement conditions imposed by the vehicular applications. The DSRC channel is divided into 7 channels of 10 MHz for different applications, where each channel is divided into 52 sub-channels which have a bandwidth of 156.25 kHz. All the safety related messages are broadcasted using the control channel which is the center channel. Depending on their criticalities, the messages are categorized into 4 priority categories, with the purpose of reducing the latency of the high importance messages. As a collision preventing mechanism, the IEEE 802.11p standard uses the well-known CSMA/CA. DSRC involves half-duplex communication with data rates from 3 to 27 Mb/s. As a modulation technique, it uses orthogonal frequency division multiplex (OFDM) to ensure data multiplex. DSRC is aiming to achieve communication ranges of up to 1000 meters.

Even if the standard was developed considering the difficult conditions encountered in vehicular application, numerous studies report issues related with it. Channel congestion affects the communication performances and represents the major impediment for a reliable communication [14]. Channel congestion is determined mainly by the vehicle density, message generation rate and transmission range. Since communication-based vehicular safety applications aim to exchange a large amount of real-time dynamic data, it is obvious that this will generate serious issues. In the case of VANETs, the different nodes will increase the channel congestion causing mutual interferences and the phenomenon

called “broadcasting storm” [15]. VANETs are characterized as highly dynamic topologies with strict constraints regarding delays and packet delivery. The quality of the channel modifies randomly in time and is difficult to predict, since it depends on the behavior of each individual communication link. Furthermore, each node (vehicle) creates interferences that cover an area wider than the covered communication area.

Another significant problem, also encountered in high traffic densities, is related with the CSMA/CA. Several studies have showed that when such conditions are fulfilled, the behavior of the CSMA/CA is approaching towards the one of ALOHA, meaning that the nodes transmit their messages after a random time, without sensing other transmissions [16], [17]. This phenomenon generates packet decoding failure even for the communication between closed-by vehicles. The failure of the CSMA mechanism in high traffic densities was also observed in [18]-[20]. These aspects are very significant especially in traffic safety applications which require latencies as low as 20 ms. Under these circumstances, in high traffic densities such as on highways or in crowded cities, the reliability of the communications is rather questionable [21]. The fact that the WAVE cannot ensure a properly message delivery in high traffic not even for high priority messages is also demonstrated in [22]. This paper concluded cannot ensure time critical message distribution. Analysis of the DSRC in a highway scenario also points out that even if the latencies requirements could be satisfied, the reliability requirements are difficult to meet mainly due to external collisions. The same study points out that the hidden node is a stringent problem in the highway scenario [23], which significantly affects the packet delivery ratio.

In addition to channel congestion, another disturbing phenomenon affecting the DSRC is the Doppler spread. The Doppler spread is causing signal spread that leads to a broader spectrum compared with the transmitted signal. The channel variations cause sub-carrier interference which degrades the performances. The negative effect of the Doppler spread is affecting both BER and throughput performances [24]. The effect of the Doppler spread is proportional to the velocity of the vehicles and to the distance separating the vehicles [25].

The multipath effect is also a perturbing phenomenon for DSRC. The multipath distortions are mainly caused by different length paths resulted due to unwanted reflections. Due to the highly dynamic nature of VANETs, this application area is characterized as a rich multipath environment. The multipath components also widen the Doppler spectrum.

The no line of sight (NLoS) condition represents a stringent problem for 802.11p. In urban conditions, buildings situated at the crossroads pose a major problem to the communication [26]. The roadside vegetation blocks the communication in the case of tight curves [27]. In case of steep crest, again, the NLoS condition makes the communication impossible [27]. Furthermore, vehicles interposed between emitter and receiver lead to packet losses or even to communication breakdown [28]. In all these instances the connectivity is lost almost immediately after the LOS is altered.

To conclude this section it can be observed that DSRC are affected mainly by high traffic densities, NLoS and high

velocities. These factors reduce the communication range, cause numerous packet collisions, increase the delays and reduce reliability. Considering the upper mentioned analytical and experimental results it can be observed that DSRC systems are fully reliable just in ideal conditions. However, in real situations, the perturbing factors previously mentioned will cumulate in plenty of the cases (eq. high speed with NLoS) leading to even poorer performances compared with the ones described above. Moreover, it is also observed that the communication breakdowns are occurring mostly in the situations for which they were meant. At high speed, in tight curves, is the moment when these systems are required the most. Taking into account that [14]-[28] represent just a narrow segment of studies that question the capability of DSRC to face all problems related to vehicular communications, the competition for the winning communication technology in vehicular networks remains open.

#### IV. VISIBLE LIGHT COMMUNICATIONS IN VEHICULAR APPLICATION

Unlike RF based communications, VLC is right from the start a direct LoS communication technology. Whereas Non-LoS communications are more reliable, flexible and robust, LoS generally maximizes power efficiency and reduces multipath distortion. However in dynamic conditions such the ones from vehicular applications, unwanted reflections may occur but their effect on communications is felt only at short distances, making VLC relatively free of multipath distortions [29].

In VLC, bidirectional connections between more than two transceivers are difficult to obtain. This reduces the load on the network and prevents the mutual interferences. When considering VLC between vehicles, the communication is performed from when vehicle to another. A scenario of VLC usage in a high way scenario is illustrated in Fig. 2. The neighboring cars receive the data by using light sensors and send them further to the next nearest neighbors by using their head/back lights. Data are thus propagated throughout the highway. Furthermore, the cars can also communicate with each other regarding their mechanical state or other issues needed to enhance the traffic safety and the security.

VLC is a relatively new communication technology, which was first considered for transport related applications in 1998 [30], [31]. Since then, these systems continuously evolved in

terms of communication range and reliability. Numerous studies showed that VLC is able to satisfy the requirements imposed in for vehicular networks in real working conditions [29], [32]. VLC was also found to be compatible with platooning, as demonstrated in [33].

Besides the theoretical studies, there are also some implemented VLC systems. Most of these systems are orientated towards the communication between traffic light and vehicles. In this case, the high power of the traffic light allows for relatively long communication distances. At this moment, such systems can achieve stable communication ranges up to 50 meters [34] - [38]. Concerning the I2V communication, VLC is also compatible with the communication between the street lighting system and vehicles [39], [40]. In this case, the constant short distance between the street light and vehicle, along with the high power implied, allows for high data rates and increased communication stability. Under these circumstances, this particular case of I2V VLC has a huge developing potential.

Nowadays, many commercial vehicles integrate LED lighting systems in headlamps, brake lights or signal lights. Based on these new lighting systems V2V VLC can be enabled. Several examples of such prototypes are presented with communication distances of few tens of meters [41]-[44]. Beside communication, VLC technology also seems to be able to add localization capabilities. This is performed by using the signal time difference of arrival [45], [46]. The localization performances of VLC have the potential to be superior to the ones of GPS and have a lower cost than radar or lidar systems.

Even if there are many favorable opinions regarding VLC usage in ITS, VLC is still an early stage technology. The communication-based vehicular applications require communication ranges longer than VLC can provide for the moment and under these conditions, its usage is suitable just in high traffic densities.

#### V. DISCUSSIONS

In the communication-based vehicular safety applications most of the high priority messages are event-driven safety messages and routine safety messages. The event driven safety messages are triggered by a change in the behavior. The event safety messages imply geographically data broadcasting rather than individually addressed messages. For example, when a

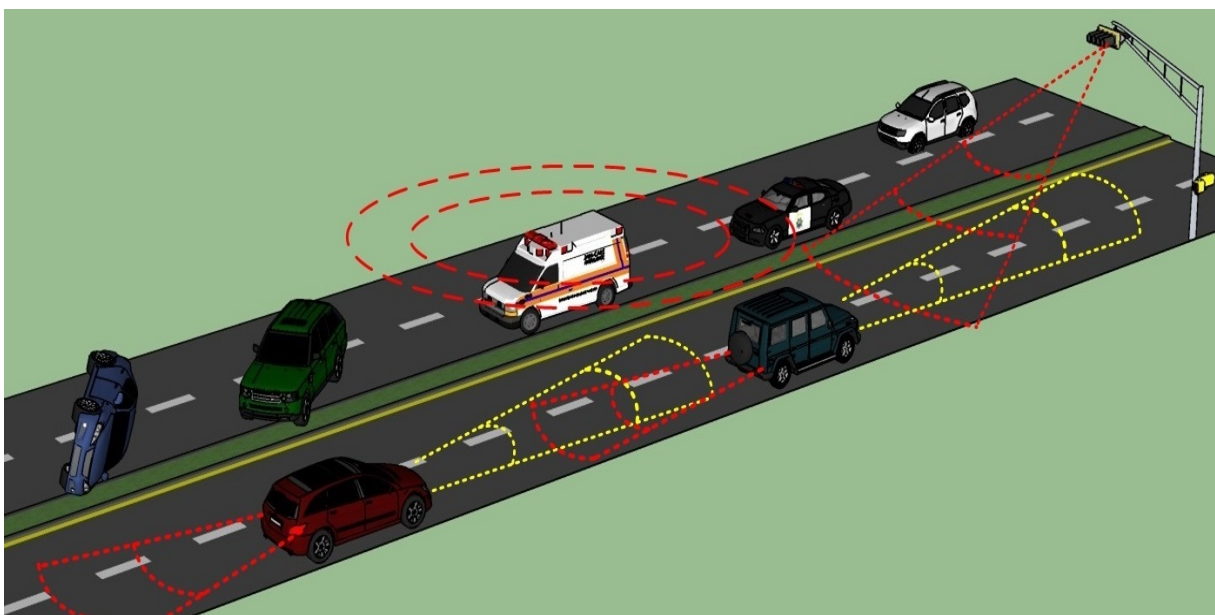


Fig. 2. Visible light communication usage in a highway scenario.

vehicle is hard braking, it is concerned to inform the vehicle behind, whoever that vehicle is. Event safety messages are relatively rare compared with the other messages, however they require high reception rates (100%). When a vehicle is transmitting a safety message it does not request an acknowledgement, but it is concerned that its action is being known by the surrounding vehicles. Due to the LoS characteristic VLC enables the messages to be sent just to the addressed vehicles, in this case the neighboring vehicles. On the other hand, RF systems cover an area much broader and cause perturbation to an even wider area, causing channel congestion. Under these conditions the shorter delays and the higher reception rate represent the most important advantages of VLC.

Secondly, the success of the ITS is strictly dependent on its penetration. Insufficient penetration means deficient data collection, distribution and connectivity. If it is to think of RF solutions for the ITS, this will not be possible for a long time ahead because, in order the system to be effective, it is required that every intersection, street and vehicle to be equipped with RF units, which involves a huge employment cost. One of the greatest advantages of VLC compared with DSRC is its low complexity and the reduced implementation cost. Being already half integrated in the existing transportation infrastructure as well as in vehicle lighting systems, makes VLC a ubiquitous technology and ensures it a fast market penetration. In the case of RF, the problem of market penetration is considered a serious issue that can block the deployment. In [47] is estimated that in order for such a system to begin to be effective, it requires at least a 10% market penetration. However, to achieve this it would require few years in which the systems brings little or no benefits, meaning that the deployment cost is mostly supported by the early buyers. Notwithstanding that a significant part of the consumers replace the car in this period without having any benefice from the purchased system.

On the other hand, the main advantage of DSRC over the VLC is the superior communication range and the wider coverage area. Currently, VLC systems can satisfy just in part the communication range requirements, but for most of the envisioned applications the range provided by VLC is insufficient. From this perspective, the VLC researchers must come with fast solutions that can enhance the communication distance. However, even with future development, VLC will not be able to compete with RF communications in terms of range.

The ISO 26262 standard, referring to the vehicles safety-related systems integrated in series passenger specifies that such application cannot rely on the data received from only one sensor. If the same principle is applied to the communication-based safety applications, the performances and the reliability of the system is significantly increased.

VLC usage does not exclude and does interfere with RF communication. Moreover, since each technology is appropriate in different conditions, the two are complementary. DSRC is appropriate in applications where

long range is mandatory, whereas VLC is appropriated in high density scenarios. Furthermore, VLC can contribute to the performance increase of the DSRC by taking some its load.

## VI. CONCLUSIONS

This paper presented a survey on the field of the communication-based safety application, analyzing the 5.9 GHz DSRC and VLC. It has been pointed out that DSRC is suitable for long range applications but it becomes unstable in heavy traffic conditions. On the other hand, VLC performances are not influenced by the number of close-by vehicles but it cannot satisfy all the communication range requirements. By highlighting the vulnerabilities of the two communication technologies, their complementarity has been pointed out. The usage of the two offers better chances to ensure a reliable communication, even in the difficult conditions encountered in VANETs.

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