Vehicle-to-Vehicle Real-time Video Transmission through IEEE 802.11p for Assisted-Driving

João Pereira*†, Miguel Díaz-Cacho‡, Susana Sargento*†, André Zúquete*, Lucas Guardalben†, Miguel Luís†
*DETI - University of Aveiro, Portugal
†Instituto de Telecomunicações - Aveiro, Portugal
‡School of Computer Engineering, University of Vigo - Vigo, Spain
{pereira.joao, susana, andre.zuquete}@ua.pt, mcacho@uvigo.es, {guardalben, nmal}@av.it.pt

***Abstract*—This work presents a V2V video transmission system to help on a car-overtaking decision using the IEEE 802.11p/WAVE communication technology. The system consists on a ffmpeg based video encoder that encapsulates the data received from a camera placed in a front vehicle into HTTP Post packets, and forwards the packet to the rear vehicle through the On Board Units (OBUs) installed on both vehicles. The rear vehicle presents the images to the driver using a visualization device. The proposed system was evaluated through real vehicular experiments in two distinct scenarios: urban and highway. Performance studies were focused on delay measurements, retransmission rate, signal strength and bandwidth consumption related with the traveling speeds and video quality. Results show that the communication delay is higher in the highway scenario, mainly due to the distance between vehicles and the different speeds. However, promising results regarding the maximum delay and the average number of retransmissions foresee important inputs for future services of assisted-driving, in general, and car-overtaking assistance, in particular.** [1]

***Index Terms*—Vehicular Networks, IEEE 802.11p/WAVE, Real-time Video Transmission, Driving Assistance.**

I. Introduction

Driver assistance systems, and particularly, cooperative collision avoidance for on-road vehicles, is one of the main use-case examples in the development of new vehicular control systems and mobile network infrastructures, as recognized in the recently published 5G white-paper for automotive and mobility [1]. The advantages are clear, focusing not only on crash reductions or safety, but also on improving the driving experience. The research lines in driver assistance systems are focused on the vehicular control technologies, and therefore, on the on-board installed sensors, controllers and actuators [2]. Nevertheless, in the recent years, the use of communication links between vehicles, and between them and the cloud network infrastructure to share sensor, actuator and control data is becoming more common [3]–[5].

The communication infrastructure to achieve the vehicle-to-vehicle (V2V) communication and to collect the environment status of the road is still under research and development. Suggested 5G mobile communications infrastructure [1] includes specific challenges to improve quantitatively certain indicators like minimum bandwidth, delays, coverage area and quality of service with respect to the actual 3G/4G infrastructure to be used in V2V communications. Nevertheless, several specific communication technologies are already available to develop applications that involve the complexity of the V2V communication, like the IEEE 802.11p/WAVE technology [6].

The IEEE 802.11p/WAVE technology is based on the well-known WiFi technology, but provides larger communication ranges (in the order of 1 Km) and small communication setup times (in the order of 10-20 msec). The data transmission between vehicles, equipped with On-Board Units (OBUs) and between them and their environment, e.g. Road Side Units (RSUs), has several challenges due the high mobility and the changing neighborhood and surrounding conditions. The IEEE 802.11p/WAVE technology establishes the specifications of the underlying layers to enable fast wireless communications without the need of association and authentication procedures. Nevertheless, the data dissemination procedures are still under research, where several solutions were already suggested with the creation of VANETs [7].

Car-overtaking and collision avoidance are currently some of the most interesting research areas in the field of advanced driver assistance. The main research and implementation lines on this topic are centered mainly on on-board installed sensors by merging the different sensor data to calculate collision risks or estimate overtaking decisions [8]–[11]. From [2] and its associated bibliography, the most important sensors involved in an assisted-driving vehicle are the pan-tilt-zoom camera, the photonic mixer device, the laser scanner, the short-range radar, the long range radar, the ultrasonic sensors (sonars), the fixed camera and the differential GPS.

The reliability of vehicle-to-vehicle real-time video transmission for driver assistance mechanisms is also an open research issue. Some research efforts have been dedicated to the efficient video-streaming in VANETs [12], and simulation models are mostly used as proof-of-concept for quality video assessment covering several general features of the IEEE 802.11p communication networks [13]–[16]. The work in [17] includes a comparison between LTE and IEEE 802.11p standards, where IEEE 802.11p offers an acceptable performance for sparse network topologies with limited mobility support, and LTE meets most of the application requirements in terms of reliability, scalability and mobility support. However, it

[1]This work has been funded by the European Commission Horizon 2020 Programme under grant agreement number H2020-ICT-2016-1/732497 - 5GinFIRE (Evolving FIRE into a 5G-Oriented Experimental Playground for Vertical industries).

is challenging to obtain stringent delay requirements in the presence of higher cellular network traffic load. This result proves that IEEE 802.11p is still a very suitable standard for inter-vehicles real-time video imaging as one of the focus of this paper. Therefore, only a few works considered field experiments on video measurements over IEEE 802.11p as presented in [18], [19]. These works proposed a real-time scalable video codec for the video information, and performed real-world measurements using the off-the-shelf Componentality FlexRoad DSRC equipment. However, they consider only experiments in urban scenarios close to the university campus in Hervanta, a suburb of Tampere, Finland.

This work provides, implements and evaluates a vehicle-to-vehicle real-time transmission architecture using IEEE 802.11p. The work developed includes the creation of communication mechanisms to provide video transmission, which includes a coding process to be executed in the OBUs. The video transmission mechanism was evaluated in two real scenarios, highway and urban, and the obtained results show that the communication delay is higher for the high speed scenario due to higher distance between vehicles and higher travelling speeds. However, other performance metrics, such as RSSI (Received Signal Strength Indicator), bandwidth and packet retransmission, are similar for both scenarios.

The remainder of this paper is organized as follows. Section II presents the proposed architecture and its components and features. In Section III we evaluate and discuss the performance of the proposed real-time video transmission mechanism. Finally Section IV depicts the conclusions and future work.

II. Proposed System and Architecture

The proposed system comprises moving vehicles and the possibility to exchange information such as video-images, vehicles' position, and other control data. The real-time video service proposed in this work is part of a wider driver assistance framework exploring the use of IoT sensors placed in traffic signals and traffic lights. Fig.1 presents the proposed architecture detailing the communication technology between each element. In this work we will focus on the vehicle-to-vehicle real-time video transmission. This way, we will be able to expand the visibility of the rear driver, allowing the vehicle to display a road view as seen by the front vehicle.

Considering the video transmission scenario, each vehicle needs to be equipped with the following set of elements[2]:

- A OBU equipped with an IEEE 802.11p/WAVE interface and its processing capabilities;
- A screen device presenting the video information received from other OBUs. The screen can be an Android device or, for experimental purposes, a Laptop;
- A Video camera recording the road status;
- A CPU that allows the video coding and the video-streaming processes.

[2]For ease of presentation, the camera and the CPU elements are placed only on the front vehicle and the screen only on the rear vehicle. However, every vehicle should be equipped with both devices.

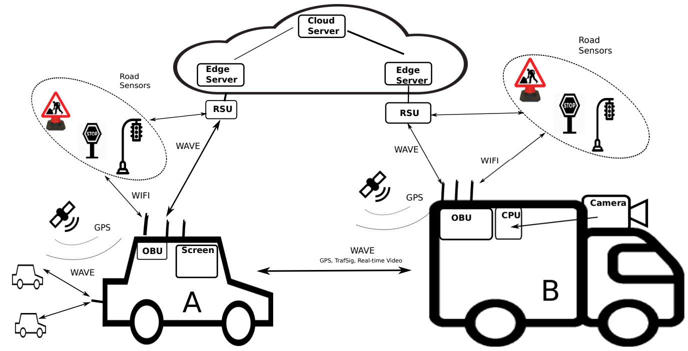

Fig. 1. Driver assistance: architecture overview.

Fig.2 portraits the main use-case for the service. Whenever there is a large vehicle on the road, it takes out the road visibility from the vehicles behind, making it difficult for a driver to properly assess whether an overtaking action should occur. To that end, the proposed system gives the possibility for a driver to request images (either photos or video) from the larger vehicle. The video feedback is provided by a camera located at the front vehicle along with a CPU that processes all the necessary codifications. This data is then relayed to the OBU which will transmit it to the requested vehicle.

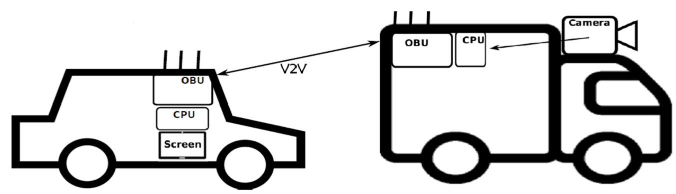

Fig. 2. Vehicle-to-Vehicle video stream service.

Fig. 3 illustrates the main functions of each entity regarding to the video transmission process. The images are provided by a camera located in the front of every vehicle. Should there be a need to convert these images or video to different formats (different encoders or containers), there is a CPU that will handle this process making use of the $FFmpeg$ tool [20]. Moreover, a streaming server integrated with the coding tool ($FFserver$) is also used to serve as an HTTP server. This allows us to take advantage of multi-platform support, as only a browser is required to watch the video content in the receiving car.

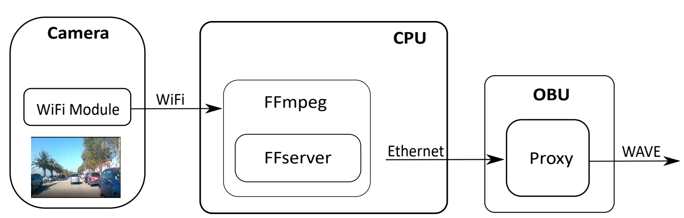

Fig. 3. Software architecture of the video transmission.

Whenever there is a request from another vehicle, the image data is relayed to the OBU which will transmit it to the vehicle that requested the video images, essentially acting as a proxy for the data transmission. The process for the reception is depicted in Fig. 4. The data is sent via IEEE 802.11p interface of the OBU which again acts as a data forwarder. The data is then relayed to the display device and presented on it using a vanilla browser.

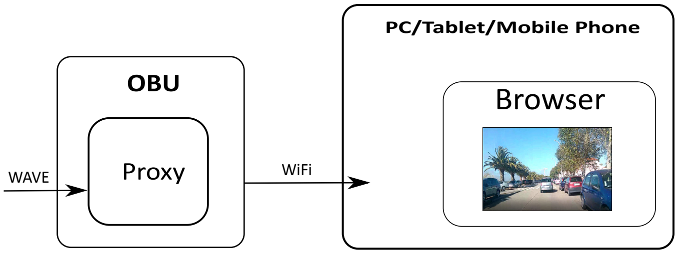

Fig. 4. Software architecture of the video reception.

An overview of the video codification and transmission process is illustrated in Fig. 5. The process starts with the request of the video images, that corresponds to an HTTP get of the video data. The request is relayed via IEEE 802.11p./WAVE interfaces between both OBUs to the CPU on the targeted vehicle. Once the CPU starts receiving the video frames it initiates the encoding process, replying to the requested vehicle the real-time video.

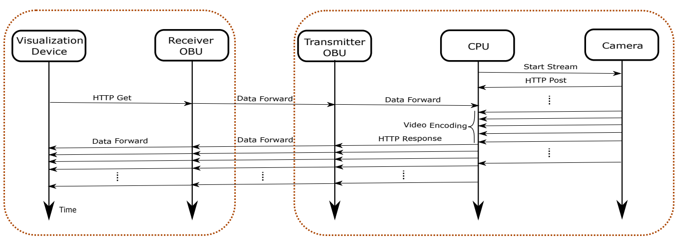

Fig. 5. Video transmission sequence flow diagram.

III. Performance Evaluation

This section evaluates the proposed real-time video transmission mechanism. To that end we have used two vehicles, equipped with the elements described in Section II, and the following setup: the front vehicle, which is continually recording, transmits on-demand the video collected to the rear vehicle. The video streaming system setup consists on a GoPro camera Hero 4 wirelessly connected to a Laptop with 8 GB RAM, Processor i5 6300HQ, Linus Mint 18. The Laptop is used to transcode the original GoPro MP4 format to MJPEG format and forward the new video data to the OBU. As explained in the previous section, the video is delivered over HTTP. The transcoding process is performed by FFmpeg/FFserver version 2.8.11, which provides a simpler way to convert video input while it is still being captured from a live source. These are the $ffmpeg$ parameters settled in this evaluation: 720p video resolution, 25 fps and buffer size of 80 MB. Fig. 6 illustrates the evaluation setup.

Fig. 6. V2V video stream setup.

As it is a real-time service that can ideally be used in emergency scenarios, we consider the communication delay as one of the most important metrics to be evaluated. Thus, comparisons are made between the communication delay and the speed of each vehicle, as well as with the quality of the IEEE 802.11p link.

In addition, some other important metrics are evaluated, such as the bandwidth and the packet retransmission rate.Furthermore, the system is evaluated following different scenarios such as different speeds, distances and levels of line of sight obstructions. To that end, experimental results were obtained in urban and highway scenarios.

The measurements were performed in the following way. Initially, the clock of the two OBUs was synchronized using NTP (Network Time Protocol). A packet capture software Tcpdump is used in both OBUs to continually record the information of all the packets sent and received on the ports specified for this service. The packet delay and also the number of retransmissions are measured by comparing the log files obtained by these captures in the following manner: first, a packet is detected on the transmitter logs. At this moment the ID and the seq. number associated with this packet are registered and a search for these parameters is made in the receiver's records. If it is found, the time difference between the two entries is made to estimate the communication delay of the packets. It should be noted that the software used to capture the packets has an temporal accuracy of each entry in the order of microseconds, which is a reasonable accuracy considering that the order of magnitude of the transmission of these packets is around 0.5 up to 3.5 milliseconds.

The RSSI measurement available is a value between $0-100$. In this scale, when the signal strength is bellow -100dBm, it corresponds to 0; when it is higher than -50dBm it is considered to be 100. For values between -100dBm and -50dBm, the relation between the RSSI and the signal strength is the following:

$$RSSI = (2 \times dBm) + 100 \quad (1)$$

In order to estimate the distance between the vehicles, their GPS position was continuously recorded in each OBU. With these measurements, the distance can be easily calculated. For the calculation of the bandwidth used, a program was created that accesses the driver information of the WAVE of each board and continuously records the number of bytes sent by each second. For a more correct measurement for the bandwidth used for video transmission, the bandwidth used without the use of this service was also measured. Thus, the numbers shown in this dissertation correspond to the total measured value subtracted from the value measured in normal operation without video transmission.

A. *Urban scenario*

Severe obstructions of line-of-sight can result in insufficient bandwidth for video transmissions. Then, it is of crucial importance to evaluate this system in such a scenario, as is the case of an urban scenario with a very dynamic environment with a large number of roadblocks. The urban scenario is also characterized by a very high vehicle's density, low traveling speeds and small distances between vehicles.

The relation between packet delay and the speed of both vehicles is depicted in Fig.7. To better understand the influence of each vehicle's velocity, several tests were performed by keeping one vehicle travelling at constant speed and the other with different speeds. For example, Fig.7 a) illustrates the case where the receiving vehicle - the rear vehicle - changes its average velocity from 5 to 50 km/h while keeping the average speed of the transmitting vehicle - the front vehicle. For this experiments, under the urban scenario, the constant speed was kept to 30 km/h.

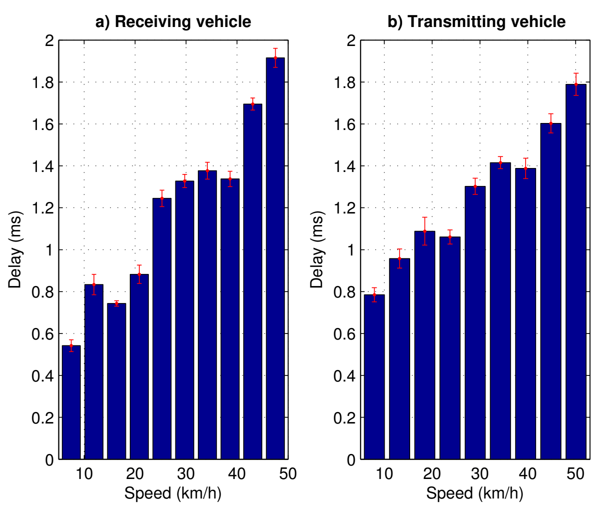

Fig. 7. Urban scenario - relation between packet delay and speed of both vehicles.

The results show us that the packet delay increases when we increase the relative velocity between the two vehicles, as a consequence of the difference of both speeds and the increase of the distance between both vehicles. It should be noted that this relationship is quite similar for both vehicle speeds, even though the receiving car's velocity has a higher impact for higher speeds.

Fig.8 illustrates the relation between the delay and the quality of the IEEE 802.11p link, by considering both scenarios presented before. Just as expected, this system performs better as the quality of the link increases. The minimum RSSI needed to reliably run this service is approximately 9 dBm, which is only observed on extremely crowded areas with a strong line-of-sight obstruction.

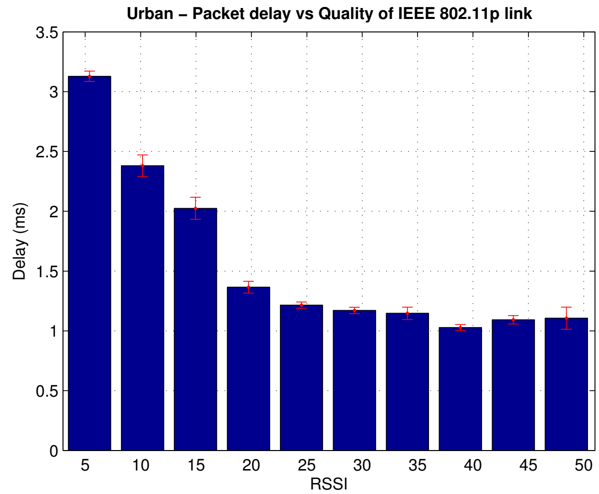

Fig. 8. Urban scenario - relation between packet delay and quality of the IEEE 802.11p link.

Overall, the delay involved in the communication is relatively low, especially when considering a scenario so dynamic such as this one. Table I shows the average values for all measurements for V2V video live stream in the urban scenario.

TABLE I: Overall average results in the urban scenario.

Distance (m)	RSSI	Delay (ms)	Bandwidth (Mbps)	Retransmissions (%)
28.45	35.41	1.22	4.71	0.80

B. *Highway scenario*

This scenario is characterized by having a lower vehicle density when compared to the previous one, but with much higher mobility of the vehicles. The vehicles move at higher speeds with bigger distances between them.

Similarly to the previous case, to determine the influence of the speed of both vehicles on the packet delay, one vehicle moves at a constant speed while the other varies in speed. For these experiments, the vehicle with a constant speed was travelling at 95 km/h, on average. The results are illustrated in Fig.9.

Just like the previous scenario, the relation between the communication delay and the travelling speeds of both vehicles is similar. Following the same trend as before, the receiving car speed has a slightly higher impact.

The relation between the RSSI and the delay is very similar to the one in the previous scenario, as shown in Fig.10. Overall the RSSI has lower values because the vehicles are naturally more spaced apart in a highway scenario. In this case the minimum acceptable RSSI for a stable connection is 13 dBm.

Table II summarizes the behavior of the vehicle-to-vehicle real-time video transmission for the highway scenario.

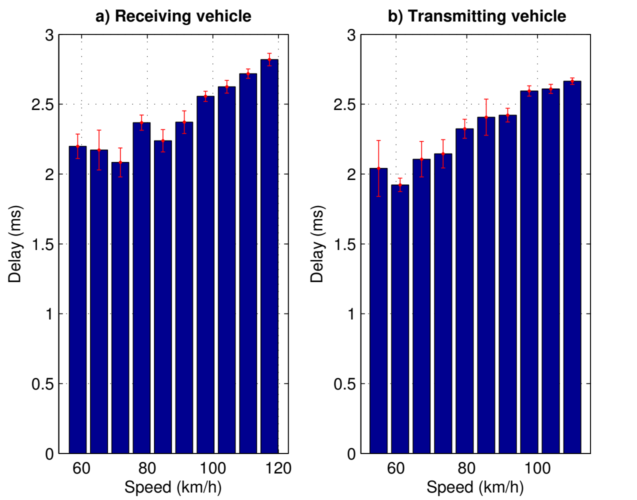

Fig. 9. Highway scenario - relation between packet delay and speed of both vehicles.

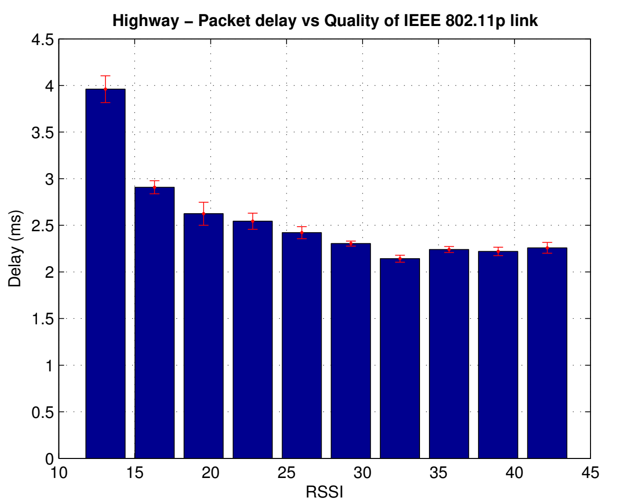

Fig. 10. Highway scenario - relation between packet delay and quality of the IEEE 802.11p link.

TABLE II: Overall average results in the highway scenario.

Distance (m)	RSSI	Delay (ms)	Bandwidth (Mbps)	Retransmissions (%)
56.90	30.74	2.44	4.71	0.81

By comparing the results of both scenarios the following considerations are enumerated:

- Communication delay is higher in the highway scenario due to higher distance between vehicles and higher travelling speeds;
- The RSSI does not seem to be a limiting factor, as most of the time the link quality is sufficient for the data involved, even with constant obstructions in the line-of-sight;
- The bandwidth used is the same, since the video characteristics are the same in both scenarios;
- Distance/delay relationship is the same in both scenarios, making sense with the results in figures 7 and 8.
- The packet retransmission rate is the same for both scenarios and it is considerably low, being less than 1%.

C. Bandwidth Availability vs Video Quality

In order to understand the impact of the video quality transmission in the remaining available bandwidth for simultaneous transmissions we performed several tests, using three different video resolutions. Table III summarizes the maximum number of concurrent transmissions considering a specific video quality, as well as the remaining available bandwidth. The average throughput available on the IEEE 802.11p interface measured on the devices was 11.6 Mbps.

TABLE III: Video transmission availability

Quality (@25fps)	Bandwidth per stream (Mbps)	Maximum number of streams	Remaining bandwidth (%)
720p	4.71	2	18.79
480p	3.10	3	19.83
360p	1.71	6	11.55

As expected, as we decrease the video quality we get the opportunity to increase the number of simultaneous video transmissions, although the maximum video transmissions available simultaneously is not very high. Nevertheless, a significant part of the bandwidth is still available to be used for other services needed by the passengers on the vehicles, or on occasions where there is more data being disseminated than the scenario considered.

While the main objective of the tests presented was to evaluate whether the WAVE technology was able to support the proposed video transmission system, it is still important to mention that other factors can determine the actual delay between the moment an image is captured and the instant that the same image appears on the receiving vehicle. Most notably, the coding time takes a huge importance on this metric, when compared to the communication delay. Furthermore, the camera used is connected via WiFi to the CPU, which causes an additional non-negligible delay. The processing delay experienced during our experimentations was the following:

- GoPro camera communication delay: 0.80 ms
- Codification delay:
  - 720p: 0.98 s
  - 480p: 0.50 s
  - 360p: 0.24 s

These two limiting factors are independent of the WAVE technology itself and depend only on the equipment. It is expected that, with a more powerful CPU, and having the camera connected directly via USB, HDMI or Ethernet, these values could be significantly decreased.

IV. Conclusions

The paper presented a car-overtaking assistance platform based on V2V video transmission where the video signal between a front and a rear vehicle is carried using the

802.11p/WAVE technology. The behavior of the video data packets sent through WAVE is studied in two typical vehicular scenarios, an urban scenario and a highway scenario. To study the performance of the system, communication delay, bandwidth, signal strength and retransmission rate are related with the velocity of both vehicles, and the processing delay and bandwidth consumption are related with the image quality. Results show that the WAVE technology meets the requirements to hold a V2V video transmission system for car-overtaking assisted driving in the terms highlighted by [1].

The goal of this service is to be part of a wider driver assistance framework to assist in the car-overtaking decision. To achieve it, future work will deepen in the integration of the V2V video transmission system with the use of IoT sensors placed in traffic signals and traffic lights. The framework will also take advantage from several WAVE features, like the vehicle position information included in the WAVE beacons to include a traffic awareness system without consumption of communication resources.

References

[1] European Commission, "5G empowering vertical industries," pp. 1–9, January 2017.

[2] A. Mukhtar, L. Xia, and T. B. Tang, "Vehicle detection techniques for collision avoidance systems: A review," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 5, pp. 2318–2338, Oct 2015.

[3] L. C. Bento, P. Bonnifait, and U. J. Nunes, "Cooperative GNSS positioning aided by road-features measurements," *Transportation Research Part C: Emerging Technologies*, vol. 79, no. Supplement C, pp. 42 – 57, 2017. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0968090X17300025

[4] B. Zardosht, S. Beauchemin, and M. A. Bauer, "A decision making module for cooperative collision warning systems using Vehicular Ad-Hoc Networks," in *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)*, Oct 2013, pp. 1743–1749.

[5] N. Alam and A. G. Dempster, "Cooperative Positioning for Vehicular Networks: Facts and Future," *IEEE Transactions on Intelligent Transportation Systems*, vol. 14, no. 4, pp. 1708–1717, Dec 2013.

[6] Y. L. Morgan, "Notes on DSRC & WAVE standards suite: Its architecture, design, and characteristics," *IEEE Communications Surveys & Tutorials*, vol. 12, no. 4, pp. 504–518, 2010.

[7] T. Taleb, E. Sakhaee, A. Jamalipour, K. Hashimoto, N. Kato, and Y. Nemoto, "A stable routing protocol to support ITS services in VANET networks," *IEEE Transactions on Vehicular technology*, vol. 56, no. 6, pp. 3337–3347, 2007.

[8] Z. Sun, G. Bebis, and R. Miller, "On-road vehicle detection: a review," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 28, no. 5, pp. 694–711, May 2006.

[9] F. Garcia, P. Cerri, A. Broggi, A. de la Escalera, and J. M. Armingol, "Data fusion for overtaking vehicle detection based on radar and optical flow," in *2012 IEEE Intelligent Vehicles Symposium*, June 2012, pp. 494–499.

[10] D. Hultqvist, J. Roll, F. Svensson, J. Dahlin, and T. B. Schön, "Detecting and positioning overtaking vehicles using 1D optical flow," in *2014 IEEE Intelligent Vehicles Symposium Proceedings*, June 2014, pp. 861–866.

[11] A. Ramirez, E. Ohn-Bar, and M. Trivedi, "Integrating motion and appearance for overtaking vehicle detection," in *2014 IEEE Intelligent Vehicles Symposium Proceedings*, June 2014, pp. 96–101.

[12] F. Soldo, C. Casetti, C. F. Chiasserini, and P. A. Chaparro, "Video Streaming Distribution in VANETs," *IEEE Transactions on Parallel and Distributed Systems*, vol. 22, no. 7, pp. 1085–1091, July 2011.

[13] A. Vinel, E. Belyaev, K. Egiazarian, and Y. Koucheryavy, "An Overtaking Assistance System Based on Joint Beaconing and Real-Time Video Transmission," *IEEE Transactions on Vehicular Technology*, vol. 61, no. 5, pp. 2319–2329, Jun 2012.

[14] I. Rozas-Ramallal, T. M. Fernández-Caramés, A. Dapena, and J. A. García-Naya, "Evaluation of H.264/AVC over IEEE 802.11p vehicular networks," *EURASIP Journal on Advances in Signal Processing*, vol. 2013, no. 1, p. 77, Apr 2013. [Online]. Available: https://doi.org/10.1186/1687-6180-2013-77

[15] H. Venkataraman, A. d'Ussel, T. Corre, C. H. Muntean, and G.-M. Muntean, "Performance Analysis of Real-time Multimedia Transmission in 802.11P Based Multihop Hybrid Vehicular Networks," in *Proceedings of the 6th International Wireless Communications and Mobile Computing Conference*, ser. IWCMC '10. New York, NY, USA: ACM, 2010, pp. 1151–1155. [Online]. Available: http://doi.acm.org/10.1145/1815396.1815660

[16] V. D. Khairnar and S. N. Pradhan, "Comparative Study of Simulation for Vehicular Ad-hoc Network," *CoRR*, vol. abs/1304.5181, 2013. [Online]. Available: http://arxiv.org/abs/1304.5181

[17] Z. Hameed Mir and F. Filali, "LTE and IEEE 802.11p for vehicular networking: a performance evaluation," *EURASIP Journal on Wireless Communications and Networking*, vol. 2014, no. 1, p. 89, May 2014. [Online]. Available: https://doi.org/10.1186/1687-1499-2014-89

[18] A. Vinel, E. Belyaev, O. Lamotte, M. Gabbouj, Y. Koucheryavy, and K. Egiazarian, "Video transmission over IEEE 802.11p: Real-world measurements," in *2013 IEEE International Conference on Communications Workshops (ICC)*, June 2013, pp. 505–509.

[19] E. Belyaev, A. Vinel, M. Jonsson, and K. Sjoberg, "Live video streaming in IEEE 802.11p vehicular networks: Demonstration of an automotive surveillance application," in *2014 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, April 2014, pp. 131–132.

[20] FFmpeg Developers, "ffmpeg tool (Version 2.8.11) [Software]," http://ffmpeg.org/, 2017, [Online; accessed 1-November-2017].