1-1-2022

# On the design and implementation of an on-board test bed system for V2V road hazard signaling

Fatma Outay
*Zayed University*, fatma.outay@zu.ac.ae

Faouzi Kamoun

Anouar Chemek

Hichem Bargaoui

Ansar Yasar
*Hasselt University*

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 203 (2022) 119–126

Procedia Computer Science

www.elsevier.com/locate/procedia

The 19th International Conference on Mobile Systems and Pervasive Computing (MobiSPC)
August 9-11, 2022, Niagara Falls, Canada

# On the design and implementation of an on-board test bed system for V2V road hazard signaling

Fatma Outay[a], Faouzi Kamoun[b,c]*, Anouar Chemek[b] , Hichem Bargaoui[b],Ansar Yasar[d]

[a] *Zayed University, Dubai P.O. Box 19282, U.A.E*
[b] *ESPRIT School of Engineering, ZI. Chotrana II, Tunis PO. Box 160, Tunisia*
[c] *ESPRIT School of Business, ZI. Chotrana II, Tunis PO. Box 160, Tunisia*
[d] *Hasselt University, Wetenschapspark 5 bus 6, Diepenbeek P.O. Box 3590, Belgium*

**Abstract**

This paper describes the design, implementation, and testing of an ITS-G5 prototype Road hazard Signaling (RHS) system that is inspired by the concept of crowdsourcing. Our approach enables drivers to interact with a touchscreen onboard interface to send ITS-G5 decentralized environmental notification messages (DENM) in order to warn nearby vehicles against the presence of a hazardous situation. These messages are analyzed, filtered for relevance, and presented to concerned drivers via the Onboard Units (OBUs) so that precautionary measures can be taken. We describe the design and implementation aspects of the proposed system and update the open source cargeo6 implementation of the ITS GeoNetworking protocol stack. We successfully implemented and validated the prototype system using an indoor testbed and carried various performance analysis experiments.



*Keywords:* Intelligent transportation systems; road hazard signaling; road safety; V2V applications; cooperative systems; enabling technologies

## 1. Introduction

Despite the remarkable advances in vehicular technologies, road traffic injuries remain a serious public concern. These injuries are often associated with hazardous situations on the road like those triggered by adverse weather conditions in addition to human errors and recklessness. According to the World Health Organization (WHO), road traffic accidents are expected to become the seventh leading cause of death by 2030 [1].

* Corresponding author. Tel.: +216-99-423-944; fax: +216-70-685-454.
*E-mail address:* faouzi.kammoun@esprit.tn


10.1016/j.procs.2022.07.017

For the past years, various promising vehicle to everything (V2x) connected vehicle technologies have been proposed as core components of next-generation Intelligent Transportation Systems (ITS) with the aim to contribute to safer roads through cooperative situational awareness and hazard avoidance mechanisms. Various Vehicle-to-vehicle (V2V) communication solutions have been proposed to enable vehicles to wirelessly exchange information about their position, speed, location, and heading. When equipped with the proper onboard safety application, vehicles can develop cooperative awareness about potential crash threats, and they can proactively alert drivers so that proper actions can be taken to avoid crashes. To act on their surrounding environment, ITS solutions rely on the exchange of data via vehicle to infrastructure (V2I) and V2V communication. In the latter case, the data is often triggered from onboard vehicle sensors such as engine speed, throttle position, steering angle, radar/infrared, and GPS sensors. In an earlier work [2], we introduced a cooperative onboard Road Hazard Signaling (RHS) solution whose goal is to complement cooperative situational awareness mechanisms with driver-triggered alerts via a touchscreen Digital Visual Interface (DVI). In this contribution, we extend our previous research by detailing its design and implementation aspects and by presenting some performance analysis results.

The remaining if this paper is organized as follows: Section 2 presents an overview of related work and highlights the contribution of this research. Section 3 describes our proposed application. Sections 4 and 5 outline the implementation of the MAC and Network/Transport layers, respectively. We describe the system architecture in section 6 and the research methods and material in section 7. We present some numerical results in section 8, and we finally provide a summary of the paper and some recommendations for future research in section 9.

## 2. Background, state of the art and research contribution

ITS-G5 is the European standard for V2x vehicular communications based on the IEEE-1609.x and IEEE-802.11p standards [3]. ITS-G5 applications cover four main functional areas namely traffic management, infotainment and comfort, road safety, and autonomous driving. This research focuses on the ITS-G5 road safety application whose main goal is to warn users against potential road dangers.

### *2.1. The ETSI ITS-G5 standard revisited*

The ITS-G5 standard defines an ITS station architecture in terms of four main protocol layers (applications, facilities, networking and transport, and access (data link and physical)) and two transverse layers (security and management) [3]. The data link layer is divided into two sublayers: medium access control and logical link control, while the physical layer implements the IEEE 802.11p standard.

The network and transport layers use two main protocols namely the Geo-Networking (GeoNW) and the Basic Transport Protocol (BTP). The GeoNW routing protocol routes packets based on the geographical position of nodes without a coordination infrastructure. The BTP transport protocol provides an end-to-end, connection-less, and non-guaranteed delivery transport service [4].

Among the key messages defined by the facilities layer are the Cooperative Awareness Messages (CAM), and the Decentralized Environmental Notification Messages (DENM). CAM messages are disseminated periodically within the network to provide information of presence, position as well as basic status of communicating ITS stations within a single hop distance. DENM messages convey information on road hazards and unusual traffic conditions.

### *2.2. Related work and research contribution*

The past few years have witnessed a growing experimentation by automotive industry, consortia, and research entities with V2x communication networks for road safety applications. Various pilot and proof of concept studies have been conducted in this regard. Among these, we can site PreVent[5], CVIS[6], SAFESPOT [7], COOPERS [8], SeVeCom [9], COMeSafety [10], INTERSAFE-2 [11], GeoNet [12], FOTsis [13] and SIM [14]. These contributions differ in terms of scope, use-cases, participating V2x entities (e.g., roadside units, pedestrians, networks, etc.), choice of communication technology and protocol stack, design intent, and validation type (e.g. simulation, lab vs field tests, real-life demonstrations) among many others. For a recent comprehensive review of the use of cellular V2x technologies for advanced road safety, we refer to the literature survey papers of Soto et al [15], Alalewi et al [16], and Farsimadan et al [17] and the references cited therein.

Unlike earlier approaches that depended on the automatic detection of walking pedestrians, the presence of Roadside Units (RSU), or on the vehicles' onboard sensors as the triggers of the DENM warning messages [18], our research is inspired from the crowdsourcing practice and suggests that drivers can use dedicated Onboard Units (OBU) to act as the triggers for road hazard warning which can be signaled to other neighboring vehicles via predefined broadcasted DENM messages. This research is carried out within the framework of the Connected Vehicle Crash Avoidance (COVCRAV) open-source project, previously introduced in [2]. With reference to ETSI technical specifications [19], our proposed solution is classified as a class-B secondary safety application. Additional contributions of the present work include the following:

- We extend our previous work [2] by (1) refining our prior design and implementation choices, (2) implementing a proof-of-concept prototype to validate the proposed approach, and (3) carrying out some performance evaluation experiments.
- We update the opensource cargeo6 implementation of the ITS GeoNetworking protocol stack [20-21].
- We leverage the concept of frame injection to enable OCB (Outside the Context of Basic Service Set) mode support across a wide spectrum of non-Atheros Wi-Fi chipsets.
- We make the source code of the entire project publicly accessible [22] to promote future developments and stimulate open collaboration.

## 3. COVCRAV application description

Fig.1 depicts a typical operating scenario.

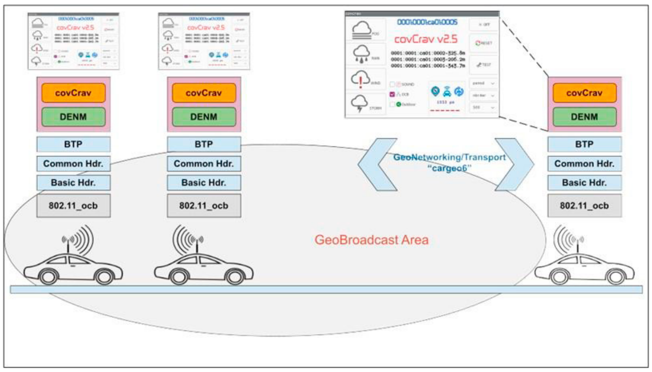



Fig.1: V2V communication via the COVCRAV RHS application

The originating ITS-G5 station (ITS-S) implements the ITS-G5 protocol stack to trigger the creation of DENM messages at the facilities layer when the driver notifies the RHS application about a specific road hazard by touching and holding the proper icon displayed on the touchscreen DVI. Basic Transport Protocol (BTP) and GeoNetworking protocols headers are properly filled with the specific scenario parameters. The DENM packets are then geo-broadcasted, and they can be relayed over several hops to warn vehicles beyond the geographical coverage.

At the receiving ITS-S, DENM messages are collected by the physical layer and forwarded to the upper layers for further decoding. The ITS facility layer analyses the DENM messages and makes them available to the application layer. The application layer processes and interprets the information and visually displays the proper icon corresponding to the warning on the touchscreen DVI along with an audible alarm. This way the driver is notified about the potential hazard and can take the necessary safety actions.

In this project, we have considered six main road hazards that were inspired from ETSI TS 101 539- technical specs [19], namely: beginning of low-visibility area, stationary vehicle ahead, roadwork ahead, stationary traffic ahead, wrong way driving ahead and presence of a hazardous location. For the protype implementation, and without any loss of generality, we just showcased samples of low visibility warnings due to fog, rain, storms, etc.

## 4. MAC layer implementation: OCB mode via frame injection

In a vehicular ad hoc network (VANET), ITS stations rely on the IEEE 801.11p protocol where the MAC layer is governed by a special mode named OCB [23]. OCB was introduced in version 3.9 of the Linux Kernel and its permits the exchange of Wi-Fi frames without the need to associate or authenticate to a Base Station Subsystem (BSS). This is accomplished by using the BSSID wildcard 0xff:ff:ff:ff:ff:ff, with the option to select a channel bandwidth of 5 MHZ or 10 MHZ. A major constraint for applying this mode of communication in GNU/Linux is the restriction to have a special Wi-Fi card with an Atheros chipset. Other non-Atheros, yet popular Wi-Fi cards such as Ralink and Realtek do not support the OCB mode. To circumvent this limitation and to permit the usage of a wider choice of Wi-Fi cards, we propose the usage of frame injection whereby the Wi-Fi card is put into a monitor mode and the frames are injected as per the instructions of the OCB mode. Another advantage of this approach is that it permits to customize some physical parameters by passing them to the Wi-Fi driver. We can for instance use one frequency for one type of packet and another frequency for other types. Frame injection also enables V2x (e.g., vehicle to pedestrian) applications that are beyond V2V and it introduces a negligible delay due to the insertion of the radiotap header. Recall that Radiotap [24] is a de facto standard for 802.11 frame injection and reception.

## 5. Network and transport layers implementation: Adapting the Cargeo implementation

To implement the ETSI ITS GeoNetworking and Basic Transport Protocols (BTP), we opted to update the cargeo6 open-source implementation of ITS GeoNetworking and we also made the source code of the entire project available on GitHub [22]. It should be noted that the latest version of Cargeo6 implementation dates back to 11 years ago and has become obsolete considering the changes in ITS Geographical addressing and forwarding standards [25]. The colored entities in Fig.2 depicts the modules that have been adapted to meet the new ITS recommendations and to fulfill the requirements of our project.

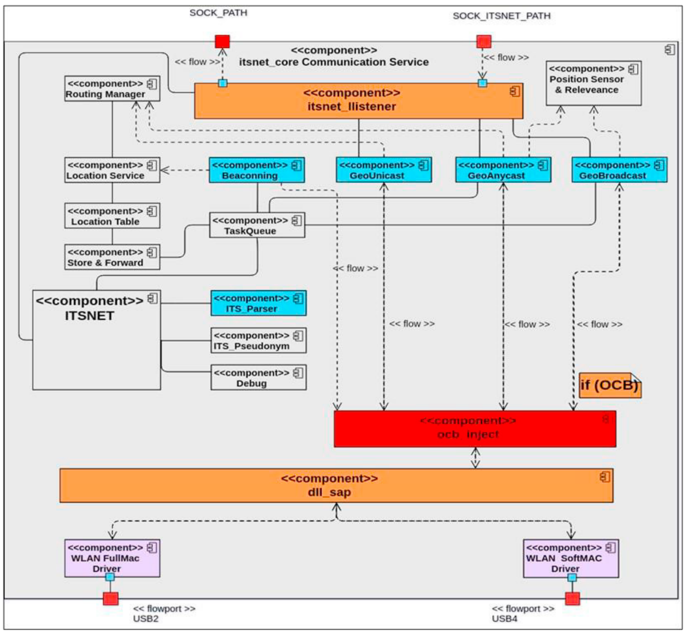
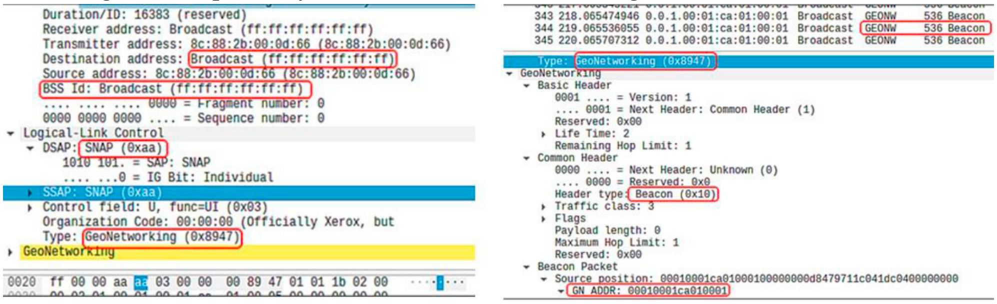



Fig. 2: Adaptations (in color) of Cargeo6 components

In red, the module ***ocb_inject*** has been added to enable frame injection using the radiotap structure. In orange, the module ***dll_sap*** has been adapted to enable the choice between a normal IBSS mode (ad-hoc with ssid=itsnet) and an OCB_inject mode and to update the MAC/LLC headers and the EtherType to meet the requirements in [26]. The modules in blue have been updated to align with the ITS standard recommendations [3, 25].

The proper updates of the MAC/LLC and the GeoNetworking headers have been successfully validated via experimental studies using frame captures by Wireshark as illustrated in Fig. 3.




**(a)** **(b)**

Fig.3: **(a)** Frame capture via Wireshark (MAC/LLC Headers) ; **(b)** Frame Capture via Wireshark (GeoNetworking Header)

## 6. System architecture

The physical architecture of our prototype solution is depicted in Fig 4. It is based on a Raspberry Pi 4 Model B, a DLINK DWA-5 Wi-Fi card with RealTek RTL888EUS chipset, an ARM Quadcore Cortex A72 CPU, an XPT046 Touchscreen controller, and two Linux drivers (SoftMac/FullMac), among others.

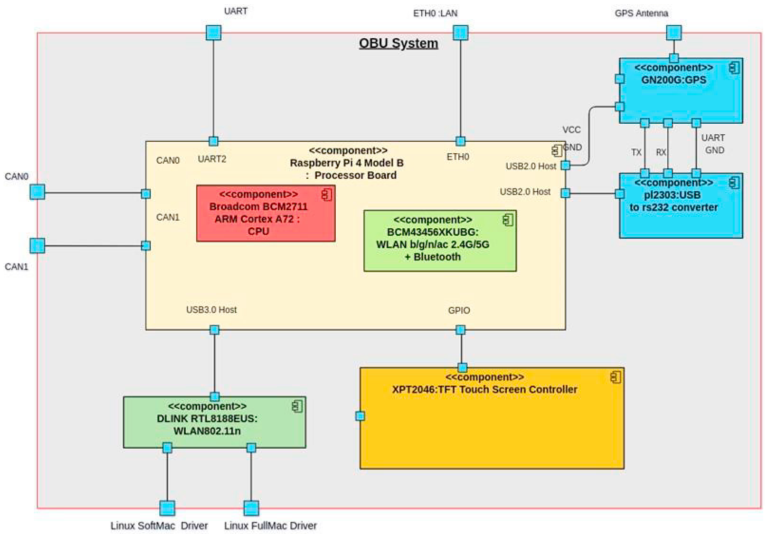



Fig.4: Physical architecture

The software deployment diagram of each ITS station is also illustrated in Fig. 5.

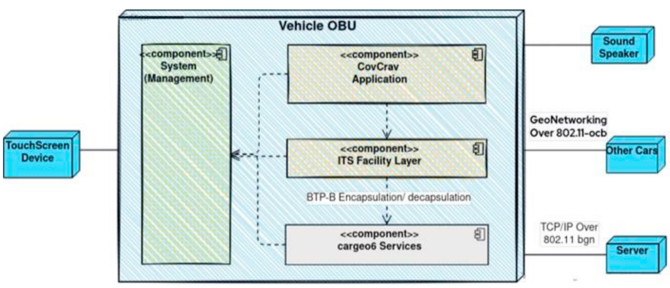



Fig.5: Software deployment diagram

## 7. Methods and material

Our indoor test bed consisted of three configured ITS stations (S1, S2, S3) as shown in F.6. (a) where station 1 is in the transmit mode and stations 2 and 3 are put in the reception mode (Fig.6. (b)).

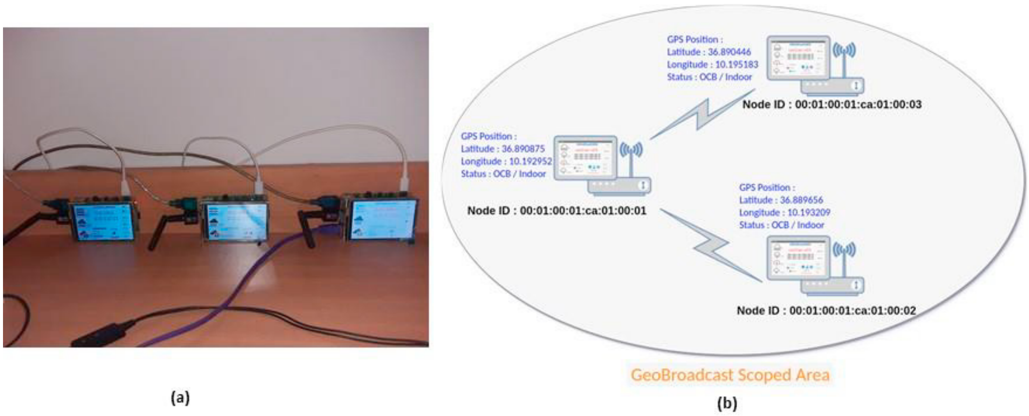



Fig.6. (a) Indoor test bed general configuration; (b) detailed view of the test bed configuration

The application protype shown in Fig 7 enables to customize various test parameters including warning type, number of geo-broadcasted packets (nbr_iter), the frequency of alert generation (period), the time between two sent packets, the geobroadcast radius (defaults to 500 meters), and the wireless networking configuration type (OCB versus IBSS mode), among others. In the center of the screen's top, the application returns the node IDs of the neighboring stations and the separating distances. It also displays in the bottom the Timestamp synchronization offset correction value in µs.

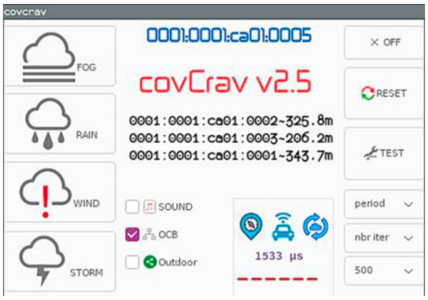



Fig.7: COVCRAV test application interface

It should be noted that for indoor testing, the GPS receivers were mainly used for node synchronizations to enable accurate packet delay calculations, whereas the geographic positions were acquired from a special "forked" service named *gps-data-sender* that provides fictitious GPS positions from a text file (based on a simulated journey). For tracing the interchanged packets among the ITS stations, and instead of using Wireshark, we opted for the glibc libraries of the GNU/Linux system because of their inherent advantages in terms of better accuracy and flexibility.

## 8. Experimental results and discussions

The two performance-metrics of interest are Average Packet Delay (APD) and Packet Loss Ratio (PLR). We tested the network by sending a fixed number of 1,000 packets and considered the following variables: time-period between two transmitted consecutive packets (1-100 msec), communication mode (IEEE 802.11p OCB_inject vs IBSS), and driver type (FullMac vs SoftMac)). Several test experiments were conducted under different scenarios.

Because of lack of space, we present herein a sample of the main results. Tables 1 and 2 show the APD and PLR values for three different modes of operations (IBSS, OCB SoftMac, and OCB FullMac) and with a time interval between two successive transmitted packets set to 1 msec and 100 msec, respectively.

Table 1. Performance comparison results (**1 msec** between two transmitted consecutive packets)

| **APD (msec)** | **IBSS mode** | **OCB mode (SoftMac)** | **OCB mode (FullMac)** |
|---|---|---|---|
| S1 → S2 | 1230 | 1.48 | 0.61 |
| S1 → S3 | 1243 | 6.41 | 2.96 |
| **PLR** | **IBSS mode** | **OCB mode (SoftMac)** | **OCB mode (FullMac)** |
| S1 → S2 | 36% | 10.8% | 15.6% |
| S1 → S3 | 0% | 10.5% | 13.7% |

Table 2. Performance comparison results (**100** msec between two transmitted consecutive packets)

| **APD (msec)** | **IBSS mode** | **OCB mode (SoftMac)** | **OCB mode (FullMac)** |
|---|---|---|---|
| S1 → S2 | 19 | 0.58 | 0.81 |
| S1 → S3 | 15.3 | 1.13 | 3.5 |
| **PLR** | **IBSS mode** | **OCB mode (SoftMac)** | **OCB mode (FullMac)** |
| S1 → S2 | 0.7% | 4.5% | 6.7% |
| S1 → S3 | 0% | 4.9% | 6.5% |

We observe that in both heavily-loaded and lightly-loaded network scenarios, the OCB FullMac mode exhibits best performance results in terms of delay at heavy load, whereas the OCB SoftMac mode performs better than the OCB FullMac in terms of packet loss. We also note that the IBSS mode provides best packet loss performance at station 3 and the worst one at station 2. For 7 test scenarios (corresponding to 1, 2 , 5 , 10 , 25, 50 and 100 msec between successive packet transmissions), we illustrate in figure 8 the APD and PLR values corresponding to station #2. We note that generally OCB FullMac mode provides best results in terms of delay, whereas IBSS followed by OCB FullMac mode exhibited best reliability performance.

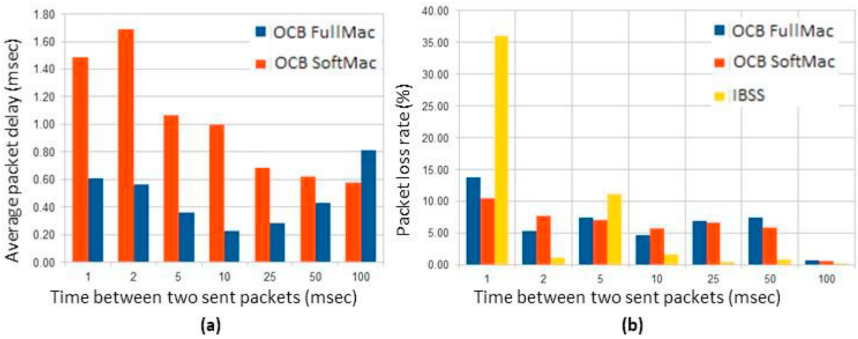



Fig.8. **(a)** APD at station #2; **(b)** PLR at station #2

## 9. Conclusion

Inspired by the concept of crowdsourcing, we presented the design and implementation aspects of a RHS solution by engaging derivers as the source of the road hazard warning. We updated the opensource cargeo6 implementation [20-21] and used frame injection to enable OCB mode on non-Atheros Wi-Fi chipsets. We made the source code of the project publicly accessible on GitHub [22]. The experimental results showed that the proposed solution successfully created and sent the proper DENM messages which were properly decoded and displayed on the drivers' DVI. We presented some numerical results to illustrate our approach. We are currently working on refining the design and implementation aspects of our prototype, with a special emphasis on enhancing the HCI features of the touchscreen DVI. We are also planning to test our prototype in a real-life outdoor environment.

As any crowdsourcing-based approach, our solution depends on the element of trust among the participating drivers. Future work will investigate efficient mechanisms to reinforce trust.

## Acknowledgements

This research project is financially supported by Zayed University under the Cluster Research Grant # R17075.

## References

[1] World Health Organization. SDG Target 3.6 Road traffic injuries, World Health Statistics. https://www.who.int/data/gho/data/themes/topics/sdg-target-3_6-road-traffic-injuries. Retrieved June 2020.

[2] F. Outay, H. Bargaoui, A. Chemek, F. Kamoun, and A. Yasar. (2019). "The COVCRAV project: Architecture and design of a cooperative V2V crash avoidance system". Procedia Computer Science, 60: 473-478,

[3] https://www.etsi.org/deliver/etsi_en/302600_302699/302663/01.02.00_20/en_302663v010200a.pdf. Retrieved June 2020.

[4] https://www.etsi.org/deliver/etsi_ts/102600_102699/1026360501/01.01.01_60/ts_1026360501v010101p.pdf. Retrieved June 2020.

[5] https://trimis.ec.europa.eu/sites/default/files/project/documents/20130118_141143_85509_1-2-04_Flament.pdf. Retrieved January 2019.

[6] CIVIS project. http://www.civisproject.eu/images/Project-deliverable/civis-final-report.pdf. Retrieved January 2019

[7] SAFESPOT Project. http://www.safespot-eu.org/. Retrieved January 2019

[8] COOPERS Project. https://cordis.europa.eu/project/rcn/79301/factsheet/en. Retrieved January 2019

[9] SeVeCOM Project. https://www.sevecom.eu/. Retrieved January 2019

[10] COMesafety Project. https://cordis.europa.eu/project/rcn/80584/factsheet/en. Retrieved January 2019

[11] INTERSAFE-2 Project. https://cordis.europa.eu/project/rcn/87267/factsheet/en. Retrieved January 2019

[12] GeoNet Project. https://cordis.europa.eu/project/rcn/85551/factsheet/en. Retrieved January 2019.

[13] FOTsis Project. http://fotsis.com/ . Retrieved January 2019

[14] https://www.eict.de/fileadmin/redakteure/Projekte/simTD/Deliverables/simTD-Deliverable-D21.2_Konsolidierter_Systemarchitekturentwurf.pdf . Retrieved January 2019.

[15] I. Soto, M. Calderon, A. Molina, ad M. Urueña. (2022). "A survey on road safety and traffic efficiency vehicular applications based on C-V2X technologies." Vehicular Communications, 33. https://doi.org/10.1016/j.vehcom.2021.100428

[16] A. Alalewi, I. Dayoub and S. Cherkaoui. (2021). "On 5G-V2X Use Cases and Enabling Technologies: A Comprehensive Survey," IEEE Access, 9: 107710-107737, 2021, doi: 10.1109/ACCESS.2021.3100472.

[17] E. Farsimadan, F. Palmieri, I. Moradi, D. Conte, and B. Paternoster, B (2021). " Vehicle-to-Everything (V2X) communication scenarios for Vehicular Ad-hoc Networking (VANET): An Overview." ICCSA 2021. *Lecture Notes in Computer Science*, 12956. Springer, Cham. https://doi.org/10.1007/978-3-030-87010-2_2.

[18] S. Shrivastava. (2019). "V2V vehicle safety communication." In Miucic, Radovan (ed.), *Connected Vehicles Intelligent Transportation Systems*, Springer Nature Switzerland AG., 117-155.

[19] https://www.etsi.org/deliver/etsi_ts/101500_101599/10153901/01.01.01_60/ts_10153901v010101p.pdf. Retrieved January 2019.

[20] https://hal.inria.fr/inria-00625789/document. Retrieved January 2020.

[21] https://cordis.europa.eu/docs/projects/cnect/9/270519/080/deliverables/001-ITSSv6D31IntermediateImplementationGuidelinev11.pdf. Retrieved May 2021.

[22] https://github.com/chemek1/covCrav.git . Retrieved April 2022

[23] IETF, Transmission of IPv4 over IEEE 802.11 in OCB mode. https://tools.ietf.org/id/draft-li-ipv4-over-80211ocb-00.xml

[24] http://www.radiotap.org/ . Retrieved January 2020

[25] https://www.etsi.org/deliver/etsi_en/302600_302699/3026360401/01.02.01_30/en_3026360401v010201v.pdf. Retrieved January 2020

[26] https://www.etsi.org/deliver/etsi_ts/102600_102699/1026360402/01.02.01_60/ts_1026360402v010201p.pdf. Retrieved January 2020