Enhancing Vehicular Systems through the Synergy between Visible Light Communication (VLC) and Radio Frequency (RF)

Cedric Bammens*, Nina Slamnik-Kriještorac†, Vincent Charpentier†, Johann M. Marquez-Barja†
* University of Antwerp, Faculty of Applied Engineering - Department of Electronics-ICT, Belgium
† University of Antwerp - imec, IDLab - Faculty of Applied Engineering, Belgium

***Abstract*—Vehicular communication is a critical technology in Intelligent Transportation Systems (ITS) that aims to improve transportation safety and efficiency. However, traditional radio-based systems, such as Cellular V2X (C-V2X) and Dedicated Short Range Communication (DSRC), may suffer from performance degradation in dense traffic scenarios. To address this issue, Line of Sight (LoS) technologies such as Visible Light Communication (VLC) are being explored as complementary technologies to RF.**

VLC utilizes LEDs on vehicles to exchange information with preceding and subsequent vehicles, allowing ITS to create a safer and less congested transportation system. Recent studies have shown that combining DSRC and VLC can minimize the performance degradation experienced by RF communication technologies.

This paper highlights the need to combine RF and LoS technologies to improve the stability and reliability of V2V communication. It discusses various LoS and RF technologies and presents combinations that can be used for communication. Finally, a hybrid strategy that combines the best properties of individual technologies is proposed, demonstrating the feasibility of such a solution.

***Index Terms*—V2V, Intelligent Transportation Systems, C-V2X, Dedicated Short Range Communication, Vehicular Visible Light Communication, Autonomous Driving, Platooning, Cooperative adaptive cruise control**

I. Introduction

The transportation industry has made vast improvements to the technical capabilities of new high-end vehicles. Most new vehicles are equipped with embedded computers that make use of sensors to interpret the surroundings of the vehicle. The sensor data is used to allow a vehicle to drive semi-autonomous, and in the near future, fully autonomous. Intelligent Transport Systems (ITS) will bring a solution to the problems that are encountered when making a vehicle drive autonomously. Autonomous vehicle platoons are an upcoming ITS technology that will make it possible to drive semi-autonomous. Platooning is a strategy that consists of partially autonomous cars driving in a close formation with small gaps between vehicles while communicating with each other. Cooperative Adaptive Cruise Control (CACC), an extension of Adaptive Cruise Control (ACC), will maintain a constant distance with the predecessor and will use wireless communication to exchange information [1]. CACC will thus be used for platooning strategies. CACC has shown improvements to the throughput of traffic, lower fuel usage, and safety [1]–[3].

A platoon consists of multiple vehicles that will drive in close proximity in a single lane, following a leader vehicle. The leader vehicle will set the route and velocity of the platoon. The others will follow this vehicle. To maintain a platoon, vehicles will need to communicate and exchange information such that the vehicles can make a correct decision. To exchange the information, vehicles will send the data that is measured by sensors to the other vehicles that are part of the platoon. Recently, there have been projects such as ENSEMBLE [4] and SARTRE [5] to see if platooning strategies can be used in a real-world scenario. In these projects, they create complex and realistic scenarios to research and validate platooning technology. To ensure the optimal use of the platooning strategy, a robust and efficient communication strategy needs to be used. With a recommended transmission latency of 20ms [6], communication between vehicles needs to be as optimal as possible. An error can cause a safe system to become an unsafe one. Current proposals use RF communication based on DSRC or C-V2X. The DSRC technology is based on IEEE 802.11p [7] while the C-V2X standard is standardized by 3GPP [8].

To guarantee safety in a platoon formation, it is important to use high update rates of at least 10Hz [9] between vehicles [10]. When multiple platoons are in proximity on the same freeway, the RF network can become congested substantially increasing the possibility of packages being delayed or not being delivered, making the CACC not able to communicate with the other vehicles in its platoon. Due to congestion, the safety of all the vehicles will diminish significantly. One approach to solve this is by using directional communication instead of omnidirectional communication. Hardes et al. [11] found that using beam forming in platooning reduces the interference of other communications and thus providing a positive effect. Another solution is using line of sight technologies to communicate. VLC is a technology that utilizes light to transmit data to other vehicles. VLC can be used to send data by utilizing the unused wavelengths from 380nm to 780nm of the electromagnetic spectrum [9]. Due to the availability of a large spectrum, VLC will be able to transmit in high data rates. When using Vehicular Visible Light Communication (V-VLC) it is possible to use the front and tail lights of modern cars. The LEDs can be used at high frequencies that are not detectable by the human eye.

Using VLC also has some downsides. When using the headlights that are already installed on the vehicle, the radiation pattern can not be changed and improved. To solve this issue, Schettler et al. found that by using Adaptive Front Light Systems (AFLS) the radiation pattern of a standard headlight can be bypassed, thus improving the LOS behaviour of VLC [12]. Light is also more susceptible to fog and rain, this needs to be taken into account when using VLC [13].

In this paper, we developed an application that enables leveraging both VLC and RF technologies to ensure communication between vehicles. We implemented the two communication methods and evaluated the performances of the different configurations. We also propose a basic hybrid strategy that will allow for the protocol to decide which communication technology needs to be used to improve the communications reliability. We then compare results and evaluate the different configurations.

II. Communication Technologies

A. RF Based Technologies

1) IEEE 802.11p: The 802.11p standard, is a standard created by the IEEE and is an amendment to the IEEE 802.11 standard [7]. 802.11p will add a vehicular communication system, WAVE, to allow for data exchange between high-speed vehicles and roadside infrastructure. In order to communicate, it utilizes the licensed ITS band of 5.9GHz. Since the communication link between moving vehicles and roadside infrastructure can exist for a short time, the 802.11p standard has created a method that allows data to be exchanged without establishing a basic service set. Therefore, no authentication and association procedures need to take place before communicating data. Consequently, the stations and messages will not be authenticated by the standard IEEE 802.11 standard. These functionalities will need to be provided by a higher layer application. DSRC will expand the IEEE 802.11p standard [14]. To ensure efficient use in high density cases, IEEE 802.11p will use a multiple access mechanism (Carrier Sense Multiple Access protocol with Collision Avoidance, CSMA-CA) to ensure that the congestion of the network is optimized.

2) LTE-V2X: LTE-V2X is a new technology that is an extension of 3GPP Rel-12 Device-to-Device (D2D) [8]. The old Rel-12 technology is based on using LTE uplink transmissions and spectrum resources for direct communication between devices. The new standard will expand on the direct communication and will allow LTE platforms to communicate between moving vehicles and infrastructure. It does this by requiring the following specifications:

- Operating with or without a eNB, base station, coverage. Users are allowed to directly communicate with each other, without requiring cell coverage of an eNB.
- Standalone operation on a dedicated unlicensed carrier or under licensed spectrum
- Enhanced D2D functionality for low latency and high speed

These enhanced requirements are addressed in with the release LTE Rel-14. In this release two new Sidelink transmission modes were created [15], see Table I. In this table, the two new modes are compared by scheduling method and channel access. In scenarios where vehicles have poor coverage or are moving on a freeway with many handovers, the most relevant mode is mode four. With this mode, we are not relying on using an eNB. We will use this mode to compare LTE-V2X with IEEE 802.11p.

TABLE I: LTE-Sidelink transmissions.

	Scheduling method	**Channel access**
Mode 3	eNB	eNB-Controlled
Mode 4	Distributed	Sensing, with persistent transmissions

B. Comparing RF with VLC

As stated earlier, there are two main approaches for communicating between moving vehicles: RF and VLC. In recent years, VLC has gained a lot of interest from the car industry and research community. To standardize this technology, several efforts have been made by the IEEE Standards Association and more research papers have been published on this topic. Although VLC has only recently seen more development, RF has been the standard technology that is currently used by vehicles to communicate.

In Table II we discuss the advantages and disadvantages of RF and VLC. One of the main disadvantages of RF is the network congestion that takes place when large amounts of vehicles are in close proximity. When the network is congested, there is a higher probability that packets will be severely delayed or completely dropped, which is a problem for our applications that rely on a constant stream of data. Due to the loss of packets, driving applications that depend on communication to ensure the safety of the vehicle will no longer function optimally.

TABLE II: Communication Technologies.

	Advantages	**Disadvantages**
RF	Omnidirectional	Not secure
	Long Range	Network congestion
	Pass through object	Limited available spectrum
VLC	LoS Communication	Short range
	High data rates	Vulnerable to ambient light
	Low power consumption	Vulnerable to weather
	Unused spectrum	

The best solution can likely be found by combining VLC and RF. VLC can make up for RF's limited radio spectrum and the potential security attacks and RF can make up for the limited range of VLC.

With these findings, we create four different approaches of communication between vehicles that are driving in a platoon

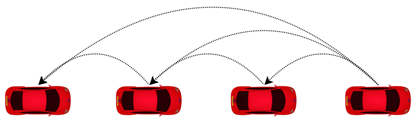

Fig. 1: Only RF (*This image shows the reachability of the strategy, the message does not need to be resent by the receivers*).

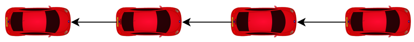

Fig. 2: Only VLC (*Messages will be forwarded by receivers*).

formation [16], and in Table III we compare these approaches:

- Only RF: In this approach, only Radio Frequency to communicate between vehicles is used (Figure 1).
- Only VLC: In this approach, only Vehicular Light Communication to communicate between vehicles is used (Figure 2).
- VLC - RF: In this approach, VLC and RF are combined. Vehicles will use both methods to send data (Figure 3).
- Hybrid VLC - RF: In this approach, all vehicles can use VLC and RF. Contrary to the previous approach (i.e., VLC-RF), a protocol will determine what method will be used to send data (Figure 3).

TABLE III: Communication strategies.

	Advantages	**Disadvantages**
Only RF	Long range Pass through object	Not secure Network congestion Limited available spectrum
Only VLC	LoS Communication High data rates Low power consumption	Short range Vulnerable to weather Multi-hopping
VLC-RF	Direct communication Long Range	Network congestion Not secure Redundant messages
Hybrid VLC-RF	Direct communication Long Range	Not secure

III. Use Case: Platooning

A. A Platooning overview

Autonomous platooning is a technology that builds on Adaptive Cruise Control (ACC) where communication allows a controller to follow the vehicle in front. The controller will change the velocity to ensure that a safe distance can be maintained. Each vehicle will be equipped with different sensors that will allow the controller to make the correct decision. With communication, the vehicles can inform the other members of the platoon about the status of itself. As a result, the platoon will drive safely. CACC has had multiple large-scale projects in the EU and US, such as SARTRE and PATH [5], [17].

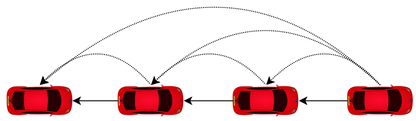

Fig. 3: VLC - RF.

To ensure that the controller has enough information to make the correct decisions, the vehicles need to communicate at a constant update rate. A study performed by Rashdan et al. [18] found that 10Hz is adequate. The medium will not be overwhelmed, and the information is still up-to-date so that the other vehicles can make a correct decision. These types of messages are Beacon messages. They comprise the individual states of a vehicle, i.e. velocity, location, and distance to the vehicle in front. For this reason, the controller can ensure that a safe distance is maintained.

The next type of message is an action message. These will send requests to the leader for action. The following action messages can be found in a platoon formation:

1) Join: An external vehicle will try to join the platoon formation. To do so, it will send a request to the leader. The leader of the platoon will decide if and where the vehicle can join.

2) Merge: Platoon A will try to merge with platoon B. To do so, the leader of A will send a message to the leader of B. B will send a message back with information on how A will need to merge.

3) Leave: A vehicle will leave the platoon. To do this, it will send a Leave message to the leader of the platoon. They will instruct all platoon members on how and when the vehicle can leave.

B. Hybrid RF-VLC Solution

In this section, we will propose an algorithm that will combine the previously mentioned technologies, VLC and RF, to ensure that we can utilize the advantages of both technologies and thus increase the reliability of the communication.

The application will use Algorithm 1 to decide what technology is used to send the packet. The algorithm will use two measured parameters, latency and update rate, to decide what technology is the most optimal at that moment. These parameters will be set based on the results of simulations done with the individual technologies. When the platooning application needs to communicate outside the platoon, it is able to set the destination of the packet to *Outside*. This will set the sending technology to the specified RF.

IV. Simulation setup

To evaluate the proposed setup and protocols we use the OMNET++ network simulator combined with the VEINS framework [19], its platooning extension Plexe [20], its VLC

Algorithm 1 Sending algorithm

```
procedure FIND_TECHNOLOGY(D)                    ▷ Destination D
    update_rate                                 ▷ measured update rate
    req_update_rate                             ▷ required update rate
    latency                                     ▷ measured latency
    req_latency                                 ▷ required latency
    result                                      ▷ the used technology
    if D is Platoon then
        if update_rate < req_update_rate then
            result ← RF
        else if latency < req_latency then
            result ← RF
        else
            result ← VLC
        end if
    else if D is Outside then
        result ← RF
    end if
    return result
end procedure
```

extension VEINS-VLC [21], and the INET framework to simulate the LTE-V2X communication [22]. We use a freeway as location to do the simulations and on this freeway we will place multiple platoons in different lanes. These platoons will drive for a set amount of time. Each vehicle will send a beaconing message at a constant interval. This message includes the necessary data to allow for safe platooning. The leader of a platoon will use ACC to maintain a constant velocity and headway to the platoon in front. The other vehicles in the platoon will use CACC to follow the leader. The controller used is described in Rajamani [23].

TABLE IV: Platoon parameters.

ACC	Desired velocity	100km/h
	Headway	1.2s
CACC	Distance	5m
	C_1	0.5
	w_n	0.2Hz
	ξ	1
Scenario	Vehicles	[5, 10, 20, 40, 80, 160]
	Platoon size	5
	Lanes	4
	Simulation time	10s

TABLE V: Communication technologies parameters.

LTE	CQI	7
DSRC	Bitrate	6Mb/s
	Transmit power	13dBm
	Fading model	Nakagami (m = 3)
	Path loss model	Free space (α = 2)
	Thermal noise floor	-98 dBm
VLC	Bitrate	1Mb/s
	Modulation	OOK
	Sensitivity	-114 dBm
	Thermal noise floor	-110 dBm

In Table IV, we list the most important parameters from the platooning setup and the overall scenario. To test the scalability of our communication strategies, we will change the number of vehicles. In the different scenarios we will simulate with 5, 10, 20, 40, 80 and 160 vehicles, corresponding with 1, 2, 4, 8, 16 active platoons.

In Table V we show the necessary parameters for the different communication methods. In this simulation, we compare the different technologies in a clean and open area. No obstacles will be added. We only need to simulate for 10 seconds because this is representative enough for the highly mobile scenarios that we consider for this paper. Therefore, increasing the simulation time does not have any effect on the results we gather.

V. Results

In this section, we will investigate the performance of the different network technologies, previously described in II. The result we display are the averages of all the vehicles inside the same platoon unless otherwise stated. We will discuss metrics that are important to the performance of the communication between each vehicle. These parameters are the packet delivery rate, latency and network quality. To ensure that a platoon can operate optimally, the communication between vehicles needs to be reliable, constantly updated and needs to contain the current information.

A. Packet Delivery Ratio

Packet Delivery ratio (PDR) will measure the number of packages received compared to the number of packages expected to be received. In a platoon, receiving messages is vital to ensure that the vehicles that are part of the platoon can make the correct decision. If packages would not be received by vehicles that expect that data, it will make the platoon unstable and unreliable. We expect a Packet delivery rate 100%. Our results show that in case of RF technologies, i.e., IEEE 802.11p and LTE-V2X, the PDR is decreasing with an increase in the number of connected vehicles. IEEE 802.11p maintains the required PDR until 20 vehicles, whereas LTE-V2X will already start losing packages with only 10 vehicles active. Both technologies have a significant drop in PDR when even more vehicles are added. In contrast to the RF technologies, VLC has a higher average PDR. Due to interference that occurs with non LoS technologies, we can see that LoS technologies maintain a close to perfect PDR even when we increase the number of vehicles. The combined setups are able to maintain a higher PDR with more vehicles active.

B. Latency

Latency expresses the time it takes for a packet of data to travel from a sender to a receiver. To ensure that a platoon can react quickly to new information, the time needed to receive a message needs to be as low as possible. In Béchardergue et al. they find that the optimal latency of a package in a platoon is lower than 20ms [6]. In Figure 5 we compare the average latency of the technologies in two different scenarios, i.e. number of vehicles. We do this by measuring the delay from the leader of the platoon sending a beacon to the second and last vehicle receiving this package. Our results show that in case of VLC, the second vehicle has a latency of 12.3ms which is within the requirements, whereas the last vehicle of the platoon has a latency of 37.2ms, which is higher then the requirement of 20ms. This is due to the multi hopping that takes place to forward the message to the vehicles behind, with every forward the latency will increase.

When we compare the RF technologies, i.e. LTE-V2X and IEEE 802.11p, we see that only IEEE 802.11p has a latency lower then the requirement. The second and last vehicle of the platoon are in both scenarios able to maintain a lower latency. LTE-V2X does not have a latency lower then the required 20ms, even when a small amount of vehicles are active. The difference in latency between the two RF technologies is due to the fact that IEEE 802.11p is using CSMA/CA. This allows for a node to sense if a channel is active, and if the channel is idle, the node can send the message. LTE-V2X uses a Semi-Persistent Scheduler (SPS), an SPS allows for each station to schedule its own recourse blocks for transmissions in time. To prevent collisions with other transmissions, LTE-V2X schedules its messages more spread out. Due to this spreading out of the messages, LTE-V2X has a higher latency compared to IEEE 802.11p.

The results of combining IEEE 802.11p and VLC shows us that in a scenario with 80 vehicles, the average latency is higher at 21.29ms compared to the 14.3ms with only IEEE 802.11p. This is due to VLC being able to deliver packages that would not have been received with only IEEE 802.11p and thus increasing our average latency. When we compare this to IEEE 802.11p and VLC using the strategy explained in III-B, the results show that with a maximum average latency of 9.4ms with 10 vehicles and 12.26ms with 80 vehicles, this combination of technologies and strategy is able to achieve the requirement of 20ms.

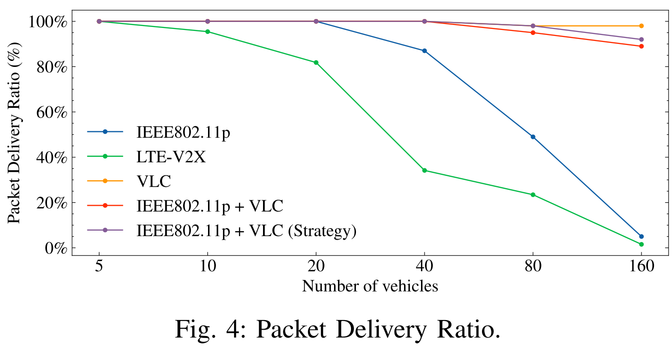

Fig. 4: Packet Delivery Ratio.

C. Network quality

In the following section, we look at the network quality of the different technologies. We do this by looking at the measured time between received messages. As mentioned in the setup we will send a beacon with a rate of 10Hz, we use this value based on previous research [6], [9], which means

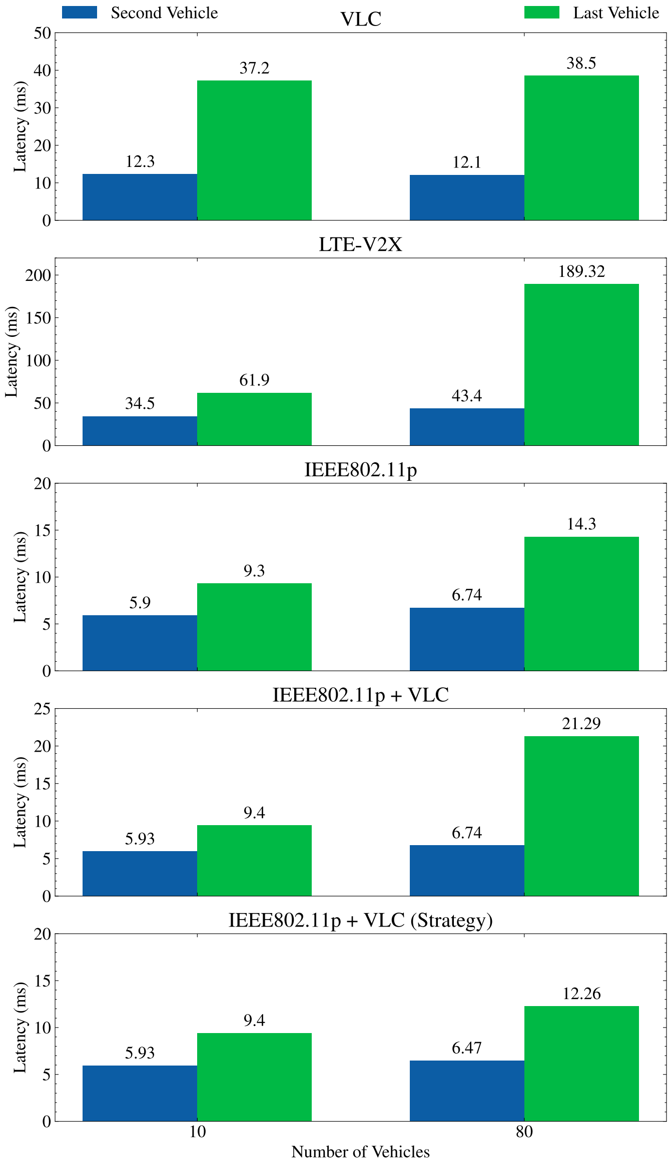

Fig. 5: Latency.

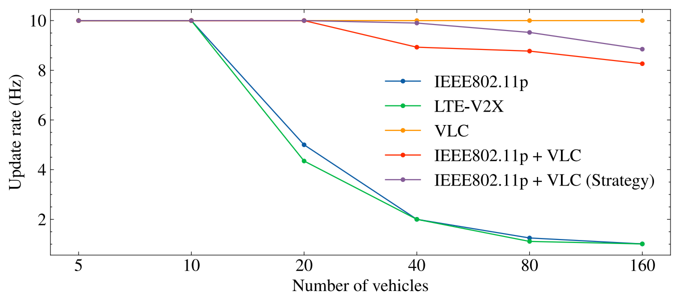

Fig. 6: Received message delay.

that the receiver expects a message every 100 milliseconds. The measured delay will change based on the network quality. The more interference, the higher the delay between messages. In Figure 6 we see that LTE-V2X and IEEE 802.11p are not able to sustain the required update rate when more vehicles are in close proximity. When 20 vehicles are sending data, the RF technologies cannot send at the required rate of 10Hz. Contrary to VLC, which was able to maintain a stable update rate of 10Hz. The combination of IEEE 802.11p and VLC shows a significant improvement over the individual technologies. After 40 vehicles, we noticed a drop in the frequency of received packets. With the hybrid strategy active, the combination of technologies will be able to maintain the required update rate with 40 vehicles, but the performance will still drop when more vehicles are active.

VI. Conclusion

In this work, we presented different communication technologies, i.e. IEEE 802.11p, LTE-V2X and VLC, in different scenarios, and we studied the scalability of these technologies when it comes to platooning scenarios. We then created a basic hybrid strategy that combines different technologies to improve the overall communication reliability.

To compare these technologies, we used the OMNET++ network simulator with different extensions active, i.e. INET and VEINS, to simulate how each individual technology compares in a fast-moving environment such as a vehicular one. Our test setup enables swift changes of the test parameters, e.g., platooning size and used communication technology, which enables for rapid testing.

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References

[1] B. van Arem, C. J. G. van Driel, and R. Visser, "The Impact of Cooperative Adaptive Cruise Control on Traffic-Flow Characteristics," vol. 7, no. 4, pp. 429–436, conference Name: IEEE Transactions on Intelligent Transportation Systems.

[2] A. A. Alam, A. Gattami, and K. H. Johansson, "An experimental study on the fuel reduction potential of heavy duty vehicle platooning," doi: https://dx.doi.org/10.1109/ITSC.2010.5625054. pp. 306–311, ISSN: 2153-0017.

[3] S. E. Shladover, C. Nowakowski, X.-Y. Lu, and R. Ferlis, "Cooperative Adaptive Cruise Control: Definitions and Operating Concepts," vol. 2489, no. 1, pp. 145–152, publisher: SAGE Publications Inc. [Online]. Available: https://doi.org/10.3141/2489-17 (Accessed 2021-10-26).

[4] The project | platooning ensemble. [Online]. Available: https://platooningensemble.eu/project (Accessed 2021-10-26).

[5] T. Robinson and E. Coelingh, "Operating Platoons On Public Motorways: An Introduction To The SARTRE Platooning Programme," p. 11.

[6] B. Béchadergue, H. Guan, L. Chassagne, S. Tohmé, and J.-L. Franchineau, "Visible Light Communication System for Platooning Applications," in *Vision 2016 Vehicule and Infrastructure safety improvement in Adverse conditions and Night Driving*. [Online]. Available: https://hal.archives-ouvertes.fr/hal-01378185 (Accessed 2022-05-11).

[7] D. Jiang and L. Delgrossi, "IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments," doi: https://dx.doi.org/10.1109/VETECS.2008.458. pp. 2036–2040, ISSN: 1550-2252.

[8] M. Harounabadi, D. M. Soleymani, S. Bhadauria, M. Leyh, and E. Roth-Mandutz, "V2X in 3GPP Standardization: NR Sidelink in Rel-16 and Beyond," vol. 5, no. 1, pp. 12–21. [Online]. Available: http://arxiv.org/abs/2104.11135 (Accessed 2021-11-29).

[9] F. Boukhalfa, M. Hadded, P. Muhlethaler, and O. Shagdar, "Evaluation of a new Radio Technology and Visible Light Communication for a Platooning Application," in *ISNCC 2021 - International Symposium on Networks, Computers and Communications*. [Online]. Available: https://hal.archives-ouvertes.fr/hal-03364383 (Accessed 2021-10-18).

[10] J. Ploeg, B. T. M. Scheepers, E. van Nunen, N. van de Wouw, and H. Nijmeijer, "Design and experimental evaluation of cooperative adaptive cruise control," doi: https://dx.doi.org/10.1109/ITSC.2011.6082981. pp. 260–265, ISSN: 2153-0017.

[11] T. Hardes, F. Klingler, and C. Sommer, "Modern WLAN for V2X Applications: Exploiting Beamforming for Platooning," doi: https://dx.doi.org/10.1109/VNC51378.2020.9318329. pp. 1–8, ISSN: 2157-9865.

[12] M. Schettler, A. Memedi, and F. Dressler, "The Chosen One: Combating VLC Interference in Platooning using Matrix Headlights," doi: https://dx.doi.org/10.1109/VNC48660.2019.9062776. pp. 1–4, ISSN: 2157-9865.

[13] G. Singh, A. Srivastava, and V. A. Bohara, "On Feasibility of VLC Based Car-to-Car Communication Under Solar Irradiance and Fog Conditions," in *Proceedings of the 1st International Workshop on Communication and Computing in Connected Vehicles and Platooning*, ser. C3VP '18. doi: https://dx.doi.org/10.1145/3267195.3267198. . ISBN 978-1-4503-5925-2 pp. 1–7.

[14] J. B. Kenney, "Dedicated Short-Range Communications (DSRC) Standards in the United States," vol. 99, no. 7, pp. 1162–1182, conference Name: Proceedings of the IEEE.

[15] A. Filippi, K. Moerman, V. Martinez, A. Turley, O. Haran, and R. Toledano, "IEEE802.11p ahead of LTE-V2V for safety applications," p. 19.

[16] M. Schettler, A. Memedi, and F. Dressler, "Deeply Integrating Visible Light and Radio Communication for Ultra-High Reliable Platooning," doi: https://dx.doi.org/10.23919/WONS.2019.8795496. pp. 36–43.

[17] Truck platooning | california partners for advanced transportation technology. [Online]. Available: https://path.berkeley.edu/research/connected-and-automated-vehicles/truck-platooning (Accessed 2021-11-15).

[18] I. Rashdan, F. de Ponte Muller, and S. Sand, "Analysis of Communication Requirements for CACC in Stop-and-Go Behavior for Energy Efficient Driving," doi: https://dx.doi.org/10.1109/VTCFall.2016.7880905. pp. 1–5.

[19] C. Sommer, D. Eckhoff, A. Brummer, D. S. Buse, F. Hagenauer, S. Joerer, and M. Segata, "Veins: The Open Source Vehicular Network Simulation Framework," in *Recent Advances in Network Simulation*, A. Virdis and M. Kirsche, Eds. Springer International Publishing, pp. 215–252. ISBN 978-3-030-12841-8 978-3-030-12842-5 Series Title: EAI/Springer Innovations in Communication and Computing. [Online]. Available: http://link.springer.com/10.1007/978-3-030-12842-5_6 (Accessed 2022-01-14).

[20] M. Segata, R. Lo Cigno, H.-M. M. Tsai, and F. Dressler, "On platooning control using IEEE 802.11p in conjunction with visible light communications," in *2016 12th Annual Conference on Wireless On-demand Network Systems and Services (WONS)*, pp. 1–4.

[21] A. Memedi, H.-M. Tsai, and F. Dressler, "Impact of Realistic Light Radiation Pattern on Vehicular Visible Light Communication," doi: https://dx.doi.org/10.1109/GLOCOM.2017.8253979. pp. 1–6.

[22] G. Nardini, A. Virdis, and G. Stea, "Simulating cellular communications in vehicular networks: making SimuLTE interoperable with Veins," p. 4.

[23] R. Rajamani, *Vehicle Dynamics and Control*. ISBN 978-1-4614-1433-9. [Online]. Available: https://link.springer.com/book/10.1007/978-1-4614-1433-9 (Accessed 2022-05-11).