A First Investigation of V2X Communication for Radar Interference Mitigation

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Abstract

As the number of vehicles equipped with radars sensors is rapidly increasing, the risk of harmful interference is rising to undesirable levels, especially since the radar waveform parameters are not regulated. Interference mitigation techniques are becoming very important for radars to operate properly in this complex environment. This article investigates the potential of V2X (Vehicle-to-Everything) technology as a side communication channel between vehicles, to coordinate usage of the radar bandwidth and thus avoid interference. Vehicles equipped with V2X technology can receive information about the upcoming radar waveform parameters of the vehicles in their vicinity, and adjust their own radar parameters accordingly, then inform them back by means of a V2X message. Simulation results reveal that V2X technology can help to significantly reduce interference levels and might thus be a promising companion communication channel for radar interference avoidance techniques.

Keywords:

V2X, radar, interference mitigation, automotive

1. Introduction

The use of Advanced Driver Assistant Systems (ADAS) is a major automotive trend, and will keep growing for the years to come as stated by [1] and [2]. Their estimation is that by 2030, 50% of cars (≈ 700 million cars) will be equipped with radars. This rapid grow in the number of radars on the road will lead to an increase of potentially harmful interference between radars. This partly originates from the lack of standardization of the radar waveforms and associated parameters for use within the radar band. Even though several studies [3] suggest that sharing the 76-81 GHz band between long range radars (LRR) and short range one (SRR) would cause saturating interference from LRRs to SRRs, radar manufacturers can design radar modules that emit anywhere within this band, with any type of waveform. In order to mitigate these harmful interference, coordination based on the V2X technology has a lot of potential. V2X technology establishes a Cooperative Intelligent Transport Systems (C-ITS) network between the different actors on the road (vehicles, infrastructure, pedestrian, etc.). An example of such C-ITS network is the ETSI ITS network, currently being rolled-out, for example with the new

Volkswagen Golf 8 cars [4] or the deployment of connected infrastructure in Austria [5], just to name a few.

Example of ITS messages are the cooperative awareness messages (CAM) [6] which convey information such as coordinates, speed and headings of the vehicles, with a vast number of optional and customizable fields as presented in Figure 1. The goal of this study is to provide a first evaluation of the potential of V2X communication for interference mitigation based on coordination and avoidance. The paper is organized as follows. Section 2 provides a brief overview of the current mitigation techniques used, Section 3 presents in more detail the V2X technology, followed in Section 4 by the process used to simulate and evaluate its use for interference mitigation. Finally, Section 5 will present the results obtained with these evaluations, followed by our conclusion in Section 6

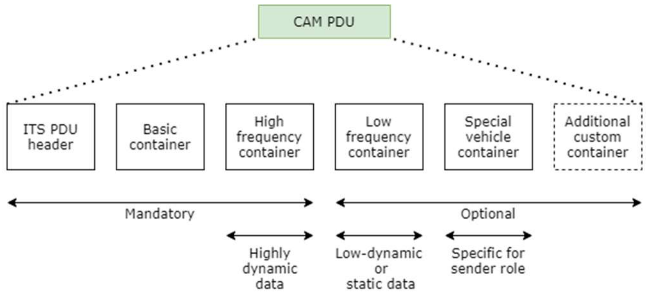


Figure 1 – CAM payload

2. Brief State-of-Art Overview

Frequency modulated continuous waveforms (FMCW) is still the most commonly used radar waveform used, decades after the initial papers such as [7] [8] just to name a few, that paved the way for modern automotive radar applications. FMCW is known for its overall good performance in terms of range and accuracy. Thus, the present research and experimentation assume usage of FMCW waveforms. Other waveforms such as Phase Modulated Continuous Wave (PMCW) or orthogonal frequency-division multiplexing (OFDM) signals are not considered presently.

A. Radar interference principles

In the case of FMCW type of signal, an interference happens when the radar receives a signal whose frequency is within the receiver's bandwidth during a chirp emission. Depending on the correlation between the interference signal and the chirp, different effects can be observed, as illustrated in Figure 2. In the case of a low correlated interferer, the main effect will be an increase of the noise floor for the victim. The more correlated is the interferer, the bigger will be the increase, leading to a potential radar blindness as the radar's echo power would be lower than the noise floor. In the case of perfectly correlated interferer, the signal resembles an echo of the radar and thus appears as a single peak instead of a global noise floor increase. This peak could be interpreted as an actual target by the radar when it actually doesn't exist. This is called a false target. These can sometimes be filtered out at the application layer by comparing the detected targets from one frame to the next.

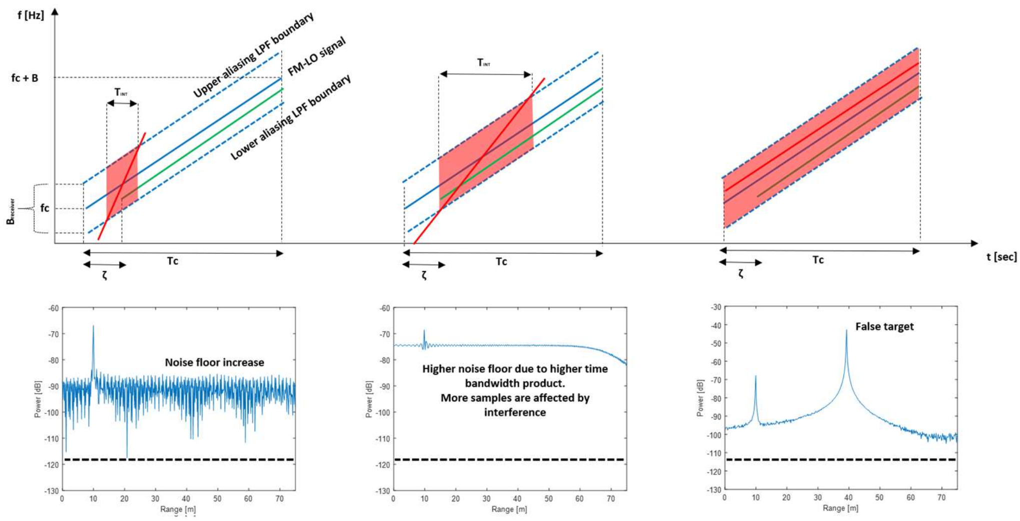


Figure 2 – Effects of interference. From left to right: (1) The interferer in red has a low correlation with the victim in blue, leading to a relatively small increase of the noise floor as few samples are affected. (2) As the correlation increases, the noise floor increases even more, leading to a potential blindness of the radar. (3) In the case of perfect correlation, the interference can be interpreted as a target as it resembles an echo of the blue signal

B. Current radar interference mitigation techniques

Interference mitigation can take place on multiple domains (time, frequency, coding, polarization, space, ...) and the strategy used can rely on one or several of the following:

- Detection
- Avoidance
- Repair, Omit
- Communication

Current mitigation techniques are mostly focusing on the detection **[9]** and reparation of the interference **[10]**, by means of signal processing at the physical layer. Once an interference is identified, different processing techniques can be applied (nulling, subtractions, extrapolation, etc.) **[11]** to reduce the noise generated by the interference.

Other techniques outside of the reparation domain consist in trying to avoid interference with randomization of the chirp parameters. Indeed, it is possible to offset the chirps' frequency and timing so they do not match for a long time with the ones from a potential interferer.

In this paper, we focus on the communication and avoidance domains for interference mitigation. Reparations at the signal processing level are not considered.

C. Full cognition strategies

Mitigation techniques can also be based on full cognition strategies. These techniques require high levels of cognition capability that can be achieved with sensors and with communication between entities on the road with each other or with a base station. Once the necessary information is gathered, the goal is to coordinate all the entities such that interference is avoided.

A simple full cognition strategy would be one using a booking system. The radar bandwidth is subdivided into multiple non-interfering time-frequency slots. Each radar can book one of these slots for a certain time window and communicate the slot booked to other entities on the communication channel. This booking process must be repeated for each time window the radar wants to emit on. This kind of techniques have multiple limitations by design.

Firstly, they are limited by the performance of the communication channel. Depending on the technology used, end-to-end delay and achievable distance can greatly vary and have a strong impact on the relevance of such side communication channel, yet impacting entities' capability to coordinate themselves. For example, with the technique described in RadChat [12], data communication is achieved using a part of the radar bandwidth and the radar hardware, to establish an ad-hoc network between facing radars. The network is asynchronous, and the 'listen-before-talk' type of channel access mechanism resembles the one from IEEE 802.11.
Re-using the radar HW for communication purposes implies inheriting the potentially narrow FoV (Field of View), which may be limiting communication only to a subset of the surrounding vehicles. Moreover, signal propagation properties at 77 GHz are such that most likely only short distances (strong propagation path loss) and NLoS (non-line-of-sight) paths may not be covered.
Secondly, since many radars are already deployed in the radar band, they might overlap with the envisioned strategy and communication channel, yielding uncertainty on the achievable overall performance. In order for such a technique to work as intended, it requires either to become a standard, or to be able to deal with situation where an interferer isn't using the same system.
The failure for a radar entity to communicate its intentions can lead to multiple radars booking the same time-frequency slots leading to maximum interference.

The booking system also has limits. By design, there is a limited number of time-frequency slots available, limiting the number of radar that can emit during a single time window. This can lead to a decrease in radars' performance in complex environment where the traffic is dense.
Moreover, this kind of cooperation-booking strategy can only work if it becomes a standard. Using only a communication network to gather information about the surrounding leads to the impossibility to coordinate with vehicles that do not use this technology.

3. C-ITS and V2X technologies

A. ITS architecture

Cooperative intelligent transport systems (C-ITS) provide a flexible framework for vehicles, VRU (Vulnerable Road Users) and infrastructure to share information, in the quest for greener and safer transportation. This network is based on the 5.9 GHz ITS band and is organized with various layers, including Access layer, Facilities and Applications layers. These stacks also specify the exact contents and triggering conditions of the V2X messages, for example of the CAM (Cooperative Awareness Messages) for ETSI ITS or BSM (Basic Safety Message) in the case of DSRC/SAE.
Figure 3 depicts a simplified representation of the ETSI ITS architecture. All ETSI ITS standards at

Facilities and Application layers are technology agnostic.

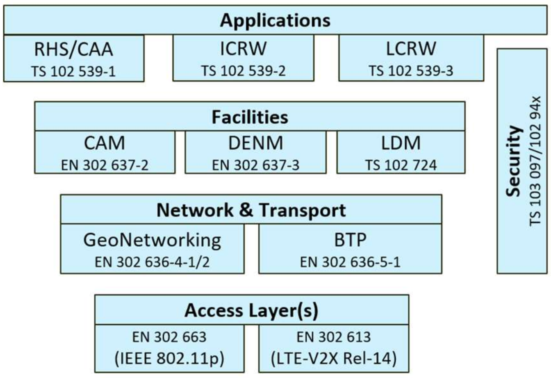


Figure 3 – ETSI ITS architecture

B. Access layers options: IEEE 802.11p/bd and C-V2X

Today, two distinct options are available to realize the access layer of such networks.

One option is to use the IEEE 802.11p standard, which is an evolution of the vastly used WiFi IEEE 802.11a standard. The IEEE 802.11p standardization effort was started back in 2004 (first draft), and was officially completed in 2010. In 2018, IEEE set up the IEEE 802.11bd task group, also referred to as NGV (Next Generation V2X) to create an evolution of IEEE 802.11p standard. The fundamental goal of NGV is to provide a seamless evolution path for IEEE-based V2X networks, with better spectral efficiency, reliability and extended range, while ensuring full backwards compatibility with IEEE 802.11p already deployed systems. ETSI ITS-G5[1] is using the IEEE 802.11p access layer.

As an alternative technology, C-V2X is an umbrella terms which covers both LTE-V2X sidelink mode 4 and 5G NR V2X mode 1. LTE PC5 (sidelink) was introduced in 3GPP Release 12, for D2D (Device-to-Device) applications. In Release 14, support for V2X support was added: mode 4 provides a physical layer for ad-hoc V2X networks with distributed scheduling, similar in concept to ITS-G5 based on IEEE 802.11p. More recently, 3GPP has developed the 5G NR standard. The 5G NR V2X sidelink modes 1 and 2 of 5G NR are similar in concept to LTE-V2X mode 3 and 4G, while built with 5G NR blocks.

C. V2X transmission key principle

Agnostic of the access layer technology choice, the key principle of V2X communication are summarized here.

- Broadcast transmission: V2X messages are sent in broadcast mode, and thus directed to all participants within the covering distance
- Omni-directional: V2X systems operating at 5.9 GHz have omni-directional antenna patterns
- Distributed scheduling: the adhoc V2X network has no "master" orchestrator and the nodes

[1] ITS-G5 defines a protocol stack for vehicular communications in an ad-hoc network to be used in the 5,9 GHz frequency band allocated in Europe. Its access layer is based on IEEE 802.11p standard. The ITS-G5 standard adds features for decentralized congestion control (DCC) to control the network load and avoid unstable behaviour.

coordinate their messages without any infrastructure need

- Typical communication range: several V2X field tests [13] [14] demonstrated a much higher maximum achievable distance, between 1000 and 1400 meters
- Typical transmission rate: US SAE/DSRC BSMs are sent at 10 Hz rate, and for ETSI ITS the CAMs are triggered based on vehicle dynamics [6] such as speed (a change in position by more than 4m), heading (a change of direction of equal or more than +/- 4°) and change of speed (a change of speed equal to or larger than 0,5m/sec), within 1-10 Hz interval.

D. Typical V2X performance

Performance of V2X networks is usually measured in terms of packet reception ratio (PRR) versus distance or versus SNR, and in terms of end-to-end delay (EED), for which a statistical distribution is used.

Numerical simulations of LTE-V2X and IEEE 802.11p access layers have been conducted to extract the PRR and EED figures. For this study, the simulator LTEV2Vsim version 5.2.5 has been used. This open-source simulator is developed by the Italian CNIT, CNR-IEIIT institute and the University of Bologna [15] and used in various technical studies such as [16]. CAM message length of 350 bytes is used, according to average CAM size observed in real-life recorded traces [17]. Reference V2X PRR and EED curves used for the present study are shown in below figure.

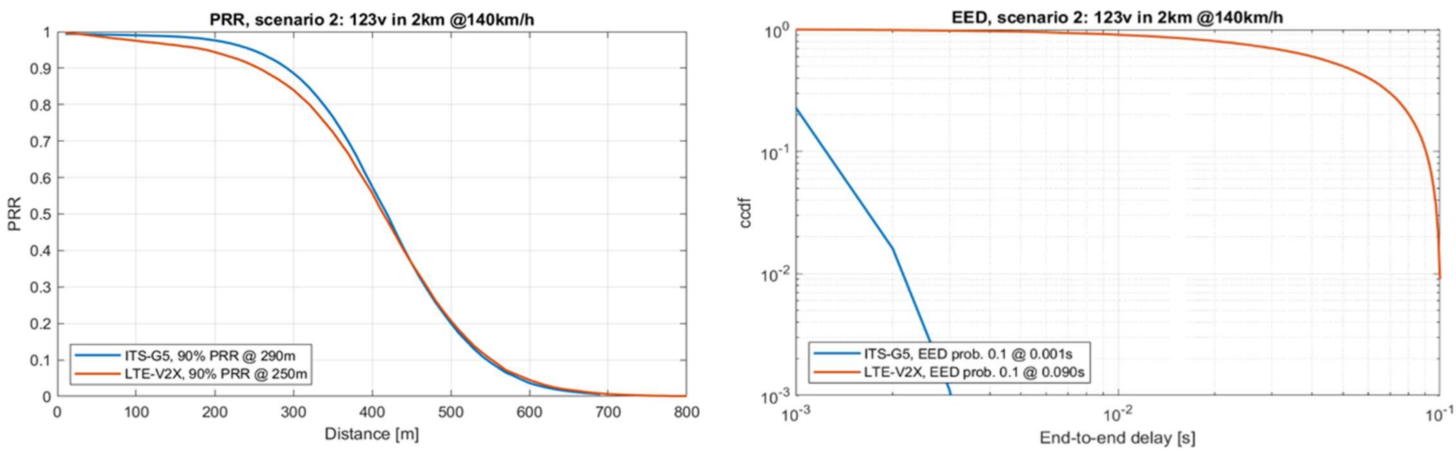


Figure 4 – V2X reference PRR and EED curves for ITS-G5 and LTE-V2X

4. Evaluation

A. Simulation environment

In order to evaluate the potential of V2X communication for interference mitigation, we have developed a simulation environment in python, which includes the different aspects of an automotive scenario using V2X and radars. The simulator is organized into three layers and takes SUMO traces as input for running numerical simulations.

SUMO is an open-source, highly portable and continuous multi-modal traffic simulation package designed to handle large road networks and is used in many of V2X studies. We configured SUMO to provide each vehicle's position every 100ms time-step.

The V2X layer simulates the transmission of a packet from a transmitter to multiple receivers. It is based on IEEE802.11p or LTE-V2X reference communication characteristics. The wireless radio performances are simulated using lookup tables of the End-to-End Delay (EED) and the Packet Reception Ratio (RRP). These lookup tables are generated from the simulations mentioned in Section 3.D. The CAM messages broadcasted by the vehicles on the V2X layer contain the standard information about the vehicle velocity, position, direction, type and ID, and additional information about the front radar physical data (direction, field-of-view, power) and its signal parameters (all the parameters necessary to fully predict the waveform).

The processing layer extracts information from CAMs and adds it to its mental map. In the simulation, the mental map is a list of the different vehicles and their radars 'seen' during the last 10 seconds. In addition to the data received, the vehicle also computes which radar is potentially in the line-of-sight of its own radar in order to filter out non relevant information for the choice of its own radar parameters. This filtering is done thanks to the radars' field-of-view, position and orientation. The processing layer computes mitigation strategies. The radar parameters are changed periodically by the vehicles. This is when different strategies can be applied on the mental map in order to find the best radar parameters to avoid interference.

The Radar layer is used to estimate the amount of interference and stores what, where and when signals are emitted. Multiple metrics are computed by this layer: the noise floor increase and the radar maximum range. The noise floor increase from an interfere is computed with the following formula:

$$nfi = int_{ratio} * (nf - P_{int})$$

Where:

- nfi is the noise floor increase in dBm
- int_{ratio} is the percentage of the signal that is interfered with
- nf is the noise floor power without interference defined in the simulation (-120 dBm)
- P_{int} is power of the interference received by the victim's antenna

Knowing the power of the victim radar, its new maximum range can be computed using the simplified radar formula:

$$R_{max}^4 = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 P_{min}}$$

Where:

- P_t, G, λ, σ are the transmitted power, the antenna gain, the radar's wavelength and the radar's cross section and are considered constant throughout the simulation for a given radar
- P_{min} is the lowest power that a signal needs to be detected. We consider it to be equal to the new noise floor

B. Simulation parameters

The two SUMO scenarios used to evaluate the different strategies are a 3km highway layout and an urban one, layouts can be seen in Figure 5.

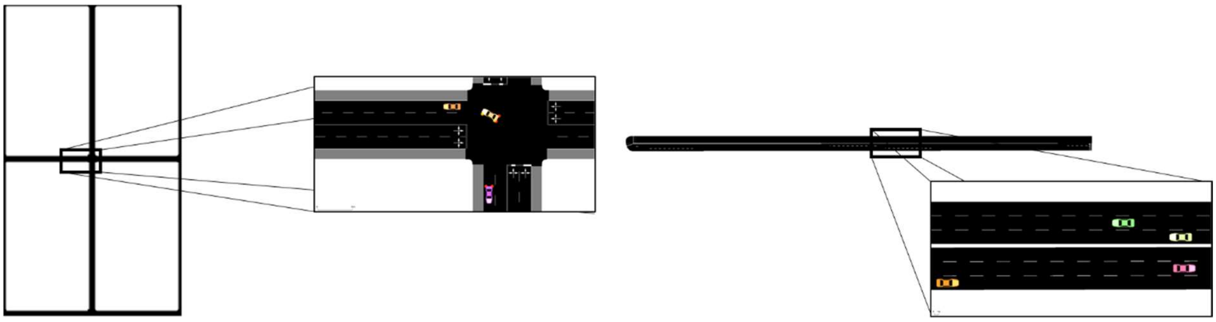


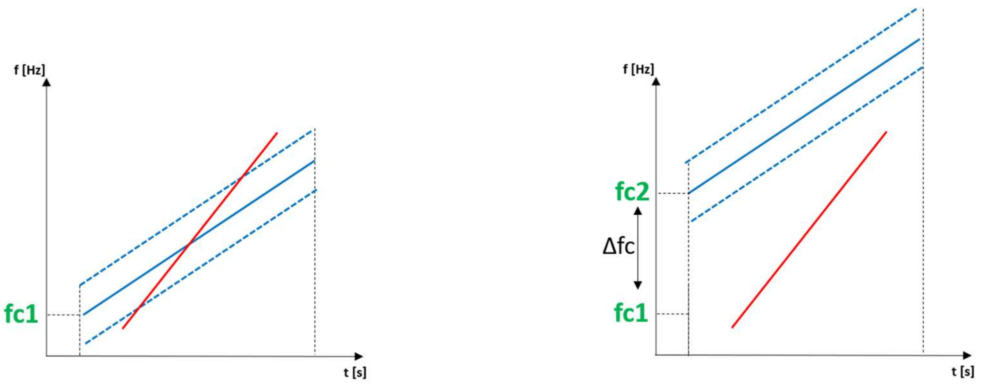
Figure 5 – Two SUMO layouts: urban (left), and 3km highway (right)

The FMCW parameters on each radar at the beginning of the simulation are generated randomly within a certain range based on the requirements on maximum range and velocity of LRR. The maximum range is thus 300±30m with a range resolution of 0.65±15m, and the maximum velocity detectable is 250±10m. These values are then used to determine the initial parameters of the radar as well as its transmission power. These ranges of values are also respected when changes are applied to the radar parameters. During the simulation, only a subset of the parameters can be changed (the start frequency of the chirp, the duty-cycle, the dwell time between chirps and the start time of the signal).

The scenario used for the simulation is a 3km highway with 10 vehicles looping around at the end. The CAM messages are generated at a constant frequency of 10Hz.

The different strategies implemented in the processing layer are the following:

- 'No behavior': The radar keeps the same parameters for the whole simulation
- 'Random changes': The radar applies a random change to its parameters every frame
- 'Random changes if interference': The radar applies a random change to its parameters only if it detects interference
- 'Best random changes': Every ≈150ms, the radar predicts the amount of interference for different set of parameters and pick the best one (or randomly in situations where no V2X information is available)



(a) Signal without parameters changes (b) Signal with a change in start frequency

Figure 6 – Example of start frequency change to avoid interference

The first three strategies serve as a baseline and are inspired by the mitigation techniques investigated by the MOSARIM consortium [2]. They are used to evaluate the one using V2X. The prediction of the amount of interference by a vehicle is done by selecting radars from the mental map that are potentially in the line of sight of its own radar (the two radars are facing each other), and computing the amount of interference between their parameters (if they keep using them) and its own parameters with slight changes. Figure 7 illustrates how this computation can be made. Without changes to its parameters (Fig 6a), the radar using the blue signal will interfere with the one using the red signal as its frequency enters the receiver bandwidth (dotted lines). By applying a change in frequency (Fig 6b), it is possible to avoid this interference. Since the vehicle knows the parameters used by the other radar in red (and its own parameters), it is possible to compute such a graph in order to estimate the amount of interference generated with different set of parameters. This strategy also needs to implement a way to handle situation where no useful V2X information is available and yet the radar receives interference. Such a situation could arise if two radars are interfering with each other but are too far away from each other to communicate their parameters. In that case, the radar's parameters will be changed randomly as long as there are interference.

5. Results

This section presents the results of the simulations. Table 1 and 2 present the average amount of noise floor increase as well as its impact on the maximum detection range of the radars for the 10 vehicles scenario on highway and urban layouts.

The simple 'Best random change' strategy yields better results than the other 3 baseline strategies in both type of scenario. For the highway scenario, the average noise floor increase using this strategy is 2.5 times lower compared to randomizing the parameters when interference is detected and more than 3 times lower compared to a fully random strategy. In the urban scenario, improvements are still noticeable even though it is much simpler environment (less radar can interfere as any given time). The 'Random changes if interference' strategy already outperforms the fully random one, but the strategy using V2X still manages to perform better.

The results of this strategy may vary with the amount of interesting information yield by the CAM messages. The set of parameters that the strategy return depends on the parameters of other radars. If other radars' parameters changes are predictable (because of their strategy, or because the CAM message contains what the parameters will be in the future), then the solution of the 'Best Random Change' strategy will be valid for a relatively large amount of time. In that situation, V2X messages from a predictable radar contains a lot of useful information.

On the other hand, if other radars change their parameters unpredictably (because of a random strategy, or because they communicate very little information), the solution found by the strategy might not be valid for very long. This instability of the surrounding radars will force the strategy to adapt more frequently to the environment, leading to the incapacity to communicate much in advance what the parameters are going to be. This principle can be seen with the results in table 3. This table presents 3

scenarios, one where every radar is changing their signals randomly, one where every radar is using the anticipation strategy, and a last one where only the observed radar is using the strategy, and the others are random.
As we can see, in an environment where other radars are unpredictable, the anticipation strategy still yields better results than a random one, but the performance are lower than what they could be in a more stable and predictable environment.

Table 1 – Average increase of the radar noise floor for the different strategies, extracted from simulation in Figure A1

	Highway scenario	Urban scenario
No changes	3.45 dBm	0.62 dBm
Random Changes	2.73 dBm	0.47 dBm
Random changes if interference	2.20 dBm	0.10 dBm
Best random changes	0.87 dBm	0.07 dBm

Table 2 – Average maximum range of the radar for the different strategies, extracted from simulation in Figure A3

	Highway scenario	Urban scenario
No changes	256 m	293 m
Random Changes	261 m	291 m
Random changes if interference	268 m	299 m
Best random changes	288 m	299 m

Table 3 – Average increase of the radar noise floor for the different strategies

Scenario	Noise floor increase
All random	2.82 dBm
All random but one	2.25 dBm
All using anticipation	0.53 dBm

6. Conclusion

In this paper, we investigated the potential of the V2X (Vehicle-to-Everything) technology as a side communication channel to coordinate the usage of the bandwidth between radars on the road. As shown by the results of the simulations, the use of V2X to communicate radars physical properties as well as the parameters of their waveform allows the use of anticipation strategies. Even the very simple strategy tested in this paper outperforms the common strategy of changing the parameters randomly as the information gathered via the V2X channel allows for a better decision making.
The V2X channel can be seen as an additional sensor of the car, gathering information about surrounding vehicles, and the data gathered could be used for more complex strategies.
However, they need to be designed to work under the V2X limitations. With a maximum of ten messages per second, and no way to coordinate these message (since they follow the rules described in Section 3.C), the strategies need to be quite stable or predictable in order for the V2X message to contain any meaningful information. More complex strategies involving A.I., Optimization or coordination messages could be investigated in future works.

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Appendix A: Simulations graphs

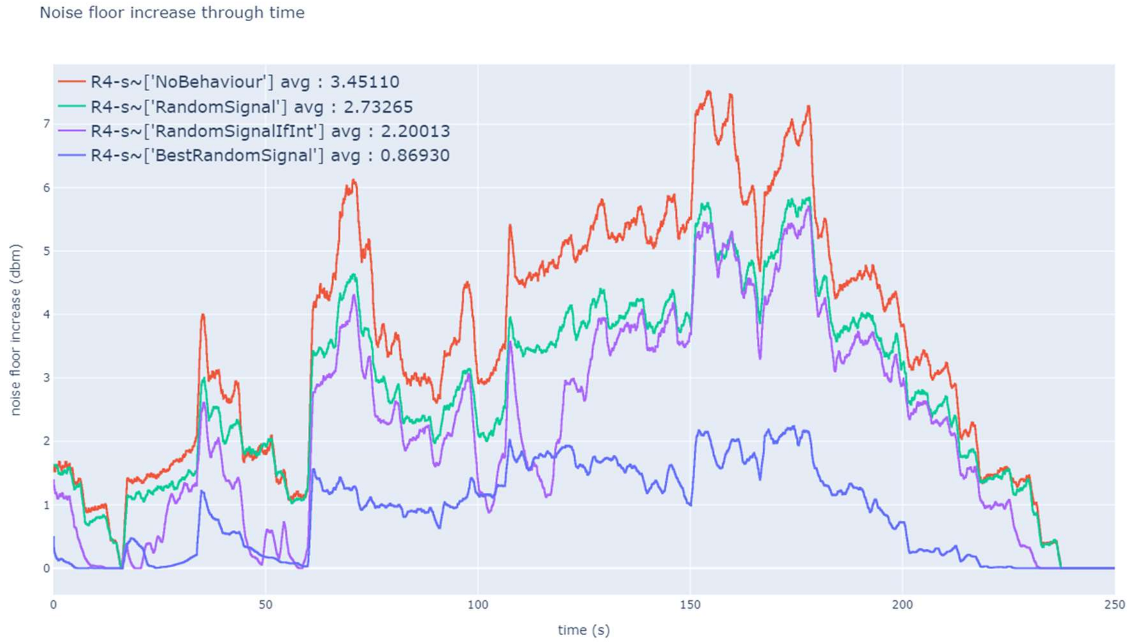

Figure A1 – Average noise floor increase for radars on a 3km highway, 10 vehicles simulation

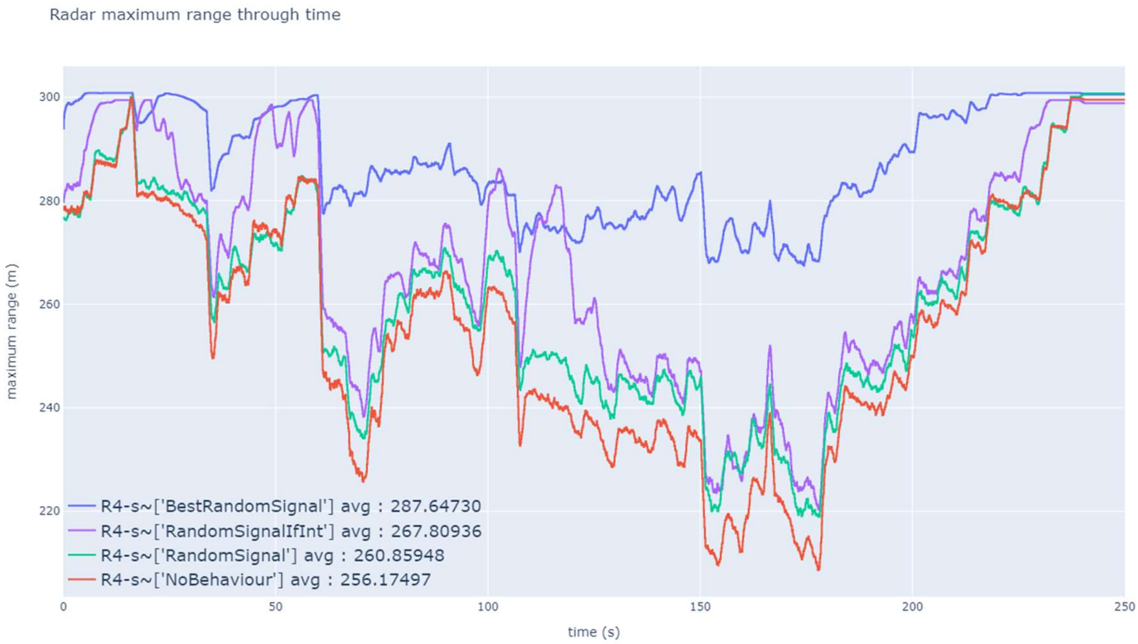

Figure A2 – Average max range for radars on a 3km highway, 10 vehicles simulation

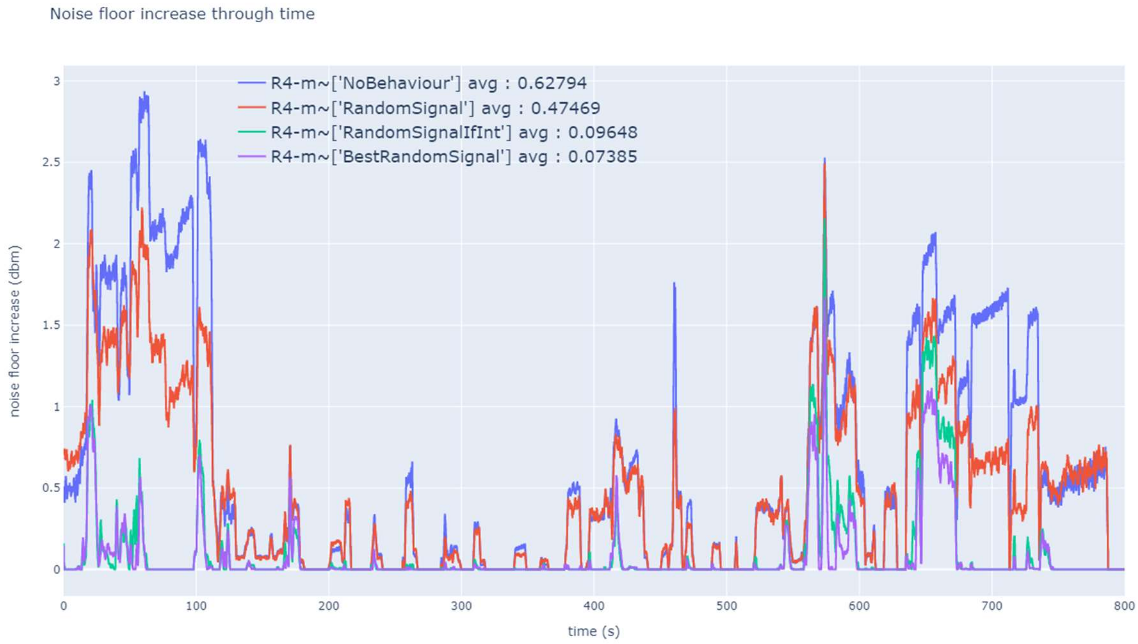

Figure A3 – Average noise floor increase for radars on an urban layout, 10 vehicles simulation

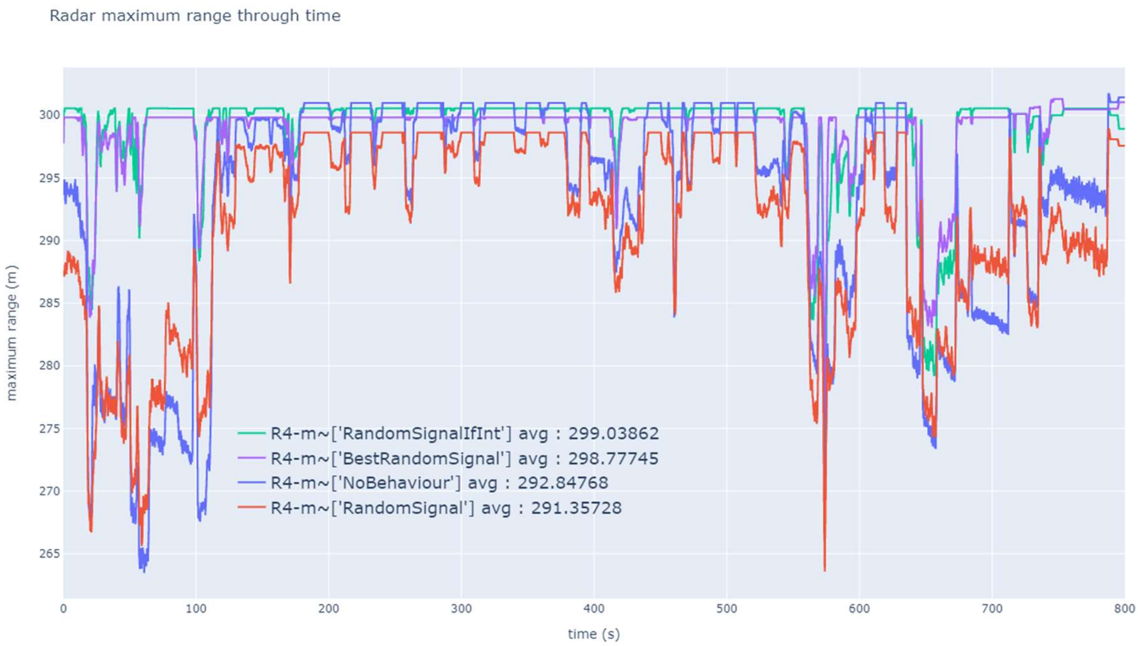

Figure A4 – Average max range for radars on an urban layout, 10 vehicles simulation

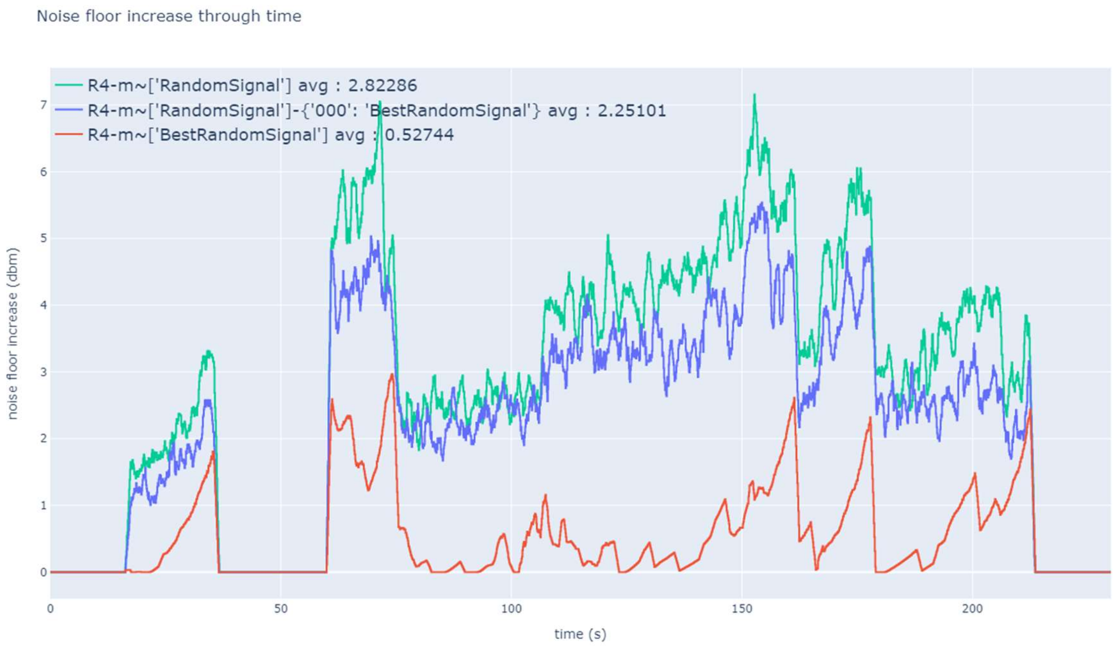

Figure A5 – Average noise floor increase on the highway scenario for different strategy distribution