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Augmented Perception by V2X Communication for Safety of Autonomous and Non-Autonomous Vehicles

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Abstract

As autonomous driving vehicles are to transform the road transportation, it cannot be realized without passing a transition period during which autonomous vehicles and non-autonomous vehicles have to cohabit. This transition period presents great challenges to the safety of the various road users, including vulnerable road users (VRUs), particularly at road sections such as intersections, roadworks areas, and bus stations that are often subject to accidents due to poor visibility conditions. In the paper, we introduce an augmented perception system, which has been developed in the French national project PAC V2X. By relying on V2X communication and sensors, equipped in autonomous vehicles and road side units (RSU), an augmented perception is provided in safety critical zones. A cooperative fusion module is proposed in the work and its impacts on autonomous vehicles have been evaluated using the computer simulator Pro-SiVIC. Our results show that by relying on precise positioning with the local sensors, an augmented perception system can overcome the limitation existing in current cooperative vehicle which are oftentimes due to degradation of the Global Positioning System (GPS). These results also highlight the potential benefit of using RSU in critical zones for extending the time horizon available for safety applications.

Keywords: Collective perception, V2X Communication, Road Side Units, Intelligent Transport Systems

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Nomenclature

C-ITS	Cooperative Intelligent Transportation System
CA	Cooperative Awareness
CAM	Cooperative Awareness Message
CP	Collective Perception
CP	Collective Perception Message
ETSI	European Telecommunications Standards Institute
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
LDM	Local Dynamic Map
RSU	Road Side Unit
V2X	Vehicle-To-Everything

1. Introduction

Autonomous driving vehicles are to open a new page of the road transportation systems with societal, environmental and economical advancements. During the past decades, a great number of research activities have been conducted on Cooperative ITS (C-ITS) for improved road safety and traffic efficiency. Standardisation organisations particularly European Telecommunications Standards Institute (ETSI) and IEEE made enormous efforts producing specifications of V2X communication protocols, security and privacy measures, and a set of target C-ITS services. Vehicles and road side units (RSU) that implement these services have to be equipped with a module, called ITS Station, compliant with the C-ITS architecture standardized by the European Telecommunications Standards Institute (ETSI), ETSI EN 302 665 (2010).

Among the different services provided by the ITS Station functionality, cooperative awareness (CA), ETSI EN 302 637-2 (2014), in which users broadcast their state (position, velocity, type…) and receivers construct a virtual representation of the neighbouring ITS stations by means of a Local Dynamic Map (LDM), ETSI EN 302 895 (2014), plays a key role in improving the road safety.

To ensure safe mobility, automated driving can only be enabled if the vehicle has a complete perception of its environment and in particular of the dynamic evolution of other mobiles which are in its vicinity. In current vehicles, this representation of the surroundings can be achieved either by means of embedded sensors (i.e. local perception) or by means of V2X communication. With local perception, nearby mobiles are detected and their position and dynamics are estimated in real-time. However, due to the sensors' limitations, the local perception system may fail in many situations, particularly in cluttered environment such as city centres... With V2X communication, the information can be disseminated at greater range via the network of vehicles or via RSUs, even though some blind spots may also exist. All the information gathered by the vehicle is stored in a LDM and can be accessed to evaluate the danger level at any instant.

As mentioned above, a set of C-ITS services, known as Day 1, have been specified in Europe in C-ITS Platform (2016). However, these services are for the moment limited to road hazard notification and signage application and do not consider any safety critical situations (emergency braking, collision avoidance…) which have to be handled by autonomous vehicles. The main limitation of current systems based only on V2X communication relies in the lack of reliability of global navigation satellite systems (GNSS) such as GPS.

Hence, to overcome the current limitations and allow cooperation between automated systems, data fusion is necessary between local perception system and data obtained by V2X communication. As these two sources provide redundant information in describing the environment but also complementary information, data fusion has to establish the correct matching between objects detected by the local perception and objects detected by V2X communication.

Based on this cooperative fusion, an extended perception is available for the ITS Station and a collective perception (CP) service has been introduced in recent work of Günther et al. (2016) and ETSI TS 103 324 (2017). The main purpose of collective perception is to exchange local perception information among ITS Station. Complementary to CA, mobile users that may not have communication capabilities are identified and a complete awareness of the local environment is possible for every vehicle.

Finally, a cooperative fusion considers all the information obtained by CA, CP and local perception to enrich the representation of the local environment and can identify whether a neighbouring mobile user is communicating data or not.

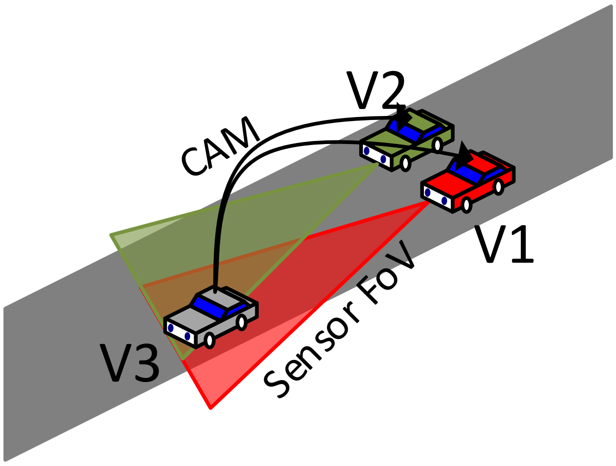

Figure 1: Cooperative vehicle that transmits CAM

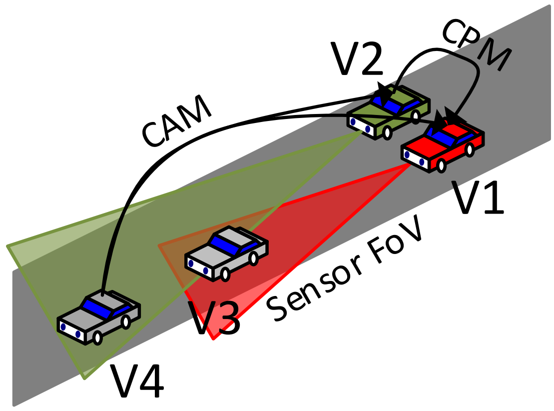

Figure 2: One cooperative vehicle is occluded by a basic vehicle

As illustrated in the figures above where the ego vehicle can be either the red (V1) or the green vehicle (V2) and the target vehicles are the grey ones, i.e. V3 in Figure 1 and V3 and V4 in Figure 2.
In Figure 1, both V1 and V2 are able to perceive V3 and to receive CA Messages (CAM) from this vehicle. In this case, V1 and V2 should be able to identify the cooperative vehicles V3 as also detected using their local sensors.
In Figure 2, on the one hand, V1 is able to detect only V3 based on its local perception as V4 is transmitting CAM. On the other hand V2 is able to detect V3 and V4 based on its local perception and to receive the CAM send by V4. Upon the reception of a CP Message (CPM) transmitted by V2, V1 can understand that the CAM originator is V4 and is located in front of V3.

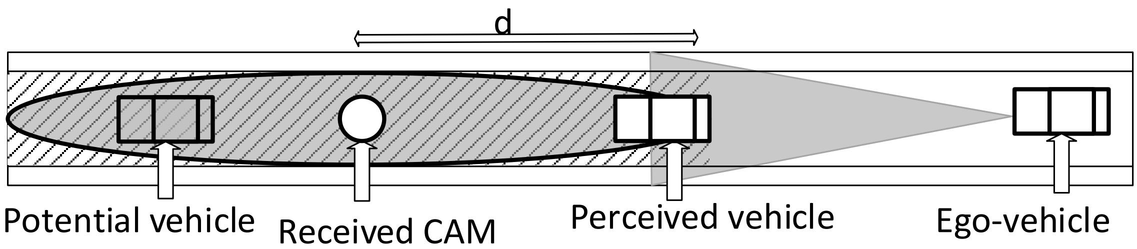

Figure 3: The Ego-vehicle has its own local perception and can receive a CAM by V2X Communication. The cooperative perception is to answer, is the perceived vehicle the originator of the received CAM?

More precisely, the local dynamic map build by the ego vehicle can contain the front vehicle detected by the local perception system (i.e. perceived vehicle), and the vehicles notified by the received CAMs. The question to solve by the cooperative fusion is to determine if the received CAM has been transmitted by the perceived vehicle or by another vehicle that is potentially occluded.
The current paper is organized as follows. Section 2 reviews the related work and section 3 introduces our proposed augmented perception systems based on RSU and cooperative vehicles information. The proposed system is evaluated based on simulations in section 4. Finally, section 5 concludes this paper.

2. Related Work

The work presented in this paper is related to multisource information fusion. This domain has been largely explored in the last decades and has been summarized in recent review Durrant-Whyte et al. (2008), Khalegi et al. (2011). As mentioned in Durrant-Whyte et al. (2008), the distinction has to be established between centralized and distributed fusion. With a centralized fusion, all the sensor measurements are merged in a unique measurement vector used for estimating the state of the mobile users. Although this approach can be optimal (Li et al. (2003)), it requires that the different sources (sensors) provide simultaneously observations which have to be independent. However, since the sensors (including V2X communication) used in the automotive industry usually embed local processing to output a list of tracks, the different observations available for an autonomous vehicle are not necessarily independent. Consequently, a distributed fusion approach Chang et al. (1997), i.e. a track-to-track fusion, is more suited for fusing information from the local perception and V2X communication. As expressed in Chong et al. (2000), two steps are required in the case of a distributed fusion 1) association

between tracks and 2) estimation of objects state and covariance.
In the ITS domain, multisource information fusion has been applied to extend local perception using wireless communication in Rauch et al. (2012), Rauch et al. (2013), Wender and Dietmayer (2007), Mourllion et al. (2004), Gan et al. (2016), Vasic and Martinolli (2015). The existing works in the domain have mainly focused on aligning data (spatially and temporally) from the different sources to apply a measurement-based fusion Rauch et al. (2012), Wender and Dietmayer (2007), Mourllion et al. (2004). Only few efforts dealt with track-to-track fusion. In Rauch et al. (2013), the authors study different algorithms for estimating the translation and rotation between local perception and CPM when the ego vehicle self localization is inaccurate. More recently, some researchers investigated the fusion based on Gaussian Mixture Probability Hypothesis (GM-PHD), Vasic and Martinoli (2015), and Sequential Monte Carlo PHD (SMC-PHD) filter, Gan et al. (2016). Although these approaches are very promising as they can handle the presence of multiple objects and the representation of the information provided by different sources, they require implementations of different types of V2X messages specific to the fusion algorithms.
Regarding the current work, there is no generalization and no common description for the data exchanged among the different cooperative users. Therefore, the current solutions are oftentimes developed specifically for the types of sensors considered by the authors. However, since multiple systems are going to co-exist, it is necessary to define a common data format. This task is a part of the specification of CPM currently being developed within a new work item (NWI) at ETSI, ETSI TS 103 324 (2017). Here, we introduce a data format for information exchange within the internal modules of the ITS Station which has to be compatible with the CPM format. Thus, it allows the development of new cooperative fusion algorithms.

3. Proposal For Augmented Perception Based on Cooperative Vehicles and RSU

3.1. System description

In this paper, we present a cooperative system, which has been developed in the French national project PAC V2X with an objective of extending the vehicles' perception by V2X communication. Particularly, augmented perception is to be provided to both autonomous vehicles and RSUs targeting in safety critical zones. Especially, the ability for RSU to share their local perception by means of CPM and for vehicles to receive such data extends the information that can be exploited to ensure road safety of autonomous vehicles as illustrated in Figure 4.

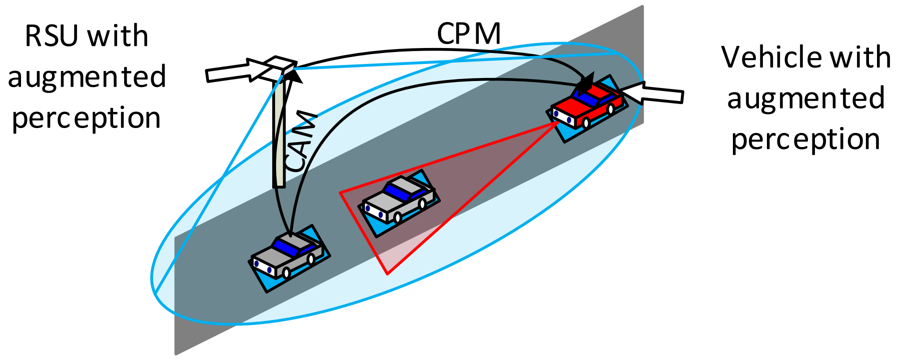

Figure 4: General description of the proposed system

3.2. Augmented perception

To handle imprecise, uncertain and incomplete data, autonomous vehicles and RSUs are equipped with different types of sensors. Hence, the first important step of the augmented perception system is fusion of multi-sensor information in order to achieve correct local perception. The information obtained from the local perception is used to generate CPMs, which are to inform existences of road users, vehicles and VRUs. Besides CPMs, communicating vehicles periodically broadcast CAMs, the ETSI-standardized message informing their positions and mobility status. The second important step of the augmented perception is to fuse the information obtained from the local perception (if it exists) and V2X communication. Correct fusion of the information obtained from the local perception (detected objects), CPM (objects detected by other vehicles), and CAMs is particularly challenging due to the different characteristics of the information sources, the vehicle position errors, and the potentially low penetration rate of V2X equipped vehicles. In this paper, we propose a system for the fusion of information obtained from sensors and V2X communication as illustrated in Figure 5. Data fusion is made considering different parameters such as the refresh period, the position accuracy, and the field of view.

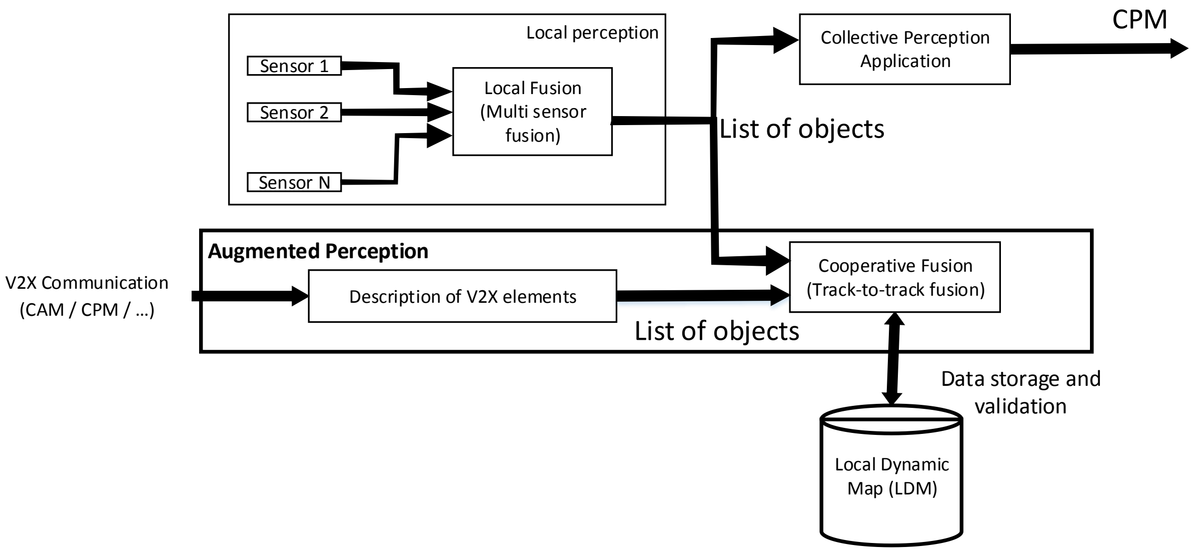

Figure 5: General architecture of augmented perception system

First, the local perception and V2X data elements extraction modules run their own processing to output a list of objects.
Then, the augmented perception is composed of two important functionalities:

- A Collective Perception Application, which is in charge of generating CPM based on the list of objects obtained from the local perception.
- A Cooperative Fusion system, which is in charge of managing the list of objects provided by the local perception and V2X communication. This module maintains a list of internal traces for every object and matches the input data with the current traces. It is in charge of verifying the consistency of the data and of storing the fused information in the LDM

As shown in Figure 5, the augmented perception system has external interface with the V2X messages and the local dynamic map. It also integrates the local perception that can rely on multiple sensors and on a local fusion module. To handle the internal information within the augmented perception system, a common format is introduced to represent the list of objects. This list of objects is exchanged using internal messages between local perception, the V2X data elements extraction, collective perception application and cooperative fusion.

3.3. Common data format for augmented perception

As mentioned in the previous section, a common data format is used for information exchange between the modules of the augmented perception system, in particular the description a list of objects provided by the local perception and description of V2X elements function to the cooperative fusion. In addition, such data format shall be as generic as possible and the data elements shall include the fields required for the CP service to facilitate the generation of CPM. The description of the complete data format is given in Figure 6. As presented in Figure 6, it has to describe at the same time the information source, i.e. the module from which the data are issued (here, the local perception or the V2X data elements extraction), and the objects that have been detected.

	Source Description		Objects Description	
(1) Header	(2) Source identification	(3) Region of Interest	(4) Objects identification	(5) List of objects

Figure 6: Data format used for information exchange within the modules of the augmented perception system

First, a common header is used to give general information such as the version, a timestamp associated with the data.
Then, the source description is divided into two parts:

- A source identification which characterizes the source type (Lidar, Camera, V2X Communication,…) and provides physical parameters on the source (physical location, aperture angles, detection,…) that may be used for further interpretation of the list of objects
- A region of interest is the source's coverage area (sensor coverage area or V2X transmitter's coverage area). The region of interest can be considered as a circular region for a 360° LIDAR or for the transmitter

of a received CAM packet. On the other hand a complex polygonal region can be expected by the local perception in cluttered environments where occlusion occurs.

Finally, the objects description is also divided into two parts:

- Objects identification to indicate the type of the objects described in the message. The most common identifier is the dynamic objects type which is used to inform of obstacles detected by local perception or of road users by CAM and CPM. With MAP message, the static environment (navigation lanes, traffic rules) can be provided to the cooperative fusion. Therefore, the proposed data format introduces lane objects type.
- The list of objects contains the different objects provided by the information source. In the case of dynamic objects listed by local perception or extracted from a CPM, every dynamic object is determined with an identifier, a position in X,Y coordinates referring to the center of the source and other parameters such as its speed, acceleration, class (vehicle, pedestrian,…) and dimension.

Based on this common description, vehicles and RSU that are equipped with different sensors are compliant to the proposed augmented perception architecture.

3.4. Cooperative fusion

Within the augmented perception framework introduced in this paper, the cooperative fusion maintains a list of internal traces for every object. Each time when new input data (here, local perception or V2X communication) is available, the list or internal traces is updated. Figure 7 illustrates how the cooperative fusion module maintains and updates these internal traces.

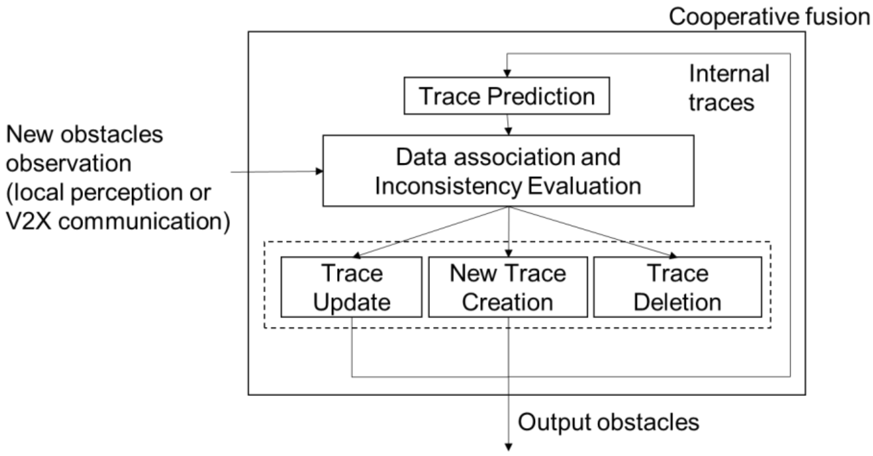

Figure 7: Diagram describing the cooperative fusion algorithm

Once a prediction of the existing traces is made, the internal traces are associated with new input data by considering the imprecision, the confidence, and data age. At this stage, the inconsistency between the internal traces and the input data can be detected by considering the source's region of interest. The idea behind the data association is to minimize a distance function between the internal traces and the input obstacles observations. When an observation is close enough to an internal trace, the two can be associated and the trace is updated. When no trace matches with an observation, a new trace can be created. When a trace has no observation associated for a long period, it is deleted. Currently, a Euclidian distance is used for the data association step.

4. Experimentation and Results

We carried out simulations using the driving simulator Pro-SiVIC in order to highlight the potential impact of collective perception on the road safety. First, the performance of the local perception system and V2X communications (both CAM and CPM) are evaluated. Then, we study the benefits of using road side infrastructure for improving situation awareness at vehicles in some critical road scenarios.

4.1. Simulation setup

Pro-SiVIC provides a virtual version of the Versailles-Satory test track enabling researchers and engineers to evaluate their algorithms before actually experimenting them in the real test track. In the simulation, the vehicles are driving on the track by following a pre-defined trajectory and make a complete loop of the track.

The simulated scenario is composed of three vehicles (a red, a blue and a grey vehicle) and one RSU as shown in Figure 8. For the rest of the section, we consider the red vehicle as being the ego-vehicle.

The ego-vehicle is assumed to be an autonomous vehicle equipped with a 360° view for perception capability by

means of LiDAR sensors and with V2X communication for transmission and reception of CAM and CPM with other vehicles and the RSU.
The two other vehicles are assumed to be PAC V2X cooperative vehicles i.e., they are not equipped with sensors, but they can enjoy augmented perception thanks to V2X communications, particularly received CAMs and CPMs.
The RSU is located close to a turn in the test track in order to monitor approximately a 100 m road section. In addition, it is equipped with a camera mounted at 10m of height and hence it has a complete view of the scene, be able to transmit CPMs with richer information.

Figure 8: Simulated scene from the RSU perspective

Figure 9: Simulated scene from the ego-vehicle perspective

During the simulation, all the vehicles are driving at 36km/h (10m/s) speed, the ego-vehicle follows the blue one while the grey vehicle is driving in the opposite direction. Blue and red vehicles cross the grey vehicle at the road section nearby the RSU, allowing the RSU be able to monitor the critical scenario. The data used for the analysis consist of a full lap on the test track which means that the data are composed a record of 8 minutes. In this record, all the data are update every 40ms which makes 12000 points used for the evaluation.
In particular, Figure 8 and Figure 9 illustrate the simulated scenario from the perception of the RSU and of the ego-vehicle, respectively. These figures clearly show that, for the ego-vehicle, the grey vehicle is not seen, while the RSU has a complete view on the three vehicles.
In what follows, we first evaluate the performance of the local perception system and of cooperative awareness by considering only the detection of the front vehicle, i.e. the blue one, by the ego-vehicle along the test track. Then, we evaluate the RSU-assisted augmented perception at the ego-vehicle particularly regarding the hidden vehicle, the grey one.
It has to be noted that the simulated data are favourable and it is not completely realistic of a real environment. However, such simulation study in the first step to evaluate the feasibility of the proposed approach.

4.2. Case 1: Comparison between cooperative awareness and local perception

In this first case, we are interested in evaluating the performance of the local perception and CAM for localizing the vehicle in front when the GNSS condition degrades. Figure 10 and Figure 11 show the root mean square error of CAM based positioning and local perception along longitudinal and lateral direction.
As relative position with CAM relies and GNSS measurement, it is expected that the error grows when GNSS noise level increases. In contrast, the local perception system is subject to an error about 0.2m in longitudinal direction and about 0.3m in lateral direction for all GNSS noise levels.

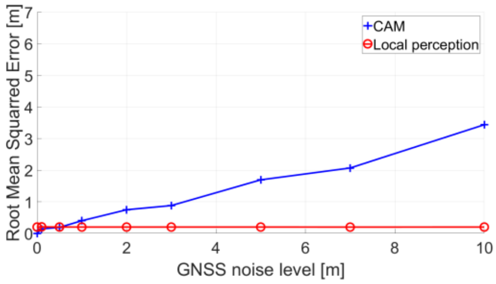

Figure 10: Positioning error in longitudinal direction

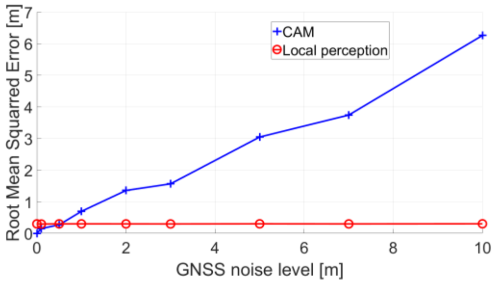

Figure 11: Positioning error in lateral direction

As a consequence, the local perception performs generally better in terms of relative position and even more when the GNSS performances are degraded as it is often the case in urban environments.

As a CPM contains data about the local perception, it has the potential to improve the localization of the neighbour vehicles at the receiver. For the moment, current cooperative vehicles can only know the position of their neighbour by relying on CAM which presents a strong limitation when non communicating users are present. Complementary to CAM, a cooperative vehicle can benefit from CPM to have more information about surrounding road users which may be non-communicating users even if it does not have any local perception system and to build an extended perception of its local environment.
The main challenge when receiving a CPM is to be able to precisely locate the emitter with respect to the receiver. In particular, we consider in our simulation that the blue vehicle can receive a CPM sent by the red vehicle. It can benefit from this information if it is able to associate its current position together with its relative position as perceived by the red vehicle. To do so, a Euclidian distance is calculated between the location of the blue vehicle in the data of the local perception and the relative location of the blue vehicle using the GNSS measurements.
Let us now express the requirements for the vehicle to successfully decode the CPM content, i.e. associate its own location with the relative location given by the CPM data:

- Along the lateral direction, the vehicle can successfully decode CPM if the vehicle can be localized in the correct lane. This means that a successful decoding requires the deviation between GNSS measurement and local perception being less than half of the lane width. Here, we consider a lane width of 3.5m.
- Along the longitudinal direction, the vehicle can successfully decode the CPM if it cannot be misassociated with any other vehicle that is in front or behind the receiver. This means that in the worst case, which is the traffic jam situation, a successful decoding requires the deviation between GNSS measurement and local perception being less than half of the vehicle length. Here, we consider the length of a vehicle to be 5m. In normal traffic situation, this requirement could be relaxed. Hence, other hypotheses are taken considering that no vehicle is present below a safety time of 1s and 2s, meaning a maximum deviation of 6.95m and 13.9m respectively at 50km/h.

The Figure 12 shows the CPM content decoding success ratio obtained in our simulations for different GNSS noise levels when considering the requirements mentioned above.

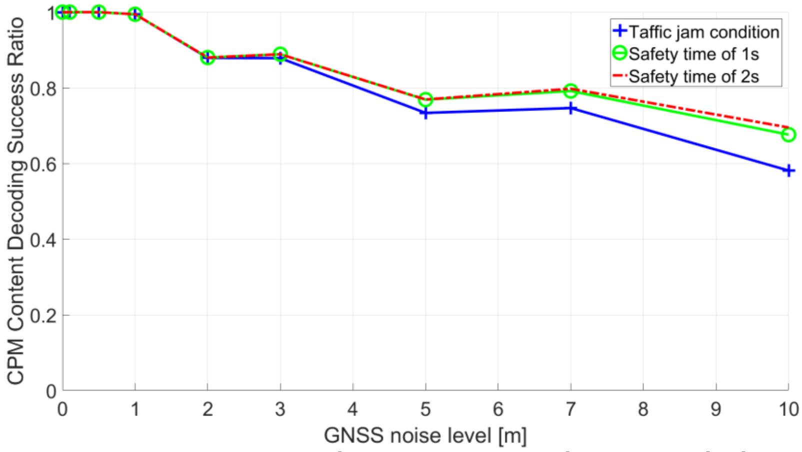

Figure 12: CPM Content Decoding Success Ratio versus the GNSS Noise level

First, it can be noted that 100% of successful message decoding can be achieved while GNSS noise level remains below 1m. Then, the performance are degraded. In addition, a small impact is noticed regarding the requirements along the longitudinal direction when the GNSS noise level increases. However, the distance requirement in the lateral direction has a significant impact has it is the smallest acceptable deviation and the positioning in this direction is less precise, as shown in Figure 11.
To summarize, by using the local perception in the CPM content, cooperative vehicles can be assisted even when the GNSS performance are degraded. However, when the noise level of GNSS is very high, the capacity of the receiver to successfully decode the received CPM is reduced.

4.3. Case 2: Benefits of RSU assisted Augmented Perception

In this second case, the RSU is used with its own local perception system in order to monitor one particular road section. Here, we study more precisely the detection of the grey vehicle, i.e. the target vehicle, which is occluded for the ego-vehicle.
Figure 13 shows the local perception of the RSU when the three vehicles are located in its field of view. In the

simulation, it is assumed that the RSU is able to detect all the vehicles with sufficient precision. In addition, as the RSU is mounted high enough, so that it does not suffer from occlusion and a region of interest (ROI) can be specified along the monitored road section. The ROI is then used in the cooperative fusion to correctly map the detected vehicles with the received CAM even in case of GNSS imprecision.

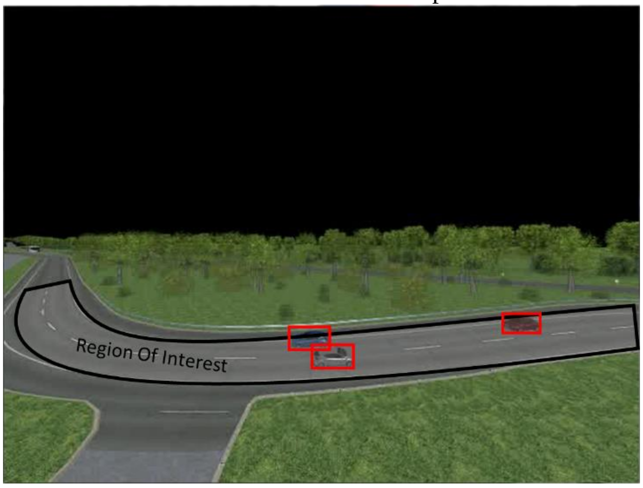

Figure 13: Vehicles detected by the RSU in a specific Region of Interest

In our simulation, the ego-vehicle is able to detect the target vehicle at a distance of 42.7m and the RSU can detect the target vehicle when the remaining travel distance between the two vehicles is 297.2m.
If the RSU can transmit a CPM and the ego-vehicle can decode such information, this could largely improve its situation awareness. However, because of the imprecise positioning of the ego-vehicle, one might not be certain of decoding the received CPM as already shown in Figure 12.
Considering that CPM could be used perfectly by the ego-vehicle when all the vehicles are detected together by the RSU, the remaining travel distance between the two vehicles is 69.8m. Such distance still improves the performance of the local perception alone.
As a perfect awareness cannot be ensured with the transmission of one message, using multiple consecutive CPMs can help, especially when the first detection occurs with a sufficient travel distance to remain. Figure 14 shows the situation awareness level as a function of the number of transmitted CPMs for different GNSS noise level. It is noted that a perfect awareness is directly achieved with accurate positioning and it necessitates at least six transmission in degraded conditions. In such a case, using an alternative solution to the common GNSS for estimating the relative location of the ego-vehicle with respect to the RSU, e.g. by exploiting the local perception of the RSU, could greatly improve the situation awareness level.

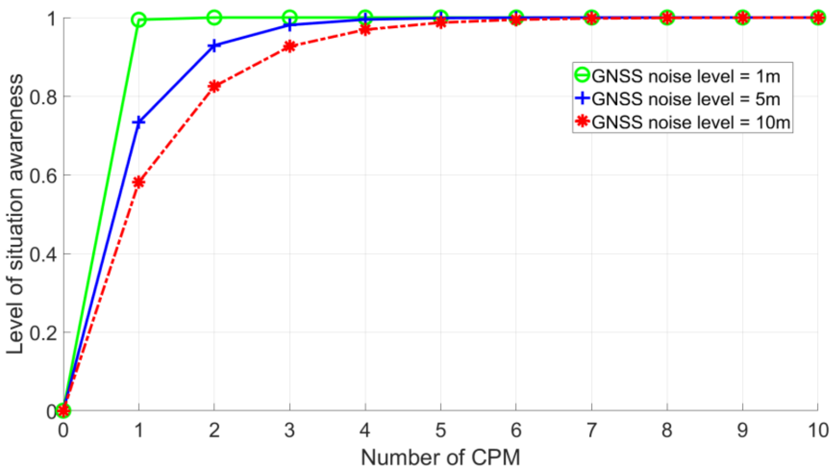

Figure 14: Situation awareness versus the number of transmitted CPM

To summarize, when installed in some critical areas, the RSU can enhance the situation awareness of an automated vehicle by extending its field of view especially in case of occlusion. By monitoring a complete area, it can assist vehicles that are situated in its own field of perception.

5. Conclusion

In this paper, we presented an augmented perception system that is to fuse information from local perception and V2X Communication. With a collective perception service, cooperative vehicles are now able to exchange information about their local environment. We have shown by means of simulation the potential of such collective perception to improve awareness and safety even when GNSS performance are degraded. Despite these promising results, further evaluations are necessary to validate this simulation study. Indeed, we plan to carry out testing with real world data which may suffer from other perturbations (imprecision of the local perception, loss of GNSS signal…). The development of the cooperative fusion algorithm is another challenge we are planning to address in the future. Indeed, the definition of a metric for association between internal traces maintained by the system and observations that are provided by many different sources is still an open subject. Finally, the use of such approach to address traffic safety in complex areas (intersection, lane merging, tolling zone) will be investigated.

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