Cooperative Safety Applications for C-ITS equipped and non-equipped vehicles supported by an extended Local Dynamic Map built on SAFE STRIP Technology

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Abstract—The work describes the contribution of SAFESTRIP EU project technology to the implementation of the Dynamic Local Map used by C-ITS safety applications. The road strips developed in SAFESTRIP are able to detect and estimate the longitudinal and lateral position of detected vehicle at lane level. This is exploited by many existing and new C-ITS applications. Here a Coorperative Intersection Support application is described and used as example to explain the concept and highlight the benefit put forward by the road strips informations.

Index Terms—Local Dynamic Map, C-ITS applications, Intersection Support, Co-driver, SAFESTRIP technology

I. INTRODUCTION

Vehicular wireless communication, also called V2X communication – Vehicle to Vehicle (V2V) and Vehicle to Infrastructure communication (V2I) – enables a variety of applications that can be classified into three categories: 1) Safety applications such as Intersection Support, Collision Avoidance etc, 2) Traffic efficiency applications such as green light timing optimisation and 3) Infotainment applications.

In particular, in the context of safety applications, V2X allows to inform road side users and infrastructure about each other’s position, dynamic and attributes. This is achieved with a regular a mutual exchange of information among road users (V2V) and between road users and road side infrastructure. The whole concept goes under the definition of cooperative awareness within road traffic, where the awareness is intended both for the road users (i.e. all kind of road vehicles like trucks, cars, motorcycles, bicycles or pedestrians) as well as for the roadside infrastructure equipment such as road signs, traffic lights or barriers and gates [1].

The cooperative awareness is meant not only for connected vehicles but also for vehicles equipped with sensors for building map of surrounding road, for self localisation and obstacle detection. V2X will extend their perception horizon, improving the accuracy of the perceived information (e.g. localisation) or even extending the domain of perceived information such as being able to “see” other vehicles or vulnerable road users in the vicinity hidden by building or other vehicles.

Connected vehicles are underpinned by ETSI EN ITS architecture [1] that supports the exchange of information with a number of layers and protocols that responds to specific and stringent requirements. The topological definition of lanes within an intersection, geometry, lanes for a road-segment, links between the segments and type of lanes and related restrictions are delivered by the MAP message [2]. SPaT (Signal Phase and Timing) message broadcasts the status of a traffic controller, with prediction of duration and phases and prioritisation [2].

The information to be exchanged for cooperative awareness is packed up in the periodically transmitted Cooperative Awareness Message (CAM) [3]. Information in term of type and position about a road hazard or an abnormal traffic conditions are packed and delivered via the Decentralized Environmental Notification Message (DENM). The construction of a DENM is triggered by an ITS-S application [4].

At present, the technology is still in the exploratory stage to evaluate the latency and reliability, especially with dense vehicle presence and the problems of traffic safety and information security brought about by V2X applications [5]. It is worth saying that two technologies are competing to support V2X systems. The first to emerge was WiFi-based 802.11p introduced to underpin traffic safety systems in the US (using DSRC) and Europe (under the auspices of the Intelligent Traffic Systems [ITS] initiative) [6]. More recently, with the introduction of wide band mobile phone connectivity, it has become clear that V2X systems using 3GPP-based LTE and 5G have a lot to offer, and proponents argue it is better placed than 802.11p to meet the communications needs of V2X systems.

SAFESTRIP European Project [7] proposes a technological solution that takes advantage of both communication
technologies. SAFESTRIP aims at embedding C-ITS applications into existing road infrastructure, including V2I and V2V communications and closing the gap providing C-ITS applications to non-equipped vehicles and potentially targeting also vulnerable road users. One of the core idea of the project is to design and develop road strips that will support intelligent transport systems (ITS), providing a large set of static passive info (i.e. speed limit, asphalt characteristics, road geometry and layout), active info (e.g. friction coefficient) and dynamic environmental/road parameters (e.g. temperature, humidity, ice, ambient light, water). Additionally, the strips can sense passing vehicles and supply their position and speed both via V2X for C-ITS equipped vehicles and for non-equipped vehicles via LTE communication channel using cloud services. Indeed one of the innovation of SAFESTRIP is its ability to extend the cooperative awareness concept also to vulnerable road users (such as pedestrians and cyclist, and Powered Two Wheelers (PTV)) since they could benefit of applications that deliver them warnings of imminent dangers without the need to buy expensive devices or sensors such as in [8]. For this reasons SAFESTRIP technology is expected to help boosting the penetration of C-ITS applications in the market.

This work focuses on the ability of SAFE STRIP technology to estimate accurate vehicle longitudinal and lateral position at lane level and with respect of relevant hot spot such as intersection, railway crossing, road works, etc, without using expensive GPS solutions or on board sensors. Collected data and estimation algorithm populate the Local Dynamic Map (LDM) provided by SAFESTRIP that gives a complete and rich picture of the environment around the user to support cooperative safety functions. The benefit and performance of SAFESTRIP technology will be tested on various existing Cooperative Intelligent Transportation Systems (C-ITS) and new ones developed specifically thanks to the innovation proposed. Among them, the Cooperative Intersection Support is here used as illustrative example of the benefits and the innovation put forward by the solution proposed. The paper is organised as follows. The next section II introduces the Local Dynamic Map. Section III explains how the proposed solution contributes to the existing technology and in particular the implementation of the LDM. Section IV describes an implementation of a new C-ITS application for intersection support that it is an improvement and extension to non-equipped vehicles of an already existing V2V application named e2Call [9], [10]. Finally, conclusions report a discussions on future works, still open challenges and limitations.

II. LOCAL DYNAMIC MAP

At present, there are two main efforts to provide to ITS applications a standardized interface for data collected and merged on map data: the Advanced Driver Assistance System Interface Application (ADASIS v3) protocol [11] and ETSI LDM API specifications [12].

The (ADASIS) protocol has been defined by key players in the automotive industry to define a standard interface to provide applications with (semi-)static digital map that anticipates the road ahead, in order to extend the ego vehicle’s horizon (i.e. Electronic Horizon). The map data sent to applications is filtered based on the Most Probable Path (MPP) concept which provides the set of roads in terms of sequence of segments with attributes that the ego vehicle is most likely to take in order to reach the destination [13].

The European Telecomation Standard Institute (ETSI) has proposed for standardization a Local Dynamic Map (LDM) that manages data coming from different sources and support the C-ITS applications [12] via mechanisms that grant safe and secure data access. The LDM stores data in four hierarchical layers related to frequency update of the information.

- **Type1**: permanent static data such as road topography, road attributes (e.g. speed limits and functional road class) and points of interests, usually provided by a map data supplier.
- **Type 2**: transient static data, obtained during operation, e.g. changed static speed limits, position of gantries and traffic signs.
- **Type 3**: transient dynamic data, e.g. weather situation, traffic information for example for road works, position, lane width, speed limits and incidents are provided.
- **Type 4**: highly dynamic data about ITS stations within the vicinilty such as vehicles and dynamic traffic signs, having mainly influence on traffic safety e.g. CAM, DEMN.

The LDM is located within an ITS station that is part of road side infrastructure (and differ from Vehicle ITS stations only in their connected sensors). LDM is built with data received from a range of different sources such as vehicles, infrastructure units, traffic centres and on-board sensors as shown in Figure 1 and is able to provide information on the surrounding traffic and RSU infrastructure to all applications that require it.

![Fig. 1. Figure shows the participants in the ITS communication architecture and a selection of ITS applications (from [12]).](image-url)
provide a consistent data of the surrounding situation of any road user that makes a request. LDM is not yet a standard and there are few examples of applications in the literature. In [14] a collision warning system is demonstrated in simulation generating vehicles in a Map via SUMO software.

In [13] the response time of the database as a function of the number of vehicles was tested by implementing a collision detection application that uses the LDM. Results show that LDM internal processing experienced a high load as the number of vehicles increased, which had an impact on the application.

In [15] paper a novel, LDM-based and CAM-supported mobility management solution designed for ITS/C-ITS environments was proposed to exploit the resources of heterogeneous radio access technologies of future vehicular networks.

In [16] a method to transmit LDM intersection information when a vehicle enters an intersection was proposed.

Finally in [17] an extension of the LDM approach with Semantic Web technologies and stream processing was presented. The work envision an architecture to define a “semantic” world model to show how these technologies can be applied in the context of the LDM and V2X integration.

III. INNOVATION OF SAFESTRIP FOR LDM

One of the main problems when using the LDM with safety application is the precise vehicle localization in the lane and with respect to hot spots such as intersection, railway crossing, etc. The problem is also relevant for connected vehicles that relies only on GPS signals to do the map matching and also automated vehicles especially when road markings are not available. Equipped vehicles commonly solve the problem fusing the information of LDM with on board sensors such as in [18] where the visual information are aligned with map data that is dynamically queried from the R-LDM by comparing virtual 3D views (so-called candidates), created from projected map data, with lane geometry data, extracted from the image of a front facing camera.

SAFESTRIP proposes to solve the problem integrating the sensing of vehicle passage directly in the road strip. The on road unit (ORU) embeds two switches lane wide that provide longitudinal and lateral position in the lane and direction of travel to a road side unit (RSB). The RSB locally matches, for an accurate localization, the IDs published by vehicles in the vicinity and the information of the detected vehicles. The information is then packed into a CAM message that is directly communicated to V2X equipped vehicles (see Figure 2) or sent as virtual CAM message via LTE to the cloud server (see Figure 3) where it is available to equipped (or in general all road users).

The advantage of the proposed solution is that every type of vehicle is detected independently from the availability of on board sensors. However, it is necessary to match the detected vehicle with a specific ID to be exploited by each vehicle for its own positioning. The matching could be done on board of equipped vehicles or locally by the RSB or even at server side but with greater inaccuracy due to latency problems. Additionally the proposed solution is able to sense pedestrian close to zebra crossing, vehicle driving in the wrong direction or provide road works geometry changes and restrictions among others. Therefore the LDM implemented in SAFESTRIP yields rich information at lane level that can be exploited by many C-ITS safety applications or used to design new ones. In the next section an example of Cooperative Intersection Support is illustrated that makes use of these information.

IV. C-ITS APPLICATION EXAMPLE: COOPERATIVE INTERSECTION SUPPORT

In [9] a new concept of intersection support application based on a biologically inspired artificial driver was proposed. The application relies on accurate GPS positioning (not always available) and digital maps. Additionally, one of the limiting
factor was the missing knowledge of the lane the vehicle was running in. This is a relevant piece of information especially for intersections to predict possible future paths of the vehicles and infer right of ways and intersections between potential paths. Here we will cover the gap exploiting the information provided by the strip along with the definition of intersection layout and geometry via MAP signal.

The scenario considered is illustrated in Figure 4, which consists in a T-intersection of two roads with one lane per direction. The Figure also shows the six allowed connections between incoming and outgoing lanes (coloured purple in Figure 4). We assumed that three vehicles (identified by ID1, ID2, ID3) are approaching the intersection and for each vehicle all the possible paths are considered. The scenario adopted is used to explain the concept and prove the system performance and the reader should not consider it as a limitation since the proposed method is scalable to more complex situations with more vehicles and with different geometric layout.

The application and the scenario was here simulated with custom developed code and latency and communication protocol are not included in the modelling.

For each vehicle all the possible paths (i.e. according driving rules) are considered, and they are labelled with $p$ (path) and numbered from 1 to 6. The yellow rectangle defined the conflict area $Q$. It is assumed that the area $Q$ cannot be occupied by two or more vehicles at the same time if they have intersecting trajectories. It is a quite conservative approach that can be made less inaccurate but paying for higher complexity in manoeuvre calculations. The dimensions of area $Q$ depend on the road geometry. Finally, it is worth noting that the longitudinal position from the intersection, the lane the vehicle is running in and the speed are assumed to be non with sufficient accuracy being provided by the strips. This is a fundamental point for the manoeuvre analysis describe in the next section.

![Fig. 4. Intersection scenario considered in this work. Figures shows also available manoeuvres for each vehicles based on intersection layout and lanes and area of conflict $Q$.](image)

### A. Algorithm of Cooperative Intersection Support

The main goal of the safety application proposed here is to assess the existence of safe manoeuvres among the possible ones rather than discovering the exact manoeuvre the driver intends to pursue. In fact it is assumed that the driver will naturally follow one of the available safe manoeuvres. If this is not the case, thanks to the method adopted, as the vehicle approaches the intersection according to an unsafe manoeuvre, the number of safe ones will shrink progressively and only the one that require an urgent intervention remain issuing a proper warning.

This is achieved adopting a control architecture with hierarchal layers: the top layer aims at solving the intersections in terms of available time to pass the area $Q$ for each vehicle, and the second generates human like longitudinal behaviour compatible with the time slots and the type of manoeuvre.

The layered control architecture is inspired by recent studies about principles of brain cognition to model the human decision making in the manoeuvre selection [19]. The control architecture is underpinned by the longitudinal motion primitives, which are atomic longitudinal human-like manoeuvres. The motion primitives are parameterized solutions of optimal control problems that minimize a cost function related to jerk and time and are referred as “human like” since they resemble longitudinal manoeuvres of human drivers. The driver selects one manoeuvre among all possible ones by means of the action selection process, and exploits the same mechanism to infer the manoeuvres followed by other road users (named mirroring approach).

According to the above architecture with action priming we refer to the computation of the sets of possible longitudinal manoeuvres to approach the intersection. Here we consider two types of manoeuvres: a) the stop manoeuvres and c) the pass manoeuvres.

The set of generated feasible manoeuvres must comply with the time slots available for each vehicle to engage the intersection. The set of the stop manoeuvres are those that have final position shorter than $s_f$ (i.e. vehicle distance from intersection). The set of the pass manoeuvres are represented by all the primitives with final time in the time slots, i.e. $T \in \mathcal{T}$ where $\mathcal{T}$ is the set of the time slots and it is a union of compact subsets thus the manoeuvres to compute are the extremal ones, two for each compact set.

$$M_{\text{stop}} = \text{stop}(a, v, s_f > s_f 0)$$  \hspace{1cm} (1)

$$M_{\text{pass}} = \text{stop}(a, v, T \in \mathcal{T})$$  \hspace{1cm} (2)

The action priming phase also generates safe manoeuvres since the construction of the time slots does not allow conflicts. The manoeuvres are then rated based in a metric space that is the construction of the time slots does not allow conflicts. The manoeuvres are then rated based in a metric space that is the intersection layout.

$J(t)$ is the derivative of the longitudinal acceleration its initial value quantifies how much the driver has to change the accelerations to perform the manoeuvre he/she has in mind. It is an instantaneous control effort required to start a manoeuvre. It is interesting
to mention that thresholds can be set to the level of jerk $J(t)$ to define the probability of acting, since the probability distribution of longitudinal instantaneous jerk is evaluated experimentally. The set $F$ of initial jerks spanned by the calculated manoeuvres is used to issue a warning if no action is available in the feasible action space $F \in [-J_{th}, J_{th}]$. More than one thresholds can be defined to issues warning at higher priority. Figure 6 shows an example of generated pass and stop manoeuvres and corresponding jerk set with thresholds.

The approach so far described is based on the availability of time slots. Time slots are derived from the scenario evaluation and this phase represents one of the novelty proposed here compared to approach in [9]. In this phase mirroring of other vehicles consists in the estimation of the time the other vehicles may occupy the conflict area of the intersection. The estimation of the time slot is performed taking into account the feasible paths of the incoming vehicles, the effective conflicts between paths and the right of way order in the intersection. The computation is performed applying the action priming approach described above given the vehicles initial conditions and computing all the manoeuvres assuming: 1) the intersection can be crossed with a maximum velocity $v_{max}$, 2) the paths associated to the same vehicle can be considered coincident out of the conflict area $Q$ and 3) the lanes can be approximated as sequences of clothoids and the path planning performed by the driver can be approximated as well as a sequence of clothoids.

The computation of the time slots is performed in several steps here described by points:

- First, the possible intersections of all the trajectories are calculated.
- The order of passing for each vehicle is based on the right of way and the “priority to the right” rule, and the yield road signal. Conflicts are represented by the right of way matrix ($R_w$). It is a square matrix, where the columns and the rows represent the possible paths (and then virtual vehicles). The matrix is antisymmetric, since for each conflict only one trajectory can have the right of way on the other. Note that the right of way matrix can be computed using a rule or provided by the infrastructure with the roads geometries.

$$R_w(i, j) = \begin{cases} 0 & \text{no intersection} \\ 1 & \text{path } j \text{ has right of way over path } i \\ -1 & \text{path } i \text{ has right of way over path } j \end{cases}$$

- The right of way matrix is used to inhibit the time slots of each vehicle cutting them with the ones of possible vehicles with higher priority. The inhibition of the time slots is performed in a specific order such that for each path the time slots with higher priority is available. Defined with $\sigma$ a vector of elements indicating the order of computation for the paths $p_j$, $\sigma(j)$ is the reordered sequence of precedents of paths.
- The condition above is equivalent to reorder the column of the matrix $R_w$ in the order $\sigma$ to obtain the resulting Matrix $R_w(i, \sigma(j))$ having $-1$ only in the upper triangular part of the matrix. If the execution of the time slots computation is performed according to the order $\sigma$, time slots of higher priority vehicle are available for cutting time slots of lower priority vehicles.
- Then the maximum and minimum velocity are computed in order to generate feasible initial time slots. The maximum velocity correspond to feasible manoeuvres including third power rule for lateral acceleration in curved one. (Note that it can be higher than the legal limit of the road).
- At this point time slots can be initialized and then cut for all the virtual vehicles according to order $\sigma$.
- The time slots computed, are used for the computation of the manoeuvres and the warnings.

The algorithm is described in IV-A. Figure 5 schematically represents the algorithm so far described, with the available paths, the time slots and the generation of manoeuvres given the time slots.

Algorithm 1 Cooperative Intersection Support Algorithm for vehicle $j$

for all $j$ do
  Get all vehicles states $s_j, v_j, a_j$
  Instantiate possible path $p_j$ and assign states
  Calculate possible path $p_j$ conflicts
end for

for all $\sigma_j$ do
  Initialize time slots $T_{\sigma_j}$ using $v_{min}$ and $v_{max}$
  Calculate $T_{\sigma_j}^{cross}$
  for all $i^*\sigma_j$ do
    Get $T_{i^*}(\sigma_j)$
    Add $T_{\sigma_j}^{cross}$ on $T_{i^*}(\sigma_j)$ before
    Add $T_{\sigma_j}^{cross}$ on $T_{i^*}(\sigma_j)$ after
    Cut $T_{\sigma_j}$ with augmented $T_{i^*}(\sigma_j)$
  end for
end for

Compute manoeuvres and warning using $T_{\sigma_j}$ as time slots.

B. Results

In Figure 6, is illustrated an example of the longitudinal manoeuvre generation. According to the time slots available, the application generates a set of manoeuvres to pass the intersection. Manoeuvres are represented as velocity versus the distance from the target entrance of the intersection (see Figure 4) The distance is computed on the lane reference line (curvilinear coordinate). A set of manoeuvres to stop is generated as well. On the right of the Figure it is represented the sets of the initial longitudinal jerk of the manoeuvres. Higher initial jerks corresponds to higher efforts on the pedal required by to the driver to perform the manoeuvre. This information can be used from the application to generate warnings in case the effort needed will exceed some threshold.

On the example of the figure the warning can be issued if no
Fig. 5. Abstraction of intersection and working principle of Cooperative Intersection Support Application. Upper figure shows exemplification of time slots associated to each vehicle’s manoeuvres. Bottom figures shows manoeuvres generated for each vehicle compliant with time slots.
safe manoeuvre has initial jerk in the range \([-1, 1]\), and a more severe warning can be issued if the no jerk is in the range \([2, -2]\). According to the example of Figure 6 there are some pass manoeuvres that have initial jerk in the in the range \([-1, 1]\), therefore the driver has the chance to safely and comfortably pass the intersection. On the contrary the stop manoeuvres are all of the range \([-1, 1]\), which means that this family of manoeuvres are less safe and comfortable than passing.

Figure 7 represents the sets of pass manoeuvres of each vehicle generated by the application. The manoeuvres are represented as the distance from the entrance in the intersection versus the time. Thick blue lines represent manoeuvres associated to bounds of gap times, and the coloured areas shows all the manoeuvres allowed in between. The application generates only pass manoeuvres that accounts for the timing of the other vehicles and the right of way order. According to the results, Vehicle 1 and vehicle 2 can pass simultaneously (i.e. no intersection between the two family of manoeuvres) since their trajectory does not have intersections. The vehicle 3 has to wait for the others to pass. This is shown from the time at the end of the sets of manoeuvres, which are overlapped for the first two vehicles and for the third is not. The relatively large gap between the first two and the third time sets is due to the time needed to clear the intersection which is taken into account.

V. CONCLUSIONS AND FURTHER WORK

This work has presented the contribution of SAFESTRIP technology to improve the performance of existing C-ITS applications. Specifically it has been described how the road strip designed in the project provide accurate localisation at lane level of both equipped and not-equipped vehicles. To explain the proposed approach the Cooperative Intersection application has been described showing and discussing the performance when three vehicles are approaching a T-shaped intersection.

The results have been obtained in simulations and effect of the latency in the communication, accuracy in the vehicle localisation and number of vehicles have not been investigated yet. These are the next steps for the technology evaluation planned both with extensive and more accurate simulations using also traffic generator software and experimental testing including user trials.

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