VAIMA: a V2V based Intersection Traffic Management Algorithm

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***Abstract*—The evolution of the standard 802.11p and the appearance of connected vehicles and vehicular communications have arisen as the solutions in the vehicular safety and traffic management. The correct management of intersections is one of the key issues to assure a fluid traffic flow and to avoid vehicles collisions. Cooperative Awareness Systems based on vehicular communications can address the management of intersections. This work proposes a management algorithm, VAIMA algorithm, which considers Vehicle-To-Vehicle (V2V) communications and information provided by each vehicle about their intention. VAIMA is compared with a state-of-the-art mechanism, VVTLA [1], showing performance gains between 11% and 26% in terms of waiting time reduction along with a better fairness behavior.**

I. Introduction

A. Introduction to Vehicular Communications

In the last few years, the appearance of the vehicular communications has arisen as the new paradigm in automotive sectors. In that sense, vehicular communications can be split into two types, Vehicle To Vehicle (V2V) and Vehicle To Infrastructure (V2I) communications. These technologies adopt IEEE 802.11p and ETSI ES 202 663 protocols to provide radio communications [2], [3]. Besides, V2V and V2I are based on the interchange of vehicle information considering Cooperative Awareness messages [4].

Most important V2V and V2I-based applications are those related to security such as cooperative awareness and collision avoidance applications. For instance, manoeuvres as cross an intersection can be controlled with these applications. The motivation of this comes from the fact that no driver interaction is needed. In such a context, the appearance of the autonomous car has increased even more the importance of V2V and V2I cooperative awareness and collision avoidance applications to take control of vehicles in these situations.

B. Related Work

In what follows, we review the existing works on the adoption of V2V and V2I communications in traffic management algorithms. One approach is the consideration of V2I communications as in [5]. Here the authors propose the adoption of V2I-based traffic management system to coordinate traffic in a limited urban area. Results show that this system offers a packet-collision probability around 0.2% and a packet-drop probability lower than 0.001%. Another approach is the adoption of V2V and V2I together as it is shown in [6]. A new simulator and algorithm are proposed. The former considers a scenario where vehicles are continuously communicating with a Road Side Unit (RSU). The later is based on V2V and V2I and also space allocation of vehicles. Applying this, authors show that the number of vehicles crossing the intersection of the scenario can be increased a 50%. Other proposals are based on V2V communications uniquely. For instance, in [7] the authors consider a V2V-based algorithm applied to roundabouts. In such a case, the purpose of the algorithm is to decrease the time of vehicles crossing the roundabout. Results show that vehicles equipped with V2V technologies are able to decrease the time around a 45% approximately. This work proposes an improvement of a V2V-based Virtual Traffic Light (VVTLA) algorithm which can be seen in [1]. Here, the algorithm manages the priorities into an intersection adopting vehicles' information. Nonetheless it does not take into account the intention of each vehicle. Thus, the waiting time is the same for all vehicles independently of the vehicle's intention.

C. Objectives

This work proposes a V2V-based Autonomous Intersection Management Algorithm (VAIMA) which considers the intention of the vehicle to decrease the waiting time at intersections. More specifically, this algorithm departs from the mechanism presented in [1] and, as we will show later, the waiting time can be significantly reduced thanks to the intention information. To show that, Time to Cross (T2C) tests are simulated by means of a realistic simulation environment (VEINS framework [8]).

In addition, performance of algorithms are also measured in terms of communications metrics such as Channel Busy Ratio (CBR) and Packet Delivery Ratio (PDR) to validate the communication robustness of proposed mechanism. Since there exist some situations where mechanisms' performance depends on traffic conditions, work in current development is addressing the adoption of machine learning techniques to select most suitable algorithm (VAIMA or VVTLA) in accordance with traffic scenario. Initial results are also presented in this work.

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II. Scenario Description

The considered scenario consists of a non-regulated urban intersection where a Collision Avoidance application is considered. In that sense, vehicles crossing the intersection will be handled through the V2V-based algorithms VVTLA and VAIMA. In terms of physical characteristics, considered intersection consists of four 500 *m* long roads. Each road presents two lanes, one in each direction. The width of a line is 3.2 *m* with a space of 10 *cm* between them.

Concerning vehicles, each one broadcasts its information in the ITS-G5 Control Channel (CCH) using the considered parameters by [3]: a bandwidth of 10 *MHz*, a data rate of 6 *Mbps*, a transmission power of 23 *dBm* and a beaconing periodicity of 100 *ms*. The information which is exchanged among vehicles corresponds to the one specified in ETSI protocol [4]. The medium access protocol corresponds to CSMA/CA protocol using a Contention Window (CW), which is the channel access mode considered in IEEE 802.11p standard [2]. Concerning the radio channel, we consider a free-space model due to it is shown as a valid option in the proposed urban scenario [9].

III. The V2V-based Autonomous Intersection Management Algorithm

Our algorithm is an improved version of the intersection management algorithm proposed in [1]. In this case, VVTLA algorithm is based on the exploitation of V2V communications to generate a Virtual Traffic Light at the intersection governed by itself. The main point of the algorithm is the adoption of the vehicles' broadcasted information and unicast messages to give priority to others (See [1] for more details).

Therefore, our algorithm (VAIMA) in this work has several changes from the VVTLA Algorithm. More specifically, the intention of the vehicle is considered here (not adopted in the VVTLA). The aim of this change is to generate a more fluid traffic. A simple example consists of a vehicle which is going from north to west and another which is going from south to east. No action has to be performed between these vehicles due to the fact that they do not incur into a conflict when the VAIMA Algorithm is considered. An increment of the type of messages is mandatory due to be taking into account the vehicles' intention.

In the case of the VVTLA these vehicles have to wait until they get the permission to cross. Another change consists in the fact that the figures of followers (vehicles crossing just behind the Road Leader) which are considered in the VVTLA is not taken into account in the VAIMA Algorithm. In this case, the process performed with the VAIMA Algorithm only takes into account the involved vehicles in the correspondent run of the algorithm. Notice that the involved vehicles in each run of the algorithm depends on the number of roads with vehicles. For instance, if only 3 of the 4 roads have vehicles, 3 vehicles, one per road, will be involved at each run of the algorithm.

Focusing on the VAIMA Algorithm, it is based on the use of unicast and broadcast messages. The broadcasted messages are adopted to send information about vehicles while the unicast ones are considered to give permission to cross the intersection. Also they are used to give acknowledge that a request has been answered. Notice that all the messages follow the ETSI TS 102 637-2 protocol which is based on ITS-G5 standard [4]. Accordingly to this, the considered messages are:

- Broadcast Messages:
  - CAM (Cooperative Awareness Message): Sent periodically (10 *Hz*), it contains the main information of the vehicle (Id, Speed or Velocity, Position)
  - CAM_status message: Extension of the CAM message, it is sent periodically instead of the CAM message. It contains the same information as the CAM message with the addition of the exterior signals of the vehicle (Blinkers, Brake and Front Lights)
  - HDOV (Handover Message): Sent when all the involved vehicles have passed the intersection, to let others execute the algorithm
  - CR (Cross Message): Sent by each vehicle when the decision if it will cause a collision is performed. It contains if the vehicle incurs into a conflict or not.
- Unicast Messages:
  - AllowPass: Give permission to a vehicle
  - Acknowledge: Ask and return any request or when the CR message is received
  - AskPermission: Request permission to cross the intersection (if the vehicle has detected it would cause a collision)

Regarding the functionality of the VAIMA algorithm, it is divided into 3 main points. First, vehicles are continuously broadcasting their information through the adoption of CAM and CAM_status messages. Vehicle's intention information is communicated through the exterior lights of the vehicle, i.e, considering CAM_status message (not considered in VVTLA). Information is gathered by vehicles until they detect that the distance to the center of the intersection is lower than the threshold distance. Hence, the first vehicle of each road will start to process the gathered information to determine if the surrounding vehicles will incur into a conflict with it. Vehicles behind will execute the algorithms when an HDOV is received. In such a case, two solutions can be determined, (i) it incurs into a conflict with other involved vehicles in the algorithm or (ii) it does not generate any conflict. Depending on the determined solution, the algorithm proceeds in different manners as it can be observed in Fig. 1.

1) If there is no conflict:
   a) Vehicle will cross the intersection sending an AllowPass message to the next Road Leader.
   b) In case there are no more Road Leaders, a HDOV Message is sent.
2) If a collision is detected:
   a) In case the vehicle is the first Road Leader, an AskPermission message is sent. When AskPermission is answered with an Acknowledge, the vehicle

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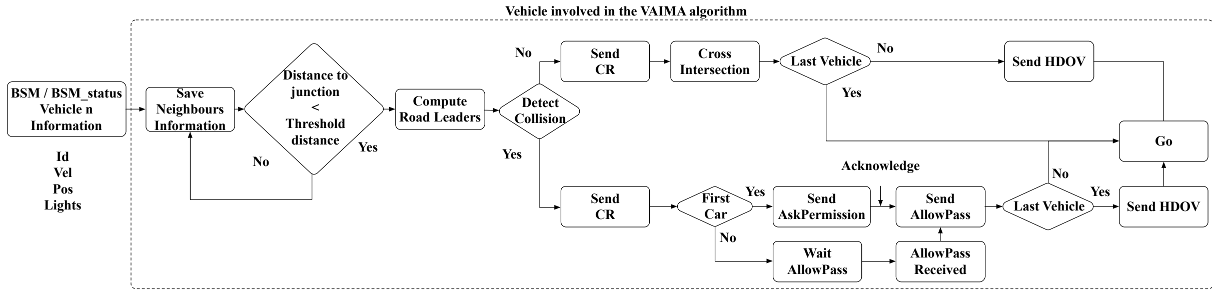

Fig. 1. Block Diagram of the algorithm process

will cross the intersection and therefore send an AllowPass to the next Road Leader. If there are not more Road Leaders it will send an HDOV.

b) In case the vehicle is not the first Road Leader, it has to wait for an AllowPass message from other vehicle to cross.

IV. Results

The behavior of VAIMA and VVTLA mechanisms are evaluated by means of a realistic simulation environment under the framework of VEINS (SUMO and Omnet++). Vehicles are generated considering different aspects such as the initial speed, depart lane and route to follow. Vehicle speed is random distributed following a normal distribution with mean 10 *m/s* and variance 0.01 $(m/s)^2$. The periodicity of vehicles entering into the scenario consists of 1 vehicle per road and second. In terms of the routes that vehicles can perform, they can go straight, turn right or turn left when they arrive at the intersection center. Turn arounds are forbidden in all the scenario. All vehicles move following the SUMO Krauss driver model [10]. In addition, separation between vehicles in the same lane is no longer than 2 *m*. Random generated traffic follows random routes. For the purpose of this work, seven different traffic conditions have been created to emulate real traffic:

- All roads are collapsed (AllCollapsed): All the roads present high density of vehicles, 20 vehicles in the scenario are considered
- Three roads collapsed (ThreeCollapsed): Three of the four roads present high density of vehicles while the remaining one presents low density, 32 vehicles in the scenario are considered
- Two roads are collapsed (TwoCollapsed): Half of the roads has high density while the other half presents low density, 24 vehicles in the scenario are considered
- Two and a Half roads collapsed (TwoandHalfCollapsed): Half of the roads has high density of vehicles. The other half presents a medium density of vehicles, these lanes are not fully collapsed but the traffic is dense. 32 vehicles in the scenario are considered
- One road is collapsed (OneCollapsed): One of the road presents high density of vehicles while the remaining ones show low density. 16 vehicles in the scenario are considered
- One and a Half of the roads are collapsed (OneandHalf-Collapsed): One of the roads presents high density, two of the remaining present medium density and the last one presents low density of vehicles. 24 vehicles in the scenario are considered
- One and a Third of the roads are collapsed (OneandThird-Collapsed): One of the roads presents high density, two of the remaining present low density, the last one presents medium density. 20 vehicles considered in the scenario

Notice that at each situation, different numbers of vehicles are used to differentiate different densities.

VVTLA and VAIMA algorithms are compared considering three type of metrics:

- PDR: The ratio of packets received per packets sent
- CBR: The percentage of time that a vehicle finds the channel busy when it wants to transmit in 1 *s*
- T2C: Amount of time to cross the intersection for each vehicle, i.e, the amount of time between the instant when vehicle enters at the scenario and the instant when it crosses the intersection.

Results show a similar CBR for both algorithms. Although the VAIMA algorithm requires more information exchange between vehicles, the impact is negligible. For instance, considering 60 vehicles in the scenario it is observed that CBR grows from 4.7 % in the case of VVTLA algorithm to 5.2 % in the case of the VAIMA. In terms of PDR, similar results are observed. Therefore, VAIMA shows the same communication robustness as VVTLA. Concerning time performance, notice that it is based on two parameters (see Table I): mean time and standard deviation of time. Mean time shows which solution performs better in terms of T2C but, fairness among vehicles is not guaranteed. For this reason, we also consider standard deviation to analyze the differences of T2C of the different vehicles in the system. Therefore, we are dealing with a multi-objective problem to select the best algorithm. Since there are situations where it is not clear what technique offers the best result (mean time could be lower but standard deviation could present a higher value (See Table I)), we consider the criterion presented at [11]. More specifically, we select the criterion named as the compromise solution, which is defined as the solution that represents a fair compromise among all objectives (mean time and standard deviation of time in this case). This solution is the point closest to the Utopia Solution, where Utopia Solution is the ideal (unattainable) solution with

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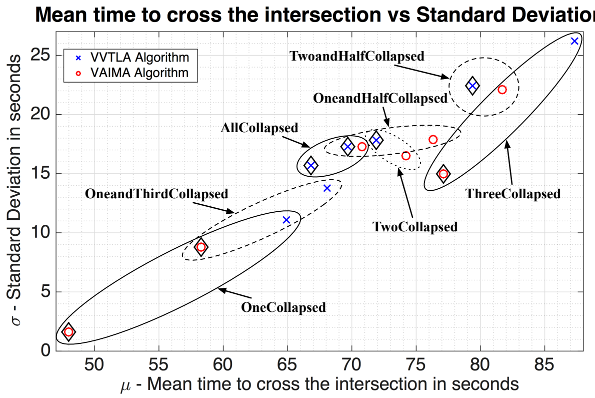

Fig. 2. Normalized Normal Constraint (NNC) method applied to each traffic situation - Best algorithm is marked with a ◇

TABLE I
MEAN TIME AND STANDARD DEVIATION TIME

Scenario	VVTLA Algorithm		VAIMA Algorithm	
	μ [s]	σ [s]	μ [s]	σ [s]
AllCollapsed	**66.8**	**15.7**	70.8	17.3
3Collapsed	87.3	26.2	**77.1**	**15.0**
2Collapsed	**71.9**	**17.8**	74.2	16.5
2andHalfCollapsed	**79.4**	**22.4**	81.7	22.1
OneCollapsed	64.9	11.1	**48.0**	**1.6**
OneandHalfCollapsed	**69.7**	**17.3**	76.3	17.9
OneandThirdCollapsed	68.1	13.8	**58.3**	**8.8**

both mean time and standard deviation equal to 0. In summary, for each traffic situation the best algorithm, which consist in the algorithm that offers the point (mean time, standard deviation of time) closest to the point (0,0), is selected. As observed in Fig. 2, algorithms' performance depends on traffic conditions. Bold results in Table I corresponds to the best algorithm. To understand the differences between algorithms, it is worth noting that VVTLA's behaviour can be modelled as a traffic light whereas VAIMA's can be modelled as a roundabout. Consequently, fully random and high-dense traffic will be better handled by VVTLA whilst pseudo-random traffic will be better administered by VAIMA as shown in the Table I. This behaviour motivates the introduction of neural network techniques to determine the algorithm to adopt as a function of the traffic pattern. However, it is worth noting that the proposed VAIMA algorithm is able to improve T2C results around 11%-26%. Concerning fairness between vehicles, VAIMA is able to provide the best results thanks to its "roundabout" behavior.

V. FUTURE WORK

As observed in the previous section, VAIMA is able to provide significant gains but VVTLA is a better option in some traffic situations. For this reason, work in development address a RSU-based system in charge of selecting the best Intersection Traffic Management algorithm according to traffic conditions. In other words, a hybrid Intersection Management algorithm will be proposed where VAIMA or VVTLA will be dynamically selected based on the traffic scenario. To do so, the implementation of an intersection traffic classifier is being developed. More specifically, a neural network (NN) has been considered to classify the traffic intersection situations by means of information broadcasted by vehicles (their position and speed). Initial results show a 91.6% accuracy for the classification of traffic conditions. Further work will be focused on showing T2C results of the proposed hybrid mechanism in a wider set of realistic traffic scenarios.

VI. CONCLUSION

In this work, an enhancement of an intersection management algorithm has been proposed. In this enhancement, the intention of the vehicle has been taking into account. To achieve this, V2V communications have been considered. The aim of the algorithm improvement is to obtain a more fluid traffic and decrease the time of vehicles to cross the intersection. To do so, VVTLA and VAIMA mechanisms have been validated in a realistic simulation environment by considering seven different situations of traffic density. Results have shown that VAIMA significantly improves VVTLA in some scenarios but performance strongly depends on traffic scenario. For this reason, our future work considers a hybrid intersection management mechanism based on selecting the most appropriate solution based on traffic conditions. To do so, a neural network-based classifier has been developed showing a high accuracy.

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