Impact of Awareness Control on V2V-based Overtaking Application in Autonomous Driving

Sandy Bolufé, *Student Member, IEEE*, Cesar A. Azurdia-Meza, *Member, IEEE*, Sandra Céspedes, *Senior Member, IEEE*, and Samuel Montejo-Sánchez, *Member, IEEE*

***Abstract*—In autonomous driving, IEEE 802.11p-based vehicle-to-vehicle (V2V) communication is considered for overcoming the intrinsic limitations of sensors and supporting safety applications. In this letter, we evaluate the effectiveness of relevant awareness control approaches, such as ETSI DMG, IVTRC, and POSACC, to support the V2V-based overtaking application in autonomous driving. For this, we assess the incident detection capability of the overtaking application when it is running with messages gathered from these approaches, considering packet losses due to channel fading. Simulations show that POSACC is more effective than the remaining approaches for detecting unsafe overtaking maneuvers in different operating conditions.**

***Index Terms*—Autonomous driving, awareness control, CAMs, incident detection, overtaking application, V2V.**

I. Introduction

Autonomous driving is expected to reduce the number of traffic accidents caused by human errors [1]. Currently, autonomous vehicles (AVs) can perform safety operations such as forward collision avoidance, traffic sign detection, and lane departure warning [2]. However, performing other safety operations such as overtaking, which requires to determine whether a gap is safe for the maneuver considering the trajectory of the AVs in the vicinity, is still challenging. This is because sensors (e.g., radars, lasers, and cameras) are incapable of determining the location of oncoming traffic successfully. Further, sensors are unable of detecting potential threats a few blocks away due to their limited view [3]. Despite sensors' limitations, they still are the cornerstone of different proposals to support overtaking applications (e.g., in [4], automotive radars are used for video rate control to improve the visual quality of drivers). A viable solution for overcoming the limitations of sensors is to enable wireless links between the AVs.

By using vehicle-to-vehicle (V2V) communication based on IEEE 802.11p [5], the motion parameters of the AV (e.g., its position, speed, and acceleration) can be regularly transmitted in the form of cooperative awareness messages (CAMs) [6]. CAMs are essential for tracking highly dynamic neighboring vehicles and supporting high-level safety applications. Standard CAMs are broadcasted at a fixed message transmission frequency ranging from 1 to 10 Hz [6]. However, the varying conditions of the wireless channel and vehicular traffic impose the necessity of considering congestion and awareness control approaches [6]-[10]. For instance, the European Telecommunication Standards Institute (ETSI) defined the dynamic message generation (DMG) approach in [6], which is a kinematic-based mechanism that controls CAMs triggering. ETSI also defined a set of decentralized congestion control (DCC) mechanisms [7] that adapt the message transmission parameters to keep the channel load below a target threshold. Unlike ETSI proposals, the Inter-Vehicle Transmit Rate Control (IVTRC) approach set by Huang et al. in [8] and its variant based on tracking error threshold (IVTRC-Th) [9], adapt the message transmission rate in a probabilistic manner based on positioning tracking error. Bolufé et al. [10] introduced a POSition-ACCuracy (POSACC) based awareness control approach where message transmission parameters are controlled depending on vehicle dynamics and surrounding road traffic to limit the position error and improve communication reliability.

Although numerous adaptive approaches with diverse goals have been proposed in the literature, to date little attention has been paid on whether the proposed approaches are adequate or not to support safety applications. In particular, safety-critical applications aimed at detecting new neighboring vehicles with sufficient time to react and avoid a traffic accident, such as the V2V-based overtaking application. To our best knowledge, no literature has put to work together the overtaking application and awareness control approaches so far.

In this letter, we evaluate the effectiveness of relevant awareness control approaches, such as ETSI DMG [6], IVTRC [8], IVTRC-Th [9], and POSACC [10], to support the V2V-based overtaking application in autonomous driving. In particular, we assess the incident detection capability of the overtaking application when it is running with CAMs gathered from these approaches. The main contribution of this work is to evaluate the impact of the addressed awareness control approaches on predicting unsafe overtaking maneuvers, taking into account motion state sensors' errors and packet losses due to channel fading.

II. System Model

We consider three AVs, A (AV that intends to overtake), C (AV that will eventually be overtaken by A), and B (AV that oncoming to A and C from the opposite lane), as illustrated in Fig. 1. Then, the overtaking application running on A should monitor the movement status of C, and at the same time, use the received CAMs for tracking the position of B in order to evaluate the suitability of the overtaking maneuver and avoid unsafe executions.

A. Overtaking Time Estimation

Assume that AVs A and C move at the same speed ($v_A = v_C$) at the beginning of the overtaking maneuver, and A starts

This work has been partially supported in Chile by CONICYT Doctoral Grant No. 21171722; Vicerrectoría de Investigación y Desarrollo (VID) de la Universidad de Chile Project ENL 01/20; ANID - Basal Project FB0008; FONDECYT Iniciación No. 11200659; and FONDEQUIP EQM180180.

S. Bolufé, C. A. Azurdia-Meza, and S. Céspedes are with the Department of Electrical Engineering, Universidad de Chile (UChile), Santiago 8370451, Chile (e-mail: {sbolufe, cazurdia, scespedes}@ing.uchile.cl).

S. Montejo-Sánchez is with Programa Institucional de Fomento a la I+D+i, Universidad Tecnológica Metropolitana (UTEM), Santiago 8940577, Chile (e-mail: smontejo@utem.cl).

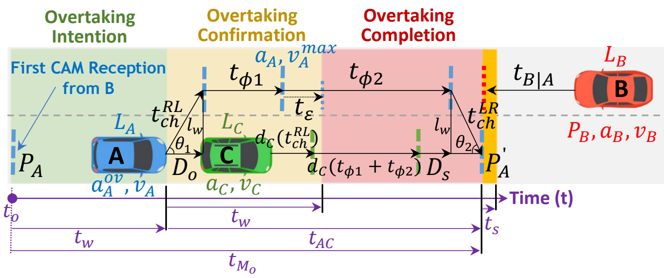

Fig. 1. Overtaking scenario. AV A changes the lane from its right to left to overtake C. To ensure the reliability of the maneuver, we assume a time window (t_w) for the overtaking intention equal to the overtaking confirmation.

accelerating with a_A^{ov} to change the lane and overtake C, as shown in Fig. 1. The initial overtaking heading (θ_1) of A can be computed as, $\theta_1 = \tan^{-1}\left(\frac{l_w}{D_o}\right)$ [11], where l_w is the lane width and D_o is the initial distance between A and C (regarding the front side of A and rear side of C). The distance travelled by A during the lane change maneuver (from its right to left) is, $d_A(t_{ch}^{RL}) = v_A \cdot t_{ch}^{RL} + \frac{a_A^{ov} \cdot (t_{ch}^{RL})^2}{2}$, where t_{ch}^{RL} represents the time needed by A to change the lane (from its right to left), which can be computed as,

$$t_{ch}^{RL} = \frac{-v_A + \left(v_A^2 + \frac{2a_A^{ov} l_w}{\sin\theta_1}\right)^{\frac{1}{2}}}{a_A^{ov}}, \quad a_A^{ov} > 0. \tag{1}$$

We assume that A accelerates with a_A^{ov} until it reaches the maximum allowed overtaking velocity, $v_A^{\max}$. The time $(t_{\phi 1})$ needed by A to reach $v_A^{\max}$ once the first lane change has been done is,

$$t_{\phi 1} = \frac{v_A^{\max} - \left(v_A + a_A^{ov} \cdot t_{ch}^{RL}\right)}{a_A^{ov}}. \tag{2}$$

Then, A completes the overtaking maneuver at uniform motion. In order to carry out the overtaking in a reasonable time and represent a more realistic overtaking situation, we also assume that: i) C moves with uniform motion during the entire overtaking maneuver and ii) sensor's noisy measurements over the real acceleration of A and C are considered, as specified in [12]. Hence, the estimated acceleration of A and C could be non zero even in uniform motion. Accordingly, a_A and a_C are the measured acceleration of A and C, respectively, in uniform motion, as shown in Fig. 1. Once $v_A^{\max}$ is reached, the time $(t_{\phi 2})$ needed by A to overtake C in a safety distance, D_s, can be derived from,

$$d_A(t_{\phi 1}) + d_A(t_{\phi 2}) = d_C(t_{ch}^{RL}) + d_C(t_{\phi 1} + t_{\phi 2}) + D_s + L_A + L_C, \tag{3}$$

where L_A and L_C are the length of A and C, respectively. So, $t_{\phi 2}$ can be estimated as,

$$t_{\phi 2} = \begin{cases} \dfrac{d_C(t_{\phi 1}) - d_A(t_{\phi 1}) + d_C(t_{ch}^{RL}) + D_s + L_A + L_C}{v_A^{\max} - v_C - a_C t_{\phi 1}}, & \text{if } a_A = a_C, \forall v_A^{\max} \,/\, \exists t_{\phi 2} > 0, \\[2ex] \dfrac{-(v_A^{\max} - v_C - a_C t_{\phi 1}) + \left[(v_A^{\max} - v_C - a_C t_{\phi 1})^2 + 2(a_A - a_C)\big(d_C(t_{\phi 1}) - d_A(t_{\phi 1}) + d_C(t_{ch}^{RL}) + D_s + L_A + L_C\big)\right]^{\frac{1}{2}}}{a_A - a_C}, & \text{if } a_A \neq a_C, \forall v_A^{\max} \,/\, \exists t_{\phi 2} > 0. \end{cases} \tag{4}$$

The time required by A to change the lane (from its left to right) depending on the final overtaking heading (θ_2) can be computed as,

$$t_{ch}^{LR} = \begin{cases} \dfrac{l_w}{v_A^{\max}\sin\theta_2}, & a_A = 0, \\[2ex] \dfrac{-v_A^{\max} + \left((v_A^{\max})^2 + \frac{2a_A l_w}{\sin\theta_2}\right)^{\frac{1}{2}}}{a_A}, & a_A \neq 0. \end{cases} \tag{5}$$

Finally, the total time required by A to overtake C is computed as,

$$t_{AC} = t_{ch}^{RL} + t_{\phi 1} + t_{\phi 2} + t_{ch}^{LR}. \tag{6}$$

B. Time Window

As shown in Fig. 1, we set the complexity of the overtaking maneuver into three different stages. 1) Overtaking Intention: it starts when AV A receives the first CAM from oncoming AV B, indicating that there is a sufficient gap to perform a safe overtaking maneuver. Here, A follows C with uniform motion maintaining controlled the distance D_o. If one or more CAMs are received into a time window confirming that the overtaking maneuver can be successfully performed, A goes forward to the second stage. 2) Overtaking Confirmation: A (into a time window) determines whether to continue or not the overtaking maneuver depending on previously received information and new CAMs arriving from B; and 3) Overtaking Completion: A completes the overtaking.

We set the same time window for stages 1 and 2. We define this time window as the time required by A to reach C during the overtaking (see Fig. 1). This is a suitable assumption since this time interval allows A to abort the maneuver without causing a dangerous situation regarding C. The time window can be computed as,

$$t_w = t_{ch}^{RL} + t_{\phi 1} + t_\varepsilon, \tag{7}$$

where t_ε is the time required by A to reach C once $v_A^{\max}$ is accomplished, as shown in Fig. 1. The time (t_ε) can be derived from,

$$d_A(t_{\phi 1}) + d_A(t_\varepsilon) = d_C(t_{ch}^{RL}) + d_C(t_{\phi 1} + t_\varepsilon). \tag{8}$$

By using kinematic equations in (8), t_ε (which is a small time interval) can be estimated as,

$$t_\varepsilon = \frac{v_C(t_{ch}^{RL} + t_{\phi 1}) - d_A(t_{\phi 1})}{v_A^{\max} - v_C}. \tag{9}$$

Note that: $\exists\, t_\varepsilon \ \forall\, v_A^{\max} \,/\, v_C(t_{ch}^{RL} + t_{\phi 1}) > d_A(t_{\phi 1})$.

C. Encounter Time Estimation

The AV A utilizes a kinematics-based trajectory prediction model and the received CAMs for tracking the new positions of B. Consider that P_A is the position of A when the first CAM from B is received, and $P_A^{'}$ is the position of A at the end of the overtaking maneuver, as shown in Fig. 1. On each received CAM, the position (P_B), speed (v_B), and acceleration (a_B) of B are used by A as input for the following prediction model equation,

$$\begin{bmatrix} P_B^k \\ v_B^k \end{bmatrix} = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} P_B^{k-1} \\ v_B^{k-1} \end{bmatrix} + \begin{bmatrix} \frac{\Delta t^2}{2} \\ \Delta t \end{bmatrix} a_B. \tag{10}$$

If past a Δt time step no CAM is received, A uses (10) and the previous information to predict the new position (P_B^k) and velocity (v_B^k) of B. In (10), k and $k-1$ are the current state and previous state, respectively.

Once the position of B has been updated, A can estimate the encounter distance as,

$$d_{B|A} = |P_A - P_B^k| - d_T, \tag{11}$$

where d_T is the euclidean distance between P_A and $P_A^{'}$. This distance is,

$$d_T = d_A(t_w) + D_o + d_A(t_{\phi 1}) + d_A(t_{\phi 2}) + \frac{l_w}{\tan \theta_2}. \tag{12}$$

Finally, the time required by B to encounter A is computed as,

$$t_{B|A} = \begin{cases} \dfrac{d_{B|A}}{v_B^k}, & a_B = 0, \\[2ex] \dfrac{-v_B^k + \left({v_B^k}^2 + 2 a_B d_{B|A}\right)^{\frac{1}{2}}}{a_B}, & a_B \neq 0. \end{cases} \tag{13}$$

D. Overtaking Maneuver Decision

As can be observed in Fig. 1, the time $(t_{M_\circ})$ needed by A to complete the full maneuver (stage 1 and overtaking) regarding the instant t_o at which the first CAM from B is received, can be computed as,

$$t_{M_\circ} = t_w + t_{AC}. \tag{14}$$

As A moves forward, the remaining maneuver time at the k^{th} time step (τ) can be computed as, $t_{M_k} = t_{M_\circ} - k\tau$. To increase safety during the maneuver, we consider an additional margin of time, called safety time (t_s), as illustrated in Fig. 1. If $(t_{M_k} + t_s)$ is less than $(t_{B|A})$, A deems the maneuver as safe and goes forward. However, if $(t_{M_k} + t_s)$ is greater or equal than $(t_{B|A})$, A deems the maneuver as unsafe and it is aborted.

III. V2V-based Overtaking Application

The steps followed by the V2V-based overtaking application can be observed in **Algorithm 1**. We assume that the responsibility of setting, controlling, and maintaining the overtaking maneuver parameters rely on the autonomous driven system (ADS) of AV A. Furthermore, AVs A and B can get their position, speed, and acceleration from on-board sensors. A also utilizes short-range sensors to regularly measure the speed and acceleration of C. In addition, A and B utilize Kalman Filters

Algorithm 1: V2V-based Overtaking Application on AV A

Initial Conditions: $\{P_A,\, v_A,\, a_A,\, P_B,\, v_B,\, a_B,\, v_C,\, a_C,\, t_o\}$
Overtaking Parameters: $\{\theta_{1,2},\, a_A^{ov},\, v_A^{\max},\, t_s,\, D_o,\, D_s\}$
Result: $\{$ABORT$\}$
Rx: *On each CAM from AV B, cancel the scheduled task and*, **do**:
begin
  call *Decide*;
  Every Δt **up to** $t_o + 2t_w^{av}$ **do**
    Update $\begin{bmatrix} P_B^k \\ v_B^k \end{bmatrix}$ (10);
    call *Decide*;

Function $Decide\,(P_B, v_B, a_B)$
  Compute t_w (7), $t_{B|A}$ (13), and $t_{M_\circ}$ (14);
  $t_{M_k} \leftarrow t_{M_\circ}^{av} - (\gamma^* - t_o)$;
  if $(t_{M_k} + t_s \geq t_{B|A})$ **then**
    set ABORT;

(KFs) to estimate the values of measured status parameters. In consequence, the parameters' values utilized by the overtaking application, as well as the included in CAMs, are the estimated values[1] resulting from applying KFs. Then, on each received CAM or state prediction, A determines whether to continue or abort the overtaking maneuver based on the computed values of t_{M_k} and $t_{B|A}$. To increase the robustness of the overtaking application, the computed values of t_w and $t_{M_\circ}$ are averaged (av) over time. The parameter (γ^*) is a function that returns the current time in milliseconds. Note that state predictions occur at regular time intervals (Δt) after each CAM received from B.

IV. Awareness Control Approaches

To evaluate the impact of awareness control on the V2V-based overtaking application, four different approaches proposed in the literature are used on the AV B: ETSI DMG [6], IVTRC [8], IVTRC-Th [9], and POSACC [10]. The awareness control approach introduced by European standards is ETSI DMG [6]. It transmits a new CAM if one of the following conditions has been detected: $i)$ The difference between current and previous position exceeds 4 m (e.g., $\Delta pos \geq 4$ m); $ii)$ The difference between current and previous velocity exceeds 0.5 m/s (e.g., $\Delta vel \geq 0.5$ m/s); and $iii)$ The difference between current and previous heading exceeds $4°$ (e.g., $\Delta head \geq 4°$). The objective of ETSI DMG is to provide a certain level of cooperative awareness while implicitly controlling the channel load.

Unlike ETSI DMG, IVTRC [8] computes the CAM transmission probability of B, $p_B(t)$, based on positioning tracking error, $\tilde{e}_B(t)$, as follows: $p_B(t) = 1 - \exp(-\alpha\, \tilde{e}_B^2(t))$, where α is a positive real number, representing the sensitivity to $\tilde{e}_B(t)$. After each CAM transmission, IVTRC uses the packet erasure rate (Ω_B) to stochastically determine the positioning tracking error $\tilde{e}_B(t)$: $\tilde{e}_B(t^+) = (1 - \zeta_B(t))\tilde{e}_B(t)$, where $\zeta_B(t)$ is a Bernoulli trial with probability $Pr(\zeta_B(t) = 0) = \Omega_B$. Then, if successful, i.e., $\zeta_B(t) = 1$, $\tilde{e}_B(t^+)$ is reset to zero; otherwise, $\tilde{e}_B(t^+)$ accumulates from $\tilde{e}_B(t)$ based on first-order kinematic model, as specified in [8]. In this work, Ω_B is estimated every second depending on CAMs received by the AV A. This is a suitable assumption since a symmetric network is considered in [8]. IVTRC-Th [9] is a variant of IVTRC based on tracking error threshold (e_{th}). Here, if the $\tilde{e}_B(t)$ is larger than e_{th}, the CAM transmission probability of B is computed as follows:

[1]Since we assume that B is moving along a straight road, the KF not only allows B to accurately estimate its lateral position, but also allows A to locate B in the correct lane.

This is the author's version of an article that has been published in this journal. Changes were made to this version by the publisher prior to publication.
The final version of record is available at http://dx.doi.org/10.1109/LCOMM.2020.3044734

TABLE I
SETTINGS OF THE AWARENESS CONTROL APPROACHES

Approach	Parameter	Value
ETSI DMG†	Δpos	≥ 4 m [6]
	Δvel	≥ 0.5 m/s [6]
	SMDI	50 ms [6]
IVTRC	Sensitivity (α)	30 [8]
	SMDI	50 ms [8]
IVTRC-Th	Sensitivity (α)	30 [8]
	Tracking Error Threshold (e_{th})	0.2 m [9]
	SMDI	50 ms [8]
POSACC	Average Position Error ($\overline{E}_B$)	1 m [10]
	Transmission Delay (t_D)	500 μs [10]

† Changes on heading of AV B are not considered since we assume that it moves along a straight road.

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Road Length	1 km
Lane Width (l_w)	3.5 m [11]
Vehicle Length (L_A, L_B, L_C)	4 m [13]
Vehicle Width	1.8 m
Initial Distance (D_o)	18, 25, 32 m [13]
Safety Distance (D_s)	18, 25, 32 m [13]
Overtaking heading (θ_1, θ_2)	$\approx 11°, 8°, 6°$
Initial Velocity‡(v_A, v_C)	60, 70, 80 km/h
Maximum Overtaking Velocity ($v_A^{\max}$)	90, 100, 110 km/h
Acceleration in Uniform Motion (a_A, a_C)	0 m/s^2
Overtaking Acceleration (a_A^{ov})	2.5 m/s^2
Safety Time (t_s)	0.5 s
Prediction Interval (Δt)	50 ms
Number of Simulated Incidents	$18 \cdot 10^5$

‡ We utilize typical movement parameters of two-way roads where overtaking maneuvers are common.

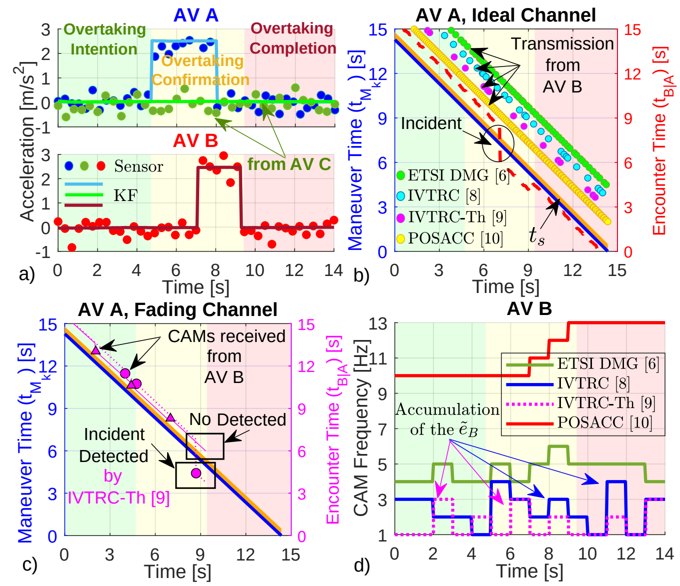

Fig. 2. Parameters involved in detecting unsafe overtaking maneuvers.

$p_B(t) = 1 - \exp(-\alpha|\ \tilde{e}_B(t) - e_{th}\ |^2)$. Otherwise, if $\tilde{e}_B(t)$ is smaller than e_{th}, there is no transmission at all from B (i.e., $p_B(t) = 0$). CAM trigger conditions on ETSI DMG, IVTRC, and IVTRC-Th are checked at a fixed time interval, denoted in this work as Status Monitoring and Decision Interval (SMDI).

POSACC [10, Alg. 1] adjusts the message transmission rate in real-time depending on the movement dynamics of B. On each CAM transmission, POSACC gets the velocity (v_B) and acceleration (a_B) of B as well as the transmission delay (t_D). Then, it defines the movement status (e.g., repose, accelerated motion, uniform motion, or deceleration) and uses a kinematic-based model to set the required CAM transmission interval for guaranteeing the pre-define average position error ($\overline{E}_B$). The settings of the awareness control approaches are summarized in Table I.

V. SIMULATION RESULTS AND DISCUSSION

The experiments were conducted with Matlab in a two-lane straight road, as illustrated in Fig. 1. To model a wide range of overtaking situations, three different initial velocities (v_A, v_C) for the AVs A and C were considered, as can be observed in Table II. We set initial (D_o) and safety (D_s) distances of 18, 25, and 32 m according to the braking distance[2] required for a velocity (v_A, v_C) of 60, 70, and 80 km/h, respectively. These distances also are within the range analyzed in [13]. We use a normally distributed noise with zero mean and standard deviation of 0.3 m/s^2, 0.27 m/s, and 1.5 m to model sensing errors [12]. These values are also utilized as initial conditions for KFs. Further, we consider communication channel impairments associated with low traffic density environments where overtaking maneuvers are common, such as packet losses due to channel fading. To model packet losses, we utilize an IEEE 802.11p V2V fading channel[3] with additive white Gaussian noise and Doppler spread. According to [5], at the physical (PHY) layer, we set a 10 MHz channel, a PHY service data unit (PSDU) of 350 bytes, a quadrature-phase-shift keying (QPSK) modulation, a code rate of 1/2, resulting in a data-rate of 6 Mbps. The remaining simulation parameters are given in Table II.

Fig. 2a illustrates the measurements that AV A gets from its own acceleration and from the acceleration of C, as well as the acceleration estimated by its KFs. By using the estimated acceleration, A computes the t_w which for an initial velocity (v_A, v_C) of 70 km/h is 4.6 s (with t_{ch}^{RL}, $t_{\phi 1}$, and t_ε equal to 1.2 s, 2.1 s, and 1.3 s, respectively). Accordingly, the $t_{M_\circ}$ is 14.1 s, where t_{AC} is 9.5 s with $t_{\phi 2}$ equal to 5.3 s and t_{ch}^{LR} of 0.9 s. In Fig. 2a, the AV B moves at 70 km/h and accelerates at 2.5 m/s^2 until reaching a maximum velocity of 90 km/h. To model an incident[4], we configure B to accelerate within the t_w of stage 2, as shown in Fig. 2a. An incident occurs when the encounter time $(t_{B|A})$ is less than the remaining maneuver time plus the safety time $(t_{M_k} + t_s)$, as illustrated in Fig. 2b for an ideal channel. Note that the probability of detecting an incident strongly depends on the transmissions accomplished by the awareness control approach running on B. Fig. 2c shows that in real operating conditions, packet losses due to channel fading significantly impair the incident detection capability of the V2V-based overtaking application. Here, the overtaking application utilizes the CAMs gathered from the IVTRC-Th approach for tracking the position of B and deciding whether to continue or abort the unsafe overtaking maneuver shown in Fig. 2b.

Fig. 2d illustrates that POSACC is more effective than ETSI DMG, IVTRC, and IVTRC-Th on reacting to the movement dynamics of the AV B. Note that when B accelerates (see Fig.

[2]Precise method for calculating the braking distance.

[3]Matlab, "802.11p Packet Error Rate Simulation for a Vehicular Channel," 2020.

[4]We assume our system to work in the worst case, *i.e.*, without channel tracking and that the maneuver is only aborted by A based on CAMs received from B.

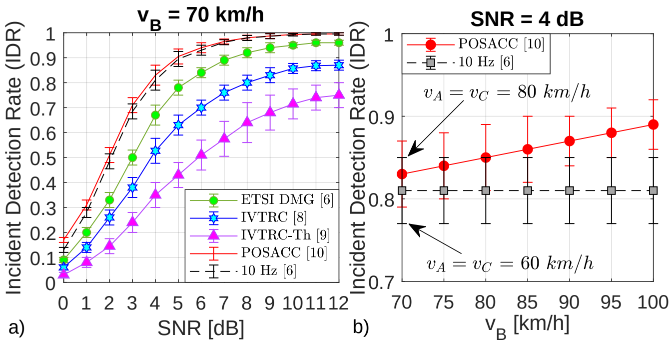

Fig. 3. Incident detection rate (IDR) for different operating conditions.

2a), POSACC increases the message transmission frequency up to 13 Hz (equivalent to 13 CAMs per second) to maintain an average position error of 1 m (see Table I). In consequence, POSACC is also more effective than the other approaches to support the V2V-based overtaking application, achieving the best performance in terms of incident detection rate (IDR), as shown in Fig. 3. The IDR is the ratio between the number of detected incidents and the total of simulated incidents. In Fig. 3, the error bars represent the standard deviation of the IDR computed for an initial velocity (v_A, v_C) of 60 and 80 km/h. Fig. 3 shows the IDR for different operating conditions, where in each simulated incident the instant at which B accelerates is uniformly distributed within the time interval $(t_w, 2t_w)$ of the stage 2. Here, the acceleration (2, 2.5, or 3 m/s^2) and maximum velocity (85, 90, or 100 km/h for Fig. 3a) of B were randomly selected on each simulation. Like POSACC, ETSI DMG also considers vehicle dynamics. However, it has serious drawbacks to achieve a stable message transmission frequency as can be observed in Fig. 2d. This is because of its divergence effect (see [10]) and the uncertainties associated with the on-board position sensor. Fig. 3a demonstrates that CAM trigger conditions specified by ETSI [6] are not sufficient to support the V2V-based overtaking application for values of signal-to-noise ratio (SNR) lower than 10 dB, achieving a mean IDR lower than 0.95. Further, unlike POSACC, ETSI DMG is incapable of achieving a mean IDR greater than 0.99 for an SNR of 12 dB. Fig. 3a also shows that IVTRC and IVTRC-Th are not suitable to support the V2V-based overtaking application. The reason is that their CAM transmission probabilities mostly depend on the accumulation of $\tilde{e}_B$, as shown in Fig. 2d. Even, once $\tilde{e}_B$ is accumulated, its reset is still stochastic. Therefore, they can not guarantee a high message transmission frequency in critical situations (e.g., when B changes its movement state). Accordingly, for an SNR ranging from 2 dB to 6 dB, POSACC increases the probability of detecting unsafe maneuvers by 10 % and 20 % in comparison to the approaches ETSI DMG and IVTRC, respectively. In Fig. 3, we also include a fixed CAM transmission frequency of 10 Hz, which is the higher message frequency specified by ETSI in [6]. Fig. 3a illustrates that for velocities of B lower than 70 km/h, the effectiveness of a fixed CAM frequency of 10 Hz to detect incidents is similar to the one achieved by POSACC, especially for SNRs higher than 6 dB. However, the drawbacks of using a fixed message frequency of 10 Hz regarding the vehicle dynamics are shown in Fig. 3b. Here, to establish the maximum velocity, we utilize an excess velocity with respect to v_B calculated as v_B + random$\{15, 20, 30$ km/h$\}$. Fig. 3b shows that POSACC outperforms the fixed CAM transmission frequency of 10 Hz in terms of IDR for velocities higher than 70 km/h. Note that the effectiveness of POSACC increases as a function of the velocity of B, exceeding by 8 % the IDR achieved by the fixed CAM frequency of 10 Hz for a velocity of 100 km/h and SNR of 4 dB.

VI. Conclusion

In this letter, we evaluated the suitability of awareness control approaches, such as ETSI DMG, IVTRC, and POSACC, to support the V2V-based overtaking application in autonomous driving. Simulation results showed the feasibility of POSACC for rapidly adapting to changes in vehicle dynamics, achieving an stable CAM transmission rate, which increases its probability of detecting unsafe overtaking maneuvers. POSACC proved its effectiveness regarding the remaining addressed approaches for supporting the V2V-based overtaking application, achieving the best performance in terms of IDR in different operating conditions.

Finally, we conclude that the design and configuration of the addressed awareness control approaches should be further investigated to increase the incident detection rate, especially at low SNRs. In future works, we intend to consider overtaking maneuvers in which the AVs collaborate to avoid an accident for increasing the performance of the V2V-based overtaking application.

References

[1] E. Yurtsever *et al.*, "A Survey of Autonomous Driving: Common Practices and Emerging Technologies," *IEEE Access*, vol. 8, pp. 58 443–58 469, 2020.
[2] I. Yaqoob *et al.*, "Autonomous Driving Cars in Smart Cities: Recent Advances, Requirements, and Challenges," *IEEE Network*, vol. 34, no. 1, pp. 174–181, 2019.
[3] J. Wang *et al.*, "Networking and Communications in Autonomous Driving: A Survey," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 2, pp. 1243–1274, 2018.
[4] E. Belyaev *et al.*, "The Use of Automotive Radars in Video-Based Overtaking Assistance Applications," *IEEE Transactions on Intelligent Transportation Systems*, vol. 14, no. 3, pp. 1035–1042, 2013.
[5] IEEE 802.11 Working Group, "IEEE Standard for Information Technology - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," *IEEE Std 802.11*, 2016.
[6] ETSI, "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service," *ETSI EN 302 637-2 V1.4.1*, 2019.
[7] ETSI, "Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part," *ETSI TS 102 687 V1.2.1*, 2018.
[8] C. L. Huang *et al.*, "Intervehicle Transmission Rate Control for Cooperative Active Safety System," *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 3, pp. 645–658, 2011.
[9] C. L. Huang *et al.*, "Adaptive Intervehicle Communication Control for Cooperative Safety Systems," *IEEE network*, vol. 24, no. 1, pp. 6–13, 2010.
[10] S. Bolufé *et al.*, "POSACC: Position-Accuracy Based Adaptive Beaconing Algorithm for Cooperative Vehicular Safety Systems," *IEEE Access*, vol. 8, pp. 15 484–15 501, 2020.
[11] O. Popescu *et al.*, "Automatic Incident Detection in Intelligent Transportation Systems Using Aggregation of Traffic Parameters Collected Through V2I Communications," *IEEE Intelligent Transportation Systems Magazine*, vol. 9, no. 2, pp. 64–75, 2017.
[12] SAE J2945/1, "On-Board System Requirements for V2V Safety Communications," 2020.
[13] M. Sepulcre *et al.*, "Application-Based Congestion Control Policy for the Communication Channel in VANETs," *IEEE Communications Letters*, vol. 14, no. 10, pp. 951–953, 2010.