NR-V2X for Cooperative Adaptive Cruise Control

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***Abstract*—The introduction of vehicular communications has long been advocated as compelling to guarantee the safety and stability of platooning, owing to the information that vehicles exchange through the wireless channel. However, connecting the vehicles through radio links introduces delays and persistent packet losses that may compromise the proper platoon functioning. To investigate this issue, the present work replicates through simulation the vehicle dynamics of a Cooperative Adaptive Cruise Control platoon and the transmission impairments that affect the platoon communications, when the 5G New Radio standard for Vehicle-to-Vehicle communications is adopted. The study first characterizes the actual behavior of the platoon when simultaneously struck by a perturbation in the leader's acceleration and a severe communication outage. In the worst examined setting, it shows that the radio technology is robust enough to guarantee platoon stability. It further demonstrates that a proper selection of the packet scheduling strategy allows to reduce the time gap between consecutive vehicles while still maintaining platoon stability, at the expense of a moderate increase in energy expenditure.**

***Index Terms*—Connected and Cooperative Automated Driving, CACC, Platoon, V2V, NR-V2X.**

I. Introduction

Vehicular Ad hoc NETworks (VANETs) represent a widely explored topic in the transportation and communication research communities, investigated via practical experimentations and theoretical studies. One of the most popular VANET implementations is platooning, which consists of a group of vehicles on a highway driving together at short distances thanks to the wireless exchange of information. Platooning has been proposed for both truck and passenger car applications. Regarding the former, decreasing the inter-vehicle gap would enable reduced air resistance thus lowering fuel consumption. Concerning the latter, although the drag reduction is indeed beneficial, the main objective would be to increase the capacity of the transportation network by decreasing the inter-vehicular distance and increasing the stability of the car-following process.

Cooperative Adaptive Cruise Control (CACC) is an intermediate step towards the longer-term vision of closely coupled automated platoons. In CACC, vehicles merge into platoons and automatically adjust their speed by employing onboard sensors and communications with the preceding vehicles. Evolving from Adaptive Cruise Control (ACC), CACC aims at enabling shorter inter-vehicle spacing than ACC to maximize traffic flow, while together enhancing the platoon's stability [1]. Such improvements are due to the exchange of information that communications empower, most notably the acceleration of the preceding vehicles. In the CACC scheme, the leader(s)'s acceleration, as well as the speed and distance of non-contiguous vehicles are transmitted relying on a Vehicle-to-Vehicle (V2V) radio technology, such as IEEE 802.11p or the most recent New Radio Vehicle-to-Everything (NR-V2X) Sidelink (SL) interface [2]. Indeed, connectivity is the most effective tool to enhance the performance of ACC operation [3], together with newer solutions such as multi-anticipative RADAR [4]. Unfortunately, wireless communications are far from being ideal, being responsible for delays and packet losses.

Traffic flow oscillations are a further issue in highway driving [5]. This phenomenon refers to the temporary and sudden decrease in vehicles' speed and may cause the string instability effect, whereby such oscillations are amplified downstream, impacting the platoon's safety and efficiency.

The present study contributes to the CACC analysis jointly considering the above phenomena. It assumes that NR-V2X SL rules intra-platoon communications without relying on the cellular infrastructure and examines the two packet scheduling schemes envisioned by the NR-V2X standard for distributed communications, termed Semi Persistent Scheduling (SPS) and Dynamic Scheduling (DS).

As the proper functioning of the CACC platoon calls for fresh information, it is critical to identify the duration of the intervals in which packet losses preclude the information exchange. Hence, the first contribution of this paper is to statistically characterize the duration of the intervals in which communications among the platoon members experience an outage. Next, the longest, although most infrequent outage intervals are focused upon; the aim is to examine how the platoon reacts to these rare events when they occur jointly with an exogenous perturbation applied to the platoon leader. Unquestionably, the platoon has to behave correctly in such demanding circumstances too. To assess the platoon behavior, a state-of-the-art simulation tool for NR-V2X SL communications [6] is coupled with a microscopic simulator of the CACC control law and vehicle dynamics [4]. Communications among vehicles outside the platoon are also taken into account, to guarantee that the radio channel is realistically loaded by packets belonging to different application flows.

It is demonstrated that the CACC platoon satisfyingly copes with the sudden perturbation even in the least favorable communication circumstances. Moreover, when employing the NR-V2X DS scheme, this study indicates that the time gap between platoon vehicles can be significantly lowered without harming CACC stability.

The rest of the paper is organized as follows. Section II provides the state-of-the-art in CACC research. Section III illustrates the approach, detailing the examined CACC control law, the communication technology, the simulated scenario, and the performance metrics. Section IV discusses the obtained results and Section V draws the conclusions.

II. Related Work

In the literature, there are several well-studied approaches that replicate the CACC dynamics; they range from Intelligent Driver Model (IDM)-inspired solutions to linear controllers with saturation or Model Predictive Controller (MPC), as effectively summarized in the recent survey works [7] and [8]. In the present contribution, a linear controller implementation is adopted, where the calibration has been performed according to the findings in [7] and [9]. The linear controller is selected as it supports a modular approach allowing for a fair comparison of different communication topologies inside the platoon [10].

One additional line of research related to the current study deals with the modeling of the CACC dynamics. In this regard, many papers model the communication channel as an ideal and latency-free medium [11]; other works assume the channel introduces a constant delay [4], [12], or elaborate about the maximum tolerated delay, such as [13], which estimates the magnitude of the transmission delay that guarantees string stability. Only a few studies concentrate on packet losses, a notable example being [14], which proposes a control strategy for graceful degradation of CACC in the circumstance of prolonged packet losses. Along a similar approach, [15] introduces an adaptive control strategy to switch from an augmented CACC to an augmented ACC depending on the communication reliability. On a different rim, [16] underlines that communication failures occur in congested traffic conditions, and therefore puts forth a CACC scheme where vehicles dynamically activate or deactivate V2V communications based on the current level of road traffic. All the above papers have in common a rigorous approach to the modeling of the controller laws; yet, no attention is paid to intra-platoon communications and the rendering of the packet loss phenomenon.

The present work contributes to the advancement of the discussion in the field by taking an alternative perspective. Namely, it investigates the string stability of the CACC platoon when a perturbation is applied to the leader's acceleration, and the leader's communication is simultaneously affected by a communication outage. The latter event is defined as the persistent lack of successfully received packets and is quantified through the duration of the outage interval. For the most severe and infrequent outages, it is demonstrated that NR-V2X preserves the string stability of the platoon. Furthermore, the selection of the DS scheme guarantees a notable reduction of the time gap between platoon vehicles, hence a better exploitation of the road capacity, at the expense of a higher energy expenditure.

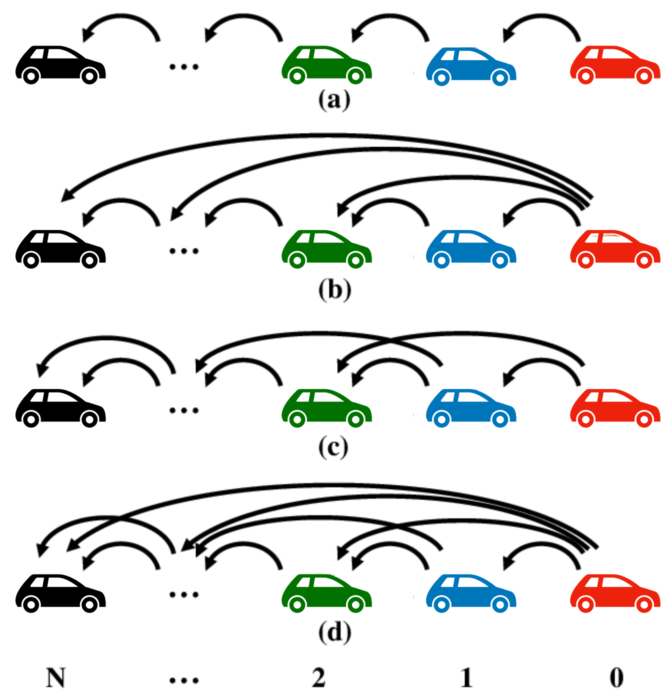


Fig. 1. CACC schemes: (a) PF, (b) PLF, (c) TPF, and (d) TPLF.

III. Methodology

A. CACC Control Law

The introduction of vehicular communications opens up a multitude of ways vehicles can exchange information in the platoon [12]. According to [12] and [17], CACC communication topologies can be classified as follows: Predecessor-Follower (PF), Predecessor-Leader Follower (PLF), Two Predecessors-Follower (TPF) and Two Predecessors-Leader Follower (TPLF). Their schematic representation is shown in Fig. 1.

Without loss of generality, this paper focuses on the CACC-PF solution: such a choice is motivated by simplicity and the need to focus on the role played by communications in maintaining a stable platoon. Furthermore, the analysis can be easily extended to other CACC configurations owing to the flexibility of the simulation-based approach.

A graphical representation of the examined CACC-PF platoon is shown in Fig. 2. In the platoon, the relative speed and distance of the preceding vehicle are retrieved via the follower's onboard sensors, namely, the front-end RADAR. Conversely, the acceleration of the preceding vehicle is conveyed in packets periodically transmitted over the wireless channel, as local acceleration measurements are noisy and provide an unreliable estimate.

A linear controller model is employed to replicate the car-following control law of the CACC-equipped vehicle:

$$\begin{aligned} u_{CACC-PF}(t) &= k_d(v_L(t-T) - v(t)) + \\ &+ k_p(s(t-T) - t_g v(t) - \eta) + k_a a_L(t-T_C)\,, \end{aligned} \tag{1}$$

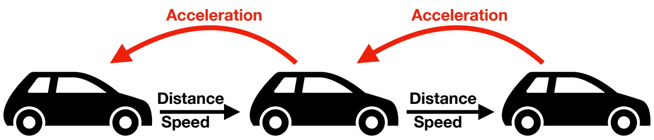


Fig. 2. The examined CACC-PF scheme.

where $u(\cdot)$ denotes the commanded control action on the acceleration of the ego-vehicle, $v_L(\cdot)$ the speed of the predecessor-leader, $v(\cdot)$ the speed of the ego, $s(\cdot)$ the distance between the predecessor-leader and the ego follower, and $a_L(\cdot)$ the longitudinal acceleration of the predecessor-leader. Moreover, k_d and k_p are the controller's gains, t_g the desired time gap, T is the estimation delay which accounts for the RADAR signal acquisition and processing (e.g., filtering of noisy measurements), η is the standstill spacing, k_a is the feed-forward predecessor-leader's acceleration gain, and T_C the communication latency.

The CACC-PF platoon is assumed to adopt the constant time gap policy, which requires that the spacing between consecutive vehicles be proportional to the follower's speed. Additionally, introducing the reference free-flow acceleration $u_{FF}(t)$

$$u_{FF}(t) = k_d(v_{FF} - v(t)), \tag{2}$$

where $v_{FF} \geq max(v_L(t))$, every platoon participant moves to a free-flow regime whenever $u_{FF}(t)$ is lower than the acceleration predicted by eq. (1). The transition to the free-flow regime implies that the target velocity is no longer dictated by the leading vehicle and signals the platoon's rupture, revealing poor stability properties. The target acceleration,

$$u(t) = \min\left\{u_{CACC-PF}(t),\, u_{FF}(t)\right\}, \tag{3}$$

is then forwarded to a double integrator with mechanical actuation latency τ_a to replicate the ego-vehicle dynamics

$$\begin{cases} \dot{x}(t) = v(t) \\ \dot{v}(t) = a(t) \\ \dot{a}(t) = \dfrac{u(t) - a(t)}{\tau_a}, \end{cases} \tag{4}$$

where $a(\cdot)$ is the chassis acceleration and $x(\cdot)$ the ego-vehicle absolute longitudinal position.

B. NR-V2X SL Communications

This paper assumes that every platoon vehicle adopts the NR-V2X cellular standard operating in Mode 2 to transmit the packets conveying the current acceleration value over the wireless channel. Mode 2 is a distributed resource allocation mode that does not require network support and, therefore, ensures vehicular communications regardless of cellular coverage. In Mode 2, two alternative packet scheduling solutions have been standardized: the SPS and the DS scheme. When adopting the SPS strategy, vehicles periodically and autonomously perform reservations of the radio resources in a selection window W, based on the activity they heard on the channel during the previous sensing window S. The selected resources are reserved for a consecutive number of times, the reservation interval being termed Resource Reservation Interval (RRI). The Reselection Counter (RC) is the counter that keeps track of the number of consecutive reservations; it is decremented after each transmission and, when it expires, new resources are selected with probability $1 - P$, $P \in [0, 0.8]$. The RC is initialized to a random value every time a new resource selection takes place, such value being dependent on the RRI [18]. When the simpler DS scheme is employed, vehicles select resources in W to perform one-shot transmissions, without any resource reservation.

In the SPS and DS solutions, packet delays are bounded by design, the maximum delay being the duration of the selection window W. Unfortunately, packet losses are unavoidable; collisions, transmission impairments, and half-duplex limitations of the radio transceivers are responsible for such losses and prevent the ego-vehicle from receiving the current acceleration value $a_L(\cdot)$ required in (1). In such a circumstance, it is assumed that the ego-vehicle relies on the value conveyed in the last successfully received packet. This implies that the control law is ruled by outdated information, which may affect the platoon's responsiveness in reacting to a traffic flow oscillation. One of the aims of this study is to investigate how harmful the prolonged lack of communication, and the use of incorrect and outdated information in the CACC-PF control law, is for the platoon's stability and how it affects its overall performance.

C. Simulated Scenario

The simulated environment consists of a multiple-lane highway segment. The first lane accommodates the CACC-PF platoon; in the remaining lanes, vehicles travel at a constant velocity. A schematic bird view is shown in Fig. 3. Every car is equipped with a NR-V2X SL transceiver. The vehicles on the non-CACC lane share the NR-V2X SL radio resources with the platoon vehicles, hence affecting the quality of intra-platoon communications.

The NR-V2X SL Mode 2 communications are replicated through the MoReV2X simulator [6], which interacts with a microscopic platoon simulator reproducing the linear control law introduced in subsection III-A. In this tool, the differential equations in (4) are time-discretized and solved at 10 Hz to mimic the real-time implementation of the controller.

The SPS and DS strategies are analyzed, assuming that packets are periodically broadcast at a 10 Hz frequency by

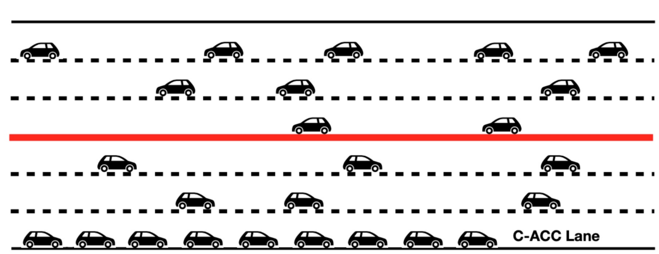


Fig. 3. Schematic view of the simulated scenario.

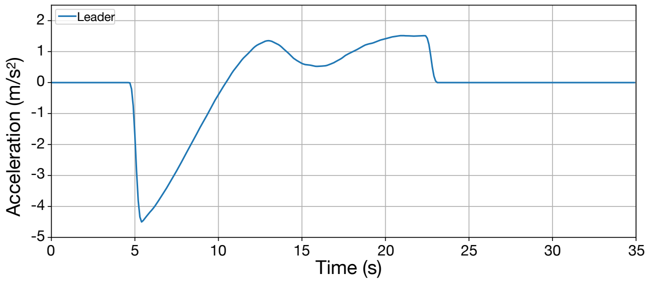


Fig. 4. The leader's acceleration over time.

the platoon vehicles and the cars traveling on the remaining lanes.

The simulation setup is such that, starting at $t = 0$ from a steady car-follow status, at $t = 5$ s the acceleration of the CACC-PF leader is subject to the perturbation displayed in Fig. 4, forcing the followers to react to it. The perturbation is derived from the "highD" dataset [19], an extensive collection of vehicle trajectories on German highways. Thus it is an instance of a realistic disturbance the CACC-PF leader could encounter in the examined environment.

D. Performance Metrics

1) Transport metrics: The first transport-related Key Performance Indicator (KPI) is the string stability, which in the present work coincides with the weak string stability [20], as the perturbation applied to the CACC-PF platoon is bounded. It is computed referring to the last platoon vehicle, as this is the follower that experiences the largest speed variation in a homogeneous platoon. We denote it by w_{SS}, its expression being

$$w_{SS} = \frac{v_{FF,leader} - \min(v_{lastfollower})}{v_{FF,leader} - \min(v_{leader})}, \tag{5}$$

where $v_{FF,leader}$ is the free-flow velocity of the leader before the perturbation occurs, $\min(v_{lastfollower})$ is the minimum velocity recorded for the last follower, and $\min(v_{leader})$ is the minimum velocity recorded for the leader. $w_{SS} \leq 1$ indicates a weak string stable system.

A further figure of merit is the average traffic flow per lane q, which is determined as

$$q = k \cdot \bar{u}_s, \tag{6}$$

where k is the platoon's density in (vehicles/km) and $\bar{u}_s$ is the harmonic mean of the speed in (km/h). This KPI measures how effectively the road infrastructure is used.

An additional KPI is the Root Mean Square (RMS) value of the longitudinal acceleration:

$$a_{x,RMS} = \sqrt{\frac{1}{N}\sum_{i}^{N} a_x(i)^2}, \tag{7}$$

where $a_x(i)$ is the value of the longitudinal acceleration at the time instant i, $i = 1, 2, ..., N$, covering the entire simulation time window. $a_{x,RMS}$ represents a proxy for driving comfort and fuel efficiency.

More transport-related KPIs are the number of rear-end collisions, N_{crash}; the mean percentage of time spent by a vehicle in car-following mode, $\overline{CF}$; the consumed energy per vehicle, E_{veh}, in kWh/100km. They quantify the CACC platoon safety, stability, and environmental sustainability, respectively.

2) Communication KPIs: It is crucial to understand how long the lack of communication may last; if excessively prolonged, it will negatively affect the CACC-PF performance. To this aim, the Packet Inter-Reception (PIR) is the KPI to consider on the communication side, useful for all those use cases that require high reliability, such as CACC platooning. For a given distance D, the PIR is defined as the time between two consecutive successful receptions of packets belonging to the same application flow, when the distance between the transmitting and receiving vehicle is within the $(0, D]$ range at the reception time of the two packets. In this work, the further notion of PIR outage probability P_{out} is introduced. This is defined as the probability that the PIR exceeds a given threshold x_{thres},

$$P_{out} = Pr\{\text{PIR} \geq x_{thres}\}, \tag{8}$$

and therefore coincides with the PIR Complementary Cumulative Distribution Function (CCDF) evaluated at x_{thres}. High values of x_{thres} are the most dangerous for the platoon, as vehicles rely on obsolete information to update their acceleration.

IV. Numerical Results

A. Settings

The examined highway segment has six lanes, three for each direction, every lane being 4 m wide. The CACC platoon consists of 10 followers plus the leader and occupies the first lane; on the remaining five lanes, vehicles travel at a constant velocity set to 90 km/h and the vehicular density is 50 or 100 vehicles/km.

Table I reports the calibrated parameters ruling the control law in (1); the values are within the intervals derived from real-world characterizations of ACC models as of [9], [21], [22]. Notice that requiring $t_g = 1.5$ s means that the bumper-to-bumper safety distance is 48.3 m at 110 km/h. Since passenger cars are considered, the longitudinal acceleration of the platoon vehicles is bounded within the $[-4.5, 2.0]$ m/s^2 interval, which is representative of the human-driving behavior [23] and acceleration and deceleration policies of commercial ACCs [24].

As regards NR-V2X SL communications, the duration of the selection window W employed by the SPS and DS schemes coincides with $RRI = 100$ ms, matching the packet periodicity. This implies that the delay experienced by packets because of the radio access technique is upper-bounded by 100 ms. In accordance to the standard, RC is randomly chosen in [5, 15] [18]. The values of the main physical layer (PHY) and Medium Access Control (MAC) parameters of NR-V2X are reported in Table II. The considered channel model is the Highway LOS/NLOSv channel model defined by 3GPP in [25].

TABLE I
VEHICLE PLATOON SIMULATION PARAMETERS.

k_p (s^2)	k_d (s)	k_a (−)	t_g (s)	τ_a (s)	T (s)	η (m)
0.1	0.5	1.0	1.5	0.3	0.2	2.5

TABLE II
MAIN PHY AND MAC SUBLAYER PARAMETER SETTINGS.

Parameter	**Setting**
Center frequency	5.9 GHz
Available bandwidth	20 MHz
Subcarrier spacing	30 kHz
Subchannel size	12 RBs
Modulation and Coding Scheme	16QAM - 0.49
Transmission power	23 dBm
Receiver sensitivity	−103.5 dBm
Noise PSD	−174 dBm/Hz
RSRP threshold	−128 dBm
Keep probability	0
Sensing window, S	1100 ms
Selection window, W	100 ms

B. CACC Ideal Behavior

It is initially assumed that the communications among the vehicles of the CACC platoon are ideal. In this circumstance, we approximate the communication latency T_C with the NR-V2X maximum delay, i.e., $T_C = 100$ ms.

Fig. 5 reports the acceleration (top), speed (middle), and spacing (bottom) between consecutive CACC-controlled vehicles as a function of time; the vehicles following the leader are identified by the symbols F_i, $i = 1, 2, \ldots, 10$, where index 1 corresponds to the vehicle closest to the leader and index 10 to the farthest; the spacing between consecutive vehicles is indicated by $S_{i,i+1}$, $i = 0, 1, \ldots, 9$, where $i = 0$ corresponds to the leader. The figure reveals that the system reaction is string stable when the perturbation of Fig. 4 is applied to the leader's acceleration. Enlarging the observation window from 35 to 100 s, the simulation would indicate that the spacing converges to 40 m for all pairs of consecutive vehicles. At 90 km/h, this corresponds to a time gap $t_g = 1.5$ s, which is the desired value.

Table III displays the values of the transport KPIs, namely, the w_{SS}, the mean vehicular flow q, the RMS of the longitudinal acceleration, as well as the average time spent in car-follow mode, the number of crashes, and the used energy per vehicle. Regarding the last parameter, its evaluation takes into account the speed and acceleration profile of each vehicle in the platoon, along with its mass, set to 1500 kg. Table III provides a useful term of comparison for the next evaluations, where the non-ideality of the communication process is introduced.

C. CACC Behavior in a Real Communication Environment

Next, it is assumed that the communications among the vehicles take place in a real propagation environment, affected by packet losses.

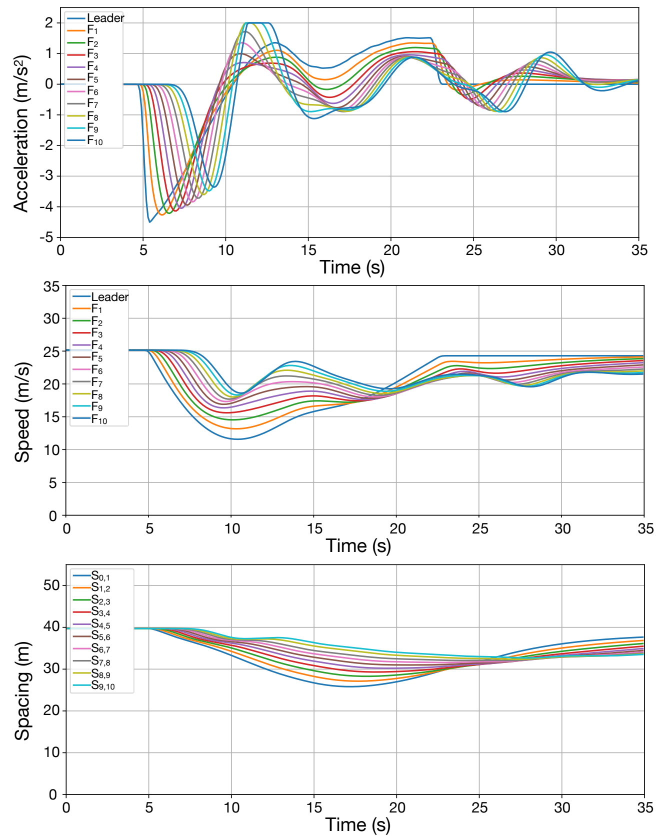


Fig. 5. Acceleration, speed, and spacing between consecutive CACC-controlled vehicles. Ideal communication with a fixed latency of 100 ms.

TABLE III
TRANSPORT KPIS IN IDEAL COMMUNICATION CONDITIONS.

w_{SS}	q (veh/h)	$a_{x,RMS}$ (m/s^2)
0.482	1935	1.029
CF (%)	**N_{crash}**	**E_{veh} (kWh/100 km)**
100	0	19.29

In this setting, the CCDF of the PIR is reported in Fig. 6 for the two radio resource assignment modes standardized in NR-V2X Mode 2, the SPS and the DS schemes, and for two illustrative vehicular densities, 50 and 100 vehicles/km. The PIR has been computed considering a radius of $D = 50$ m around the transmitting vehicle. The latter is a conservative choice, as the platoon vehicles are closer. At those distances, the PIR is almost exclusively affected by packet collisions, while packet losses due to poor propagation conditions are rare.

Recalling (8), different values of the outage probability

TABLE IV
PIR THRESHOLDS x_{thres}.

		Outage Probability		
		10^{-3}	10^{-4}	10^{-5}
Resource Allocation Scheme	**SPS**	210 ms	1130 ms	1350 ms
	DS	260 ms	310 ms	350 ms

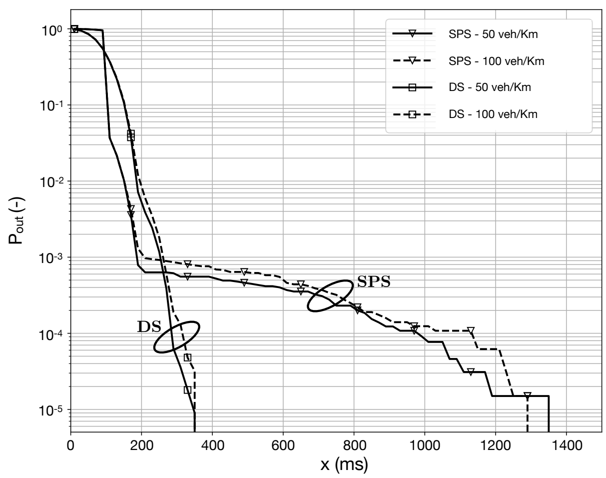


Fig. 6. PIR CCDF for different vehicular densities and different resource allocation techniques.

P_{out} are considered, namely, 10^{-3}, 10^{-4}, and 10^{-5}. The corresponding PIR thresholds x_{thres} are reported in Table IV, as derived from Fig. 6. They represent the duration of the interval in which no communication takes place among the platoon vehicles. The figure and the table reveal that the DS strategy is by far better performing than the SPS alternative, as it is characterized by shorter outage intervals, in the majority of the cases. This is the case since the SPS strategy, due to its periodic reservation of resources, is characterized by persistent packet collisions.

In what follows the longest outage durations are deliberately considered, despite their rare occurrence, as the $P_{out} = 10^{-5}$ value indicates. To begin with, the worst case of an outage lasting 1350 ms is examined, experienced when the SPS scheme is adopted.

Several simulations are then run introducing the following concurrent disturbances in the CACC platoon: (i) the perturbation of Fig. 4 is applied to the leader's acceleration; (ii) a deterministic breakdown in the communication between the leader and its first follower is assumed, that lasts 1350 ms and begins at the worst possible time, i.e., when the derivative of the leader's perturbation reaches its maximum, at time $t = 5$ s.

In this new scenario, Fig. 7 reports the acceleration, speed, and the spacing between consecutive vehicles as a function of time, disclosing that the system successfully absorbs the perturbation.

Moreover, the transport KPIs in Table V reveal that string stability is still ensured and no rear-end collisions occur. The comparison against the values in Table III indicates the mean flow is not affected, whereas the energy consumption increases by less than 14%. Overall, it is concluded that the platoon safely operates even in these challenging conditions.

Next, the following question is addressed: given the better-performing DS strategy is adopted, can the platoon be made more compact without affecting its stability? In other words, to what extent can the time gap t_g be reduced without risk?

In analogy with the previous investigation, it is then assumed that a 350 ms-long breakdown in the communication between the leader and its first follower is superimposed to the

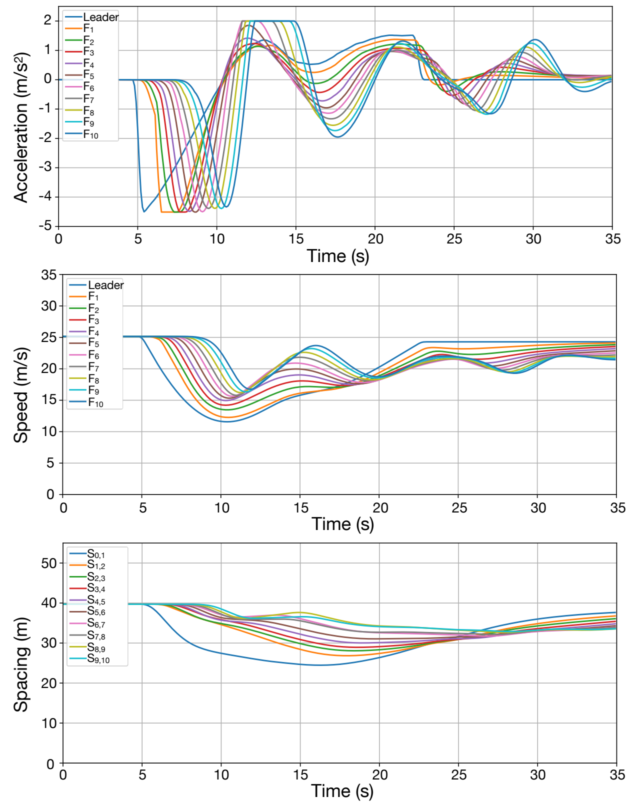
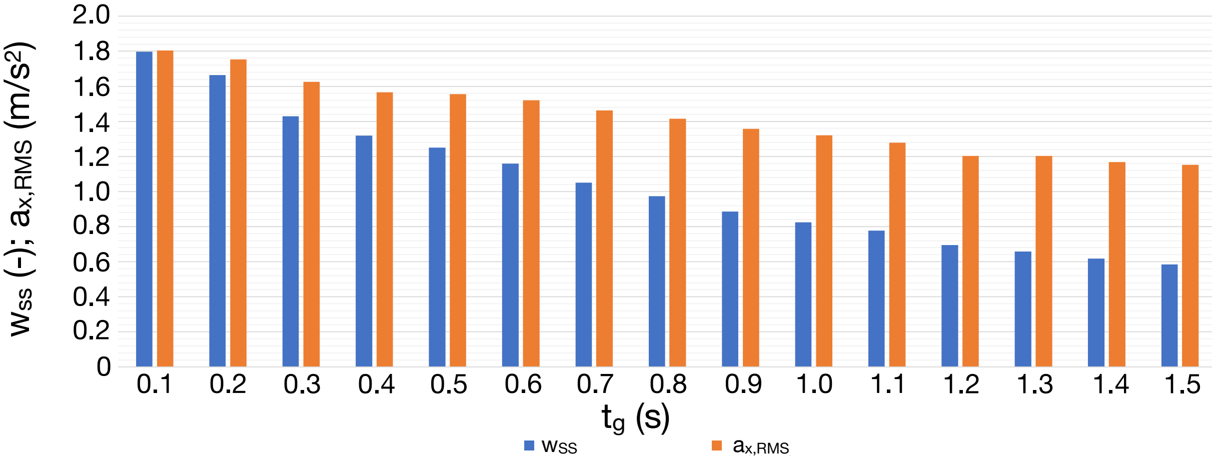


Fig. 7. Acceleration, speed, and spacing between consecutive CACC-controlled vehicles. Worst-case outage scenario.

perturbation of the leader's acceleration. Recall that 350 ms is the longest observed outage duration that characterizes the DS solution. Fig. 8 displays the string stability w_{SS}, the RMS value of the longitudinal acceleration $a_{x,RMS}$, and the number of crashes N_{crash} as a function of t_g in this new setting. The figure unveils that the stability property is maintained as long as $t_g \geq 0.8$ s. At a vehicular speed of 90 km/h, $t_g = 0.8$ s corresponds to a bumper-to-bumper safety spacing equal to 22.5 m. Moreover, at $t_g = 0.8$ s the percentage of time spent by the platoon's vehicles in the car-following mode is still 100% and $a_{x,RMS} = 1.416$ m/s^2. In parallel, the mean flow increases to $q = 3108$ vehicles/h, at the expense of a higher energy consumption, $E_{veh} = 25.26$ kWh/100 km. These results indicate that the adoption of the DS scheme allows the platoon to operate at shorter inter-vehicular distances without any safety penalty. Furthermore, there is an inevitable trade-off between the increased road capacity and the higher energy consumption that reacting to the unexpected traffic oscillation requires.

TABLE V
TRANSPORT KPIS IN REAL COMMUNICATION CONDITIONS.

w_{SS}	q (veh/h)	$a_{x,RMS}$ (m/s^2)
0.617	1935	1.219
$\overline{CF}$ (%)	N_{crash}	E_{veh} (kWh/100 km)
100	0	21.94



N_{crash}	8	4	-	-	-	-	-	-	-	-	-	-	-	-	-

Fig. 8. w_{SS}, $a_{x,RMS}$ and N_{crash} as a function of t_g.

V. Conclusions

This paper coupled an accurate state-of-the-art simulator of NR-V2X SL communications with a car-following simulator. The aim was to investigate the effects of communication failures on the safety and stability of the CACC-PF topology. Under the assumption that communications inside the platoon are ruled by NR-V2X Mode 2, the work quantified how a persistent lack of communication and a simultaneous perturbation of the leader's acceleration affect CACC performance.

The two scheduling strategies envisioned by the NR-V2X standard in Mode 2, namely, the SPS and DS schemes, were examined. It was shown that the SPS approach, despite statistically exhibiting longer bursts of packet losses, still guarantees the CACC-PF platoon safety in the most harmful among the considered settings. The CACC proved robust to the prolonged sequence of packet losses and was able to maintain string stability, exhibiting only a marginal reduction in comfort, energy efficiency, and a reduced capability of dampening the perturbation. Furthermore, when the DS strategy was studied and the same perturbation was applied, the CACC platoon was demonstrated to remain stable for a time-gap as low as 0.8 s, and therefore reliably operate at much shorter inter-vehicle spacings.

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