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Does ETSI beaconing frequency control provide cooperative awareness?

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Abstract—Platooning is an emergent vehicular application aiming at increasing road safety, efficiency and driving comfort. The cooperation between the vehicles in a platoon is achieved by the frequent exchange of periodic broadcast Cooperative Awareness Messages (CAMs) also known as beacons. CAM triggering conditions are drafted in the standard ETSI EN 302 637-2 and are based on the dynamics of an originating vehicle. These conditions are checked repeatedly with a certain sampling rate. We have discovered that the improper choice of the sampling rate value may increase the number of collisions between CAMs at the IEEE 802.11p medium access control layer and, therefore, diminish the efficiency of beaconing in a platoon.

Index Terms—VANET, cooperative awareness, beaconing, congestion control, platooning, ETSI.

I. INTRODUCTION

Design of the inter-vehicle communication protocols to support coordinated maneuverings and automated driving is recognized by the vehicular networking community as an emergent research topic [1]. Real-time exchange of kinematic information by all the maneuvering vehicles is crucial for their cooperation [2]. Broadcasting of Cooperative Awareness Messages (CAMs) by every vehicle to their neighbors is studied for multi-channel scenario [3], for the hidden-nodes case [4] and for enabled congestion control approaches [5], to name a few.

Communication support for platooning is currently getting a lot of attention, but the results so far are limited to, e.g., packet loss measurements [6] and a study on the content of the information to be exchanged and its role in the control application [7]. Still, several studies and proposals of how to use IEEE 802.11p in platooning have been reported, e.g., a slotted approach [8], retransmission schemes together with a TDMA approach [9], [10], analysis of the connectivity probability [11], and a study of send rate adaptation, message type prioritization and warning dissemination strategies [12]. However, the recently proposed CAM generation rules are not taken into account in any of the mentioned work.

In comparison to the studies mentioned above, this paper is focused on the ongoing ETSI standardization efforts for CAMs generation rules [13], which have not received an adequate publication activity so far. We focus on the cooperative awareness provisioning for the emergent platooning application [14], where a caravan of semi-autonomous vehicles

perform maneuvering together aiming at increased safety and reduced fuel consumption.

The contribution of this paper is twofold:

- a phenomenon of CAM triggering moments synchronization between platoon members is discovered;
- potentials to diminish a negative influence of this phenomenon on the cooperative awareness are discussed.

The manuscript is organized as follows. The assumptions of the system model are outlined in Section II. ETSI CAMs generation rules are summarized in Section III, while in Section IV the identified problem is described. Sections V and VI discuss potential ways to address the identified problem and conclude the paper, respectively.

II. SYSTEM MODEL

We consider a platoon comprised of N vehicles: a leading human-controlled vehicle and a caravan of automated vehicles moving together along the highway, Fig. 1. To enable functioning of the platooning control systems, each vehicle:

- generates CAMs in accordance to ETSI EN 302 637-2 specification [13];
- transmits CAMs on a dedicated channel in accordance to the IEEE 802.11p Medium Access Control (MAC) specification [15].

Fig. 1: Reference scenario

The following assumptions are adopted in our study:

- All the vehicles in the platoon are in each others communication range. This is a valid assumption for the realistic set-up of a platoon with up to 20–25 vehicles, when the IEEE 802.11p communication range is in the order of 400–500 m, inter-vehicle distance is 5 m and truck length is 15 m (see [16], p. 111).
- All the vehicles in the platoon increase or decrease their speed synchronously. This is a reasonable assumption since the speed deviations within a platoon are targeted to be marginal¹ (see [17], p. 433).
- The kinematic parameters of the leading vehicle are modeled via the Constant-Acceleration Heuristic (CAH) [18] state-of-the-art car-following mobility model².

III. ETSI COOPERATIVE AWARENESS BASIC SERVICE

Cooperative Awareness Basic Service [13] sets up the rules for the CAM generation, which are summarized in three items below³.

Firstly, the generation rate limits for CAMs are defined as follows:

- The CAM generation interval shall not be inferior to $T_{\min} = T_{\text{GenCamMin}} = 100$ ms. This corresponds to the maximal CAM generation rate of 10 Hz.
- The CAM generation interval shall not be superior to $T_{\max} = T_{\text{GenCamMax}} = 1000$ ms. This corresponds to the minimal CAM generation rate of 1 Hz.

Secondly, the above conditions for triggering the CAM generation shall be checked by a vehicle repeatedly every $\Delta = T_{\text{CheckCamGen}}$. We refer to $1/\Delta$ as the CAM triggering condition sampling rate.

Thirdly, within the specified limits, the CAM generation depends on the dynamics of the originating vehicle. A CAM shall be triggered in one of two cases:

- The time elapsed since the last CAM generation is equal or larger than $T_{\max}$.
- The time elapsed since the last CAM generation is equal or larger than $T_{\min}$ and any of the following events has occurred:
 - “Event A”: the absolute difference between the current position of the vehicle and its position included in the previous CAM exceeds $d_{\min} = 4$ m;
 - “Event B”: the absolute difference between the current speed and the speed included in the previous CAM exceeds $v_{\min} = 0.5$ m/s;
 - “Event C”:⁴ the absolute difference between the current direction of the vehicle and the direction included in the previous CAM exceeds 4° .

¹In Subsection V.B we discuss the relaxation of this assumption.

²This particular mobility model is chosen for the illustrative purposes only, however, the considerations in the paper are valid for any mobility patterns.

³CAM generations are also influenced by the ETSI Decentralized Congestion Control (DCC) [19]. However, throughout of this paper DCC is not considered.

⁴Event C is not considered in the paper, since we assume that the platoon moves along the highway and changes its direction slowly. Nevertheless, all the presented considerations and conclusions are valid also in case Event C might occur.

IV. IDENTIFIED PROBLEM

Throughout this Section we assume that Δ is negligibly small, i.e. the CAM generation rules are continuously checked by every vehicle.

A. CAMs Generation Moments: Synchronization

To illustrate the discovered effect of possible CAM generation times synchronization, let us consider two examples.

Example 1: Let the platoon change its velocity, e.g. it temporally slows down due to reduced speed limits in a road construction segment or due to a slow vehicle ahead.

Let us denote the CAM generation moments of the i -th vehicle as $V_1, V_2, \dots, V_N$, Fig. 2. When the platoon moves with a constant speed of 90 km/h, each vehicle triggers a CAM every $\tau = d_{\min}/v = 160$ ms due to the periodic occurrence of *Event A*.

Due to the deceleration, in a short time period a change of the platoon speed exceeds 0.5 m/s (*Event B*) and the vehicles with $t - t_i \geq T_{\min}$ (i.e. 4, 5 and 6) synchronously trigger their CAMs at time t_0 . Other vehicles (i.e. 1, 2, 3, 7 and 8) trigger their CAMs as soon as the time elapsed since their recent CAM generation turns to $T_{\min} = 100$ ms. When the platoon speed stabilizes, the vehicles trigger CAMs with a constant period again (*Event A*).

The following proposition characterizes the phenomenon described above.

Proposition A. Let a platoon move with a constant speed v during time interval $[0, t_0]$. If *Event B* occurs at t_0 , then the mean number of CAM generation moments synchronized at t_0 is

$$\rho = \frac{\tau - T_{\min}}{\tau} \times N,$$

where $\tau = d_{\min}/v$.

Proof: Let the CAM generation moments of all the vehicles be enumerated and denoted as T_n , $n \geq 1$. The CAM generation moments in the interval $[0, t_0]$ represent the following stochastic process:

- Due to the random and independent occurrence of the first CAM generation moment of each of the N vehicles, the $N - 1$ intervals between pairs of subsequent CAMs of any N consecutive generation moments are exponentially distributed, i.e. $\forall n : T_{n+k} - T_{n+k-1} \sim \exp(\tau/N)$, $k = 1, N - 1$.
- Due to the periodic occurrence of *Event A*, all the vehicles generate CAMs with period τ , i.e. $\forall n : T_{n+N} - T_n = \tau$. Therefore, any time interval of duration τ , contains exactly N CAM generation moments (one per vehicle).

All the N vehicles detect *Event B* simultaneously at t_0 . However, due to the restriction on the value of the minimal possible CAM generation interval $T_{\min}$, only those vehicles, whose CAM generation moments belong to $[t_0 - \tau, t_0 - T_{\min})$, are triggered at t_0 , Fig. 3. Taking into account the above properties of the considered stochastic process, the mean number of CAM generation moments in $[t_0 - \tau, t_0 - T_{\min})$ is $\frac{\tau - T_{\min}}{\tau} \times N$. ■

Fig. 2: Example 1 – Synchronization of CAM triggering moments in the platoon

Fig. 3: Illustration for the proof of Proposition A

Example 2: Let the platoon slow down and accelerate several times, see Fig. 4.

Fig. 4: Example 2 – Some subsequent maneuvers

Each platoon maneuver influences the CAM triggering process according to the mechanism described in Example 1. More CAMs might become synchronized as long as more maneuvers are performed due to the concurrent occurrence of *Event B*. For example, in Fig. 5 CAMs from vehicles 7, 8, 9, 10 and 11, 12 become synchronized with the ones from 1, 2, 3, 4, 5, 6 after the 2nd and the 3rd maneuvers, respectively.

Notice, that once the synchronization of the CAM triggering times has occurred, further accelerations/decelerations will not lead to desynchronization. *Event B* occurs simultaneously for all the synchronized vehicles, since their recent CAMs contain the same kinematic information.

B. CAM Transmission Moments: Grouping

Transmission of CAMs generated as discussed above is governed by the IEEE 802.11p MAC protocol, which presumes that CAMs from different vehicles may collide due to their simultaneous transmissions. Synchronization of the CAM generation times does not lead to a guaranteed collision as well as their desynchronized generations do not impose that collisions are impossible [3], [15]. This phenomenon can be characterized using the notions of *groups*.

Let us consider a platoon moving with a constant speed with all the vehicles periodically triggering CAMs. Let us select a sequence of $T_i \leq T_{i+1} \leq T_{i+2} \leq \dots \leq T_{i+N-1}$ CAM generation moments of each vehicle in the platoon such that CAMs from vehicles i and $i+N-1$ cannot collide (formal way to do it is proposed in [16], p. 112).

Algorithm 1 CAMs Grouping Algorithm

```

1: for  $j \leftarrow 1, N$  do
2:    $L_j \leftarrow 0$ ;
3: end for
4:  $l \leftarrow i$ ;    $K \leftarrow 1$ ;
5: while  $l < i + N - 1$  do
6:    $\Omega \leftarrow \{l\}$ ;    $m \leftarrow 1$ ;
7:   while  $T_{l+m} - T_l \leq m \times [AIFS + (W - 1)\sigma] +$   

    $+ (m - 1) \times T_{CAM}$  do
8:      $\Omega \leftarrow \Omega \cup \{l + m\}$ ;
9:      $m \leftarrow m + 1$ ;
10:  end while
11:   $\Phi_K \leftarrow \Omega$ ;
12:   $L_m \leftarrow L_m + 1$ ;    $l \leftarrow l + m$ ;
13:   $K \leftarrow K + 1$ ;    $m \leftarrow 1$ ;
14: end while

```

One can execute Algorithm 1, where *AIFS* is the Arbitrary Inter-Frame Space, σ is a *aSlotTime*, W is the Contention Window [15] and T_{CAM} is the CAM transmission time. The outcome of the Algorithm operation is that all N vehicles are split into K sets denoted as Φ_k , $k = 1 \dots K$ and further referred to as *groups*. L_m is the number of groups consisting

Fig. 5: Example 2 – CAM triggering after several deceleration/acceleration maneuvers

of exactly m vehicles.

Proposition B. The CAMs of vehicles belonging to different groups Φ_k ($k = 1 \dots K$) cannot collide.

Proof: From the IEEE 802.11p backoff rules it follows that in the empty system two CAMs can never collide if their generation moments are spread in time for at least $a + (W - 1)\sigma$, see line 7. When the CAMs are generated during the ongoing transmissions of other vehicles, the backoff counters freeze until the channel becomes idle. Respective maximum possible transmission delays are checked at line 7. ■

Let us consider time intervals, where the speed of the platoon is constant, i.e. before any maneuvers and after each of the four maneuvers (see Fig. 6).

Fig. 6: Reference maneuvers

The probability distribution function (PDF) of the number of groups with m vehicles is defined as $Q(m) = Pr\{x = m\} = L_m/K$. Empirical PDF $Q^*(m)$ for the above distribution is depicted⁵ in Fig. 7. The results are obtained via simulations with standard IEEE 802.11p parameters as in [16]. In the first simulations, the value of Δ is set to be very small, namely, $\Delta = \sigma$.

From Fig. 7 it follows that if the CAM triggering conditions are checked by all the vehicles in the platoon con-

tinuously with a small step, then the IEEE 802.11p MAC layer CAM collision probability increases after each acceleration/deceleration maneuver due to reduced time diversity of the generation moments.

Fig. 7: Influence of maneuvers on time diversity of CAM generation moments when $\Delta = \sigma$

V. POTENTIALS TO SOLVE THE PROBLEM

A. Reduced sampling rate

Let us examine how the increase of the sampling interval Δ influences CAMs grouping. A reduction of the sampling rate results in the increase of CAM generation moments time diversity (Fig. 8). Moreover, in contrast to the case of $\Delta \rightarrow 0$, this time diversity may increase as a result of a maneuver for $\Delta = 500\sigma$ (see $Q^*(m)$ after the 3rd and the 4th maneuvers). A group might be split when "Event B" occurs between its CAM generation moments.

B. Practical considerations

Although the movements of platoon members are desired to be perfectly synchronized during all the maneuvers, a real system will impose certain restrictions to achieve this goal due to the inter-vehicle communication delays, automated control induced delays, inertness of the braking system and inaccuracies in kinematic parameters measurements.

⁵For the sake of the plots clarity, the values of $Q^*(1)$ are not depicted.

Fig. 8: Influence of maneuvers on the time diversity of CAM generation moments when $\Delta = 500\sigma$

Let $\delta = \text{uniform}[0, k\sigma]$ be a random delay, which is added to each CAM generation moment when the maneuver is performed, where k is the maximum delay expressed in time slots. δ aims at modeling the overall inaccuracies between the instance when the CAM would be triggered in the ideally synchronized platoon studied up to now and in the platoon with a non-synchronized movement of members. A random component in CAM triggering moments may diminish the grouping effect (Fig. 9).

Fig. 9: Influence of maneuvers on time diversity of CAM generation moments when $\Delta = \sigma$ and $\delta = \text{uniform}[0, 500\sigma]$

To assess the actual impact of the ETSI rules on the CAM successful delivery performance, we examine the cases when the platoon keeps a constant speed (i.e. Event A triggering CAMs) after each maneuver performed (see Fig. 6). From Fig. 10 one can see that the tunings of the parameters discussed above have a crucial impact on the CAM collision probability.

VI. CONCLUSIONS AND FUTURE WORK

Emerging platooning application, where a caravan of heavy-duty vehicles automatically follow a leading one, requires an exchange of updated kinematic information. This is achieved through the triggering of beacons in accordance to the ETSI EN 302 637-2 specification and their transmissions over a dedicated IEEE 802.11p random access channel.

Our study reveals a surprising conclusion: enlarging the sampling rate of the kinematic parameters will not necessarily lead to the improved cooperative awareness, because an increased congestion in the communication channel might decrease the reception rate of beacons.

We believe that our insights should be rapidly delivered to the vehicular communication research and development community and might influence the ongoing ETSI standardization.

Our future work will be dedicated to the detailed analysis of the identified problem and will be focused around two major research questions:

- What are the gains and losses in the kinematic data updateness with respect to the sampling rate chosen?
- Is it possible to achieve ungrouping of CAM generation moments through the adjustment of the parameters?

Fig. 10: CAM collision probability

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