Cooperative Awareness Message Dissemination in EN 302 637-2: an Adaptation for Winding Roads

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***Abstract*—This paper evaluates the performance of the Cooperative Awareness Message (CAM) dissemination stated in the European Standard EN 302 637-2 in risky sharp bends and winding roads. We propose a novel triggering condition based on the dynamic estimation of the road radius, used as a risk metric. So as lower the radius, the higher the beaconing rate. As a case study, two real road sections, with different lengths and angles, have been simulated to prove that both a better awareness and responsiveness are achieved in the vehicles, to later ensure a proper application layer functioning. Finally, congestion constraint is also tested to check that no significant interferences are found in the described behavior.**

***Index Terms*—Vehicular communications, CAM dissemination, Rate control, Winding roads, Congestion control.**

I. Introduction

INTELLIGENT transportation systems (ITS) [1] have been widely studied in recent years since drivers' safety could substantially be preserved in many ways. Supplementary assistance and more intelligent embedded apps may reduce the risk caused by the human factor. The efficiency reached by emergency services in a traffic incident can be significantly improved thanks to these kinds of wireless communications in a vehicular environment. And, also, among other advantages, from a routing viewpoint, traffic control can be optimized by taking into account real-time data of the surrounding traffic conditions.

Given the importance of these networks, as a step towards its implementation in the automotive industry, different entities and governments have started standardization works. Both American and European standards adopted the Dedicated Short Range Communications (DSRC) 5.9 GHz band (5.850-5.925 GHz) to accommodate inter-vehicle communications. This band was considered and proposed by the Institute of Electrical and Electronics Engineers (IEEE, hereinafter) through IEEE 802.11-2012 standard (IEEE 802.11p), which defines the medium access control (MAC) and physical layers (PHY) for wireless communications among vehicles. Furthermore, the IEEE 609 group has set the IEEE 609.x protocol stack, called Wireless Access in Vehicular Environment (WAVE), as an extension of the aforementioned IEEE 802.11p MAC layer, management, and security. The European profile standard ITS-G5, drafted by European Telecommunication Standard Institute (ETSI), is based on IEEE 802.11-2007 and includes physical features of the IEEE 802.11p and data-link layers of the IEEE 1609 framework. ITS-G5 also defines the required regulations to allow cooperative awareness, which is one of the basics to guarantee safety.

The awareness concept can be defined as the information that a vehicle has about the surrounding traffic and the environment whereby it is located in a given time. This information exchange among vehicles is conducted through the so-called Cooperative Awareness Messages (CAM) in Europe or the Basic Safety Messages (BSM) in the US, also known as beacon, defined in EN 302 637-2 standard [2]. Since the road is a highly dynamic environment with short-life communications and severe fading effects, periodical beaconing broadcast is required to keep the information updated. Several problems may occur if the beaconing rate is not adequately allocated. On one side, if the rate is too low, the application layer may receive outdated or wrong data. In contrast, if the aggregated load caused by beacons in the wireless channel is too high, unexpected and severe errors may also be produced as a result of channel congestion, especially if the event-driven messages from DEN service are lost. This bandwidth unavailability is referred to as channel congestion.

In carrying out these kinds of congestion solutions in a real-world environment, some important considerations must be followed, in addition to keeping channel usage below a certain limit: the channel capacity must be assigned fairly. This means that each vehicle must reflect in its beaconing rate the current status of the surrounding area. To disregard the fairness concept can cause not only a high resource waste but also jeopardize the safety of the road since a fair beaconing rate implies to favor a proper application layer functioning. For example, some vehicles in a dangerous situation could not be differentiated if an algorithm assigns a similar rate to all the vehicles.

The algorithm stated by European standards, which we call here CAM-DCC, satisfies the mentioned requirements by combining the operation of two procedures:

- A fair allocation is provided by some vehicle dynamics dependent CAM generation rules, specified in [2]. More to the point, CAM-DCC measures the absolute difference between a current heading, position, and speed, and those included in the previously transmitted CAM. If the

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time elapsed since the last generation and one of these conditions overcome some predefined thresholds, a new CAM is generated. CAM-DCC results in a beaconing rate which is a function of the vehicle speed. In this way, vehicles with higher speeds are considered to have more risk than slower ones, and consequently, they will allocate a higher rate.

- As regards the congestion mitigation, the ETSI defined the Cross-Layer Decentralized Congestion Control (DCC) Management Entity [3]. The main aim of the DCC is to avoid overloading the ITS-G5 radio channel. This entity was tested and validated through two of the most extended pure rate control algorithms in the standardization tasks: (i) a reactive control [2], where the message rate is controlled by a finite state machine, and (ii) an adaptive linear control, called LIMERIC [4], one of the most extended congestion control.

Some drawbacks can be found in the mentioned CAM-DCC procedures. First, a CAM synchronization problem for cooperative maneuvers seriously degrades its performance, as discussed in [5]. Secondly, according to [6] [7], the CAM-DCC stability leaves room for improvement as channel load measurement presents considerable fluctuations when only the facility layer control is applied and severe state oscillation when different DCC control methods are combined. Finally, CAM-DCC lacks clear motivation for the triggering rules. In the absence of abrupt variations, few or even no additional beacons are generated, which leads to ignoring risk when vehicles operate at low and medium speed. For instance, a vehicle in curvy roads, urban environments, or motorway entrances and exits.

In this paper, we propose a novel CAM dissemination for EN 302 637-2 standard to try to meet most of the requirements imposed by vehicular scenarios. A more sophisticated approach is introduced to increase the risk awareness through prioritization with higher rates in low and medium speed curves, whereas the original algorithm only limits the beaconing rate as a function of the speed and decreases the rates even if in presence of risk. To this purpose, vehicles evaluate the safety of the traffic situation by computing the bending radius of the road, and the result is used to set a new CAM triggering condition.

The rest of this article remains as follows. In Section II we introduce the basic background and formulates the proposed model. Section III validates the model, compare it against the original congestion control approach, and discuss the obtained results. Finally, Section IV summarizes major conclusions.

TABLE I: Look-up table for FSM-DCC rate control

Channel state	CBR	T_GenCam_Dcc (s)	TX Rate (Hz)
Relaxed	<0.30	0.1	10
Active	0.30-0.39	0.2	5
Active	0.40-0.49	0.3	3.33
Active	0.50-0.59	0.4	2.5
Restrictive	>0.60	0.5	2

II. System description

CAM-DCC was defined in the EN 302 637-2 standard and updated in the newest 1.4.1 version in 2019, and consists of setting some CAMs generation rules and mechanisms dependent upon vehicle kinetics. Since the congestion control is out of the scope of this article, we use the default DCC finite states machine (FSM, hereinafter), whose states are depicted in Table I. The rates are limited between 1 and 10 Hz, or between times $T\_GenCamMax$ = 1 s and $T\_GenCamMin$ = 0.1 s, and the algorithm is executed every $T\_CheckCamGen$ seconds. The congestion is controlled using the time between CAMs provided by the DCC, called T_GenCam_Dcc time, which depends on the measured CBR. If the elapsed time reaches this limit, congestion avoidance is satisfied, and then, a new beacon may be triggered. First, CAM-DCC measures the absolute difference between the current heading, called Heading Condition (HC), position (PC), and speed (SC), and those included in the previous transmitted CAM. If one of these conditions overcome 4º, 4 m or 0.5 m/s, respectively, a new CAM message shall be generated. Conversely, if there are no vehicle changes in speed, position or heading, a new CAM is generated if the elapsed time since the last message sent is higher or equal to the called T_GenCam. In this latter case of low dynamics, the algorithm will send until N_GenCam = 3 consecutive CAMs before setting the minimum rate (1 Hz). The whole algorithm is summarized in Algorithm 1.

Algorithm 1: CAM generation frequency

foreach *interval* $T\_CheckCamGen$ **do**
  $T\_GenCam\_Dcc \leftarrow$ look-up result from FSM
  Check T_GenCam_Dcc boundaries
  if $lastCam\_elapsed\_time \geq T\_GenCam\_Dcc$ **then**
    if HC OR SC OR PC **then**
      Generate a CAM
      $T\_GenCam \leftarrow lastCAM\_elapsed\_time$
      $N\_GenCam \leftarrow 0$
    else if $lastCAM\_elapsed\_time \geq T\_GenCam$ **then**
      Generate a CAM
      N_GenCam++
      if $N\_GenCam > 3$ **then**
        $T\_GenCam \leftarrow T\_GenCamMax$
      end
    end
  end
end

In this paper, a new triggering condition is developed and tested to achieve a more adequate rate even when the vehicle dynamics are low. This is due to that in some cases, the current triggering conditions based on heading, position, and speed of the CAM-DCC mechanism may not be enough to send a significant number of CAM messages to fulfill the application layer requirements, so we think that there is also still room for improvement in this sense. Let us first define the curve risk, the road design to set the most suitable and realistic parameters, and then give an example of a road to prove the aforementioned weakness.

One way to quantify the risk of a road is to measure the so-called crash rate (CR), defined as the number of crashes per Million Vehicle Kilometer (MVKm). As studied in [8], the CR is highly related to the radius of curvature (R), being the most dangerous curves the sharpen curves with a low R (<250 m). According to US Department of Transportation [9], the inferred design of the radius of curvature of a road (R, in ft) depends in turn on the vehicle's speed (V, in mph), the superelevation rate (e, %), which is the lateral inclination of the road, and the side friction (f, %), which is taken at right-angles to the line of movement of the vehicle, as follows:

$$0.01e + f = \frac{v^2}{15R} \tag{1}$$

In this way, we can illustrate a real risky curve with a high CR. For example, given a vehicle that is traveling in a simple semicircular curve, with a single radius, at a steady speed of 30 mph (13.41 m/s), its maximum side friction will approximately be stated as 0.2%. The maximum allowed side friction factor is studied by the American Association of State Highway and Transportation Officials [10] and depends upon the intended speed of the vehicles in that road section. Finally, if the superelevation rate is supposed as 6.6%, the radius will be around 225.56 ft (68.75 m), which effectively entails that the curve is more sharpen and has a higher CR.

Once the road has been characterized, let us prove that the achieved beaconing rate may be insufficient. The traveled distance in the aforementioned semicircular curve will be $\pi \times R$ = 215.98 m. Likewise, the traveled distance until the vehicle heading varies 4º is 4.80 m, and hence, the minimum elapsed time required to trigger a CAM message due to heading variation is $\frac{4.8\ m}{13.41\ \frac{m}{s}}$ = 358 ms. According to [2], $T\_CheckGenCam$ time must be equal or lower than 100 ms. The lower this parameter, the higher motion resolution, and responsiveness will be achieved. If, for example, we set $T\_CheckGenCam$ to 10 ms, which is a very good resolution, we will need more than 35 steps until a new CAM is triggered due to heading condition. The algorithm would allocate $\frac{1\ s}{0.358\ s}$ = 2.79 Hz due to heading condition. Similarly, the position condition will be sent a new CAM every time the position changes 4 m, which is equal to $\frac{4\ m}{13.41\ \frac{m}{s}}$ = 298 ms, or $\frac{1\ s}{0.298\ s}$ = 3.35 Hz. Finally, the speed condition will depend on both the acceleration and deceleration experienced while traveling the curve or will be null (0 Hz) if the speed of the vehicle is constant, as in the example above. The CAM message sending is carried out if the elapsed time reaches T_GenCam_Dcc, not always that the triggering conditions are satisfied. So, the beaconing rate of this curve is not the sum of all the aforementioned individual contributions (2.79 Hz + 3.35 Hz + 0 Hz), but approximately the same as those which results from position condition, 3.35 Hz, plus some peaks from heading and speed conditions. This is a low rate for a curve with a high CR and risk, which results in channel bandwidth underuse and awareness degradation in the neighboring vehicles.

Since the radius of curvature is related to the CR, it is considered a risk factor, and a new CAM triggering condition could be based on this metric. In particular, we propose to dynamically estimate the radius of curvature of the road as vehicle moves from different positions. A schema of the proposed mechanism and the notation employed are summarized in Figure 1. Before moving to further details, it is important to mention that in a real implementation, these positions may be sensitive to noise from the onboard GPS. There are two worst-cases depending upon where the wrong position is located. On one hand, some extra beacons could be triggered by false sharp bends, producing unnecessary channel usage. In contrast, a risky curve may go unnoticed losing the awareness. The aforementioned inaccuracies can be solved by supporting the radius metric with other ones such as heading change rate or the heading threshold degree variation; this has been left as future work.

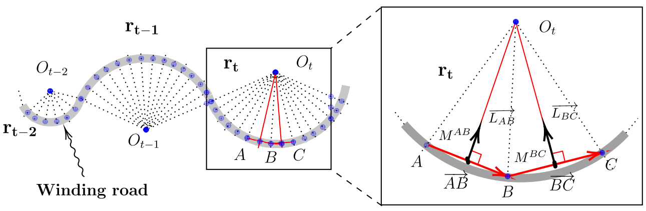

Fig. 1: Notation and schema used to derive the radius metric.

Let us define A, B and C the last three vehicle positions, being C the current position and A the older one. There are different ways to estimate the radius of an arc from three position points, but, in our particular case, we employ the perpendicular bisectors of two chords that meet at the center of the circle. First, we define $\overrightarrow{AB}$ and $\overrightarrow{BC}$ as the chords of the arc described by the road, and M^{AB} and M^{BC} as their corresponding midpoints. Secondly, we calculate the gradients of the chords, $\nabla(\overrightarrow{AB})$ and $\nabla(\overrightarrow{BC})$, to obtain the tensors that tell us how they change in any direction. Since $\overrightarrow{AB}$ and $\overrightarrow{BC}$ are perpendicular to their bisectors, called $\overrightarrow{L_{AB}}$ and $\overrightarrow{L_{BC}}$, their gradients will also be perpendicular to each other: $\nabla(\overrightarrow{AB}) \perp \nabla(\overrightarrow{L_{AB}})$ and $\nabla(\overrightarrow{BC}) \perp \nabla(\overrightarrow{L_{BC}})$. Using the gradients of $\overrightarrow{L_{AB}}$ and $\overrightarrow{L_{BC}}$ and the midpoints, we find the equations of the aforementioned bisectors, as follows:

$$y - M_y^{AB} = \nabla(\overrightarrow{L_{AB}})(x - M_x^{AB}) \tag{2a}$$

$$y - M_x^{BC} = \nabla(\overrightarrow{L_{BC}})(x - M_x^{BC}) \tag{2b}$$

Finally, solving these equations we obtain the center point (x, y), called O. The radius is easily obtained through the module of the vector formed from a position point and the estimated center, R = $|AO|$ = $|BO|$ = $|CO|$. As vehicle moves, the position points stored in the system are updated and a new radius r_t is estimated. If and only if the time between updates is sufficiently low, the next radius can be assumed to be similar to the current one. With this in mind, we update the radius every second (t = 1 s), which is regarded as a low time interval from a vehicular viewpoint. The proposed CAM-DCC adaptation introduces a new CAM triggering condition based on a radius threshold, similarly to speed, heading and position. More details about our proposal performance and the radius employed as threshold are given in the following.

III. Results

In this section, we evaluate the performance of the proposed mechanism against the original CAM-DCC. To this, OMNet++ v5.3 together with the INET v3.5 library, are used to replicate some realistic vehicular environments regarding the wireless channel. Concretely, the INET library implements the IEEE 802.11p standard (PHY and MAC layers), a realistic propagation and interference model for computing the Signal to Interference-plus-Noise Ratio (SINR) and determining the packet reception probabilities, considering also capture effect. In Table II, we summarize the simulation parameters.

TABLE II: Simulation parameters

Parameter	Value
Frequency (f)	5.9 GHz
Power (P)	251 mW
Sensitivity (S)	-92 dBm
Data rate (D)	6 Mbps
SNIR Threshold (T)	4 dB
Background Noise (N)	-110 dBm
Path loss	Nakagami-m
Beacon size	760 μs
Maximum rate (R_v^{max})	10 CAM/s
Minimum rate (R_v^{min})	1 CAM/s
$T\_CheckGenCam$	10 ms
N_GenCam	3

In the first stage, we intend to observe only the turning effect of the vehicle in the proposed algorithm, so channel congestion is ignored by adding a few numbers of cars. We take a winding road section belonging to the State Hwy 22 from Kentucky, US, and set a uniform speed of 20 m/s throughout it. In Figure 2, we plot the transmission rate of a vehicle running both the original CAM-DCC and the proposed, named CAM-DCC-R, the heading angle of the vehicle to better appreciate the curves effect, the speed, and a birds-eye-view sketch of the road, including the times whereby the vehicle passes through these points. As can be observed, the proposed CAM-DCC-R triggers some extra beacons when the vehicles take a curve, and every time that the estimated road radius is lower than 20 m, increasing the awareness of the traffic situation.

A more realistic scenario is replicated in Figure 3, where the different road sections have been adapted to the real speed limitations, which means that the equation (1) is satisfied. In this case, we have used the mountain road section of E-22 road, located between Cartagena and Puerto de Mazarrón, in Murcia, Spain; the radius employed as a threshold the same as in the previous case, 20 m. In the speed profile, we can observe

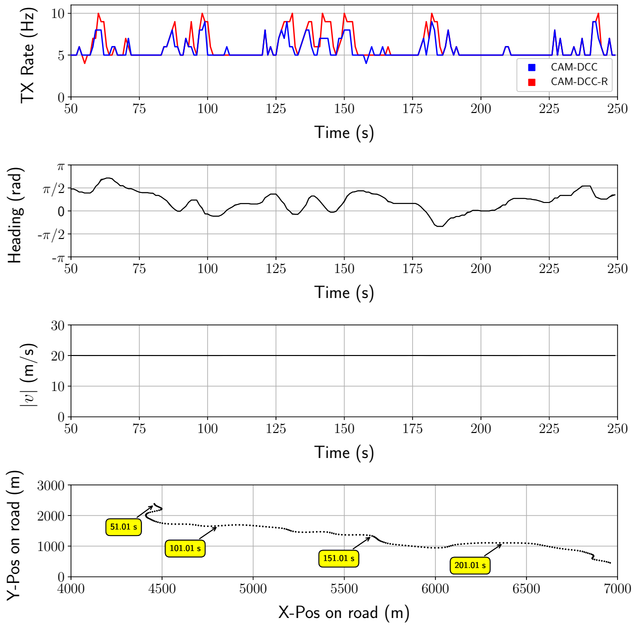

Fig. 2: Comparison between original and radius-metric-adapted CAM-DCC evaluated in a section of the State Hwy 22, Kentucky, US. A uniform speed of 20 m/s have been set in the whole road section to study only the turning effect of the vehicle.

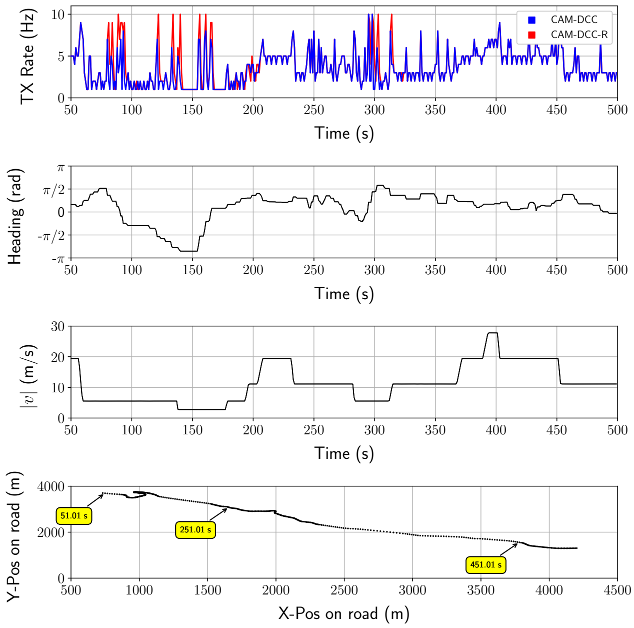

Fig. 3: Comparison between original and radius-metric-adapted CAM-DCC evaluated in the mountain road E-22, located between Cartagena and Puerto de Mazarrón cities, Murcia, Spain. Sections between edges have been adapted to real speed limitations.

that several sharp turns are located about 1000 m, between 75 and 175 seconds of the recorded vehicle's path. Also, a curve is located at 2000 m, about 300 s. The extra transmissions produced by the proposed CAM-DCC are quantified as the ratio between the average beaconing rate of the original CAM-DCC over those of the proposed one, called $\Delta(\%)$. The radius R used as a threshold, that determines if a new CAM is sent or not, will make the extra transmissions percentage Δ vary. For instance, a high R means that a higher number of curves will be included in the CAM triggering, whereas if R is very low, CAM-DCC-R will only take into account the most sharpen curves. This behavior is depicted in Figure 4, where different radiuses between 10 m and 500 m are evaluated, and different Δ are obtained between 2.06 to 36.9%, respectively.

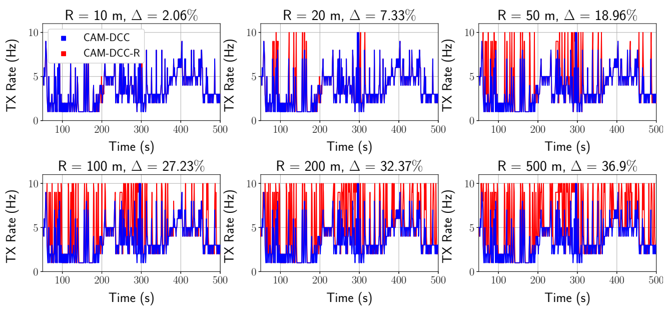

Fig. 4: Evaluation of CAM-DCC-R for different radiuses values in road E-22.

In the previous scenarios, we have used the default CBR limits of the DCC-FSM, and, since we have introduced a few vehicles, the congestion mechanism is not used. Once we have assessed the performance of including new extra CAMs in the standard, it is necessary to prove that it still works in the presence of congestion limitations. Rather than append more vehicles to the simulations, in an equivalent manner, we have reduced the CBR limitations stated by the FSM. More concretely, we have divided by 10 the CBR intervals shown in Table I. For instance, the CBR values lesser than 0.3 becomes to be lesser than 0.03, the 0.30-0.49 interval become to be 0.03-0.049, and so on. The study of packet collisions, losses, fading, and further effects is outside the scope of this article, so maintain a few vehicles is a good approach. We have plotted the results obtained in the E-22 road of the original CAM-DCC with the default FSM scale, and those of the radius-based CAM-DCC-R both with the original and the scaled FSM using a radius threshold of 20 m. As can be shown in Figure 5 for CAM-DCC-R 1/10, notwithstanding the scaled congestion limits, the curves are still reflected with a higher rate, and the CBR is under the stated limits.

IV. Conclusion and Future Work

We have presented a novel triggering condition for the CAM dissemination mechanism of the European Standard EN 302 637-2 to address the likely deficiency of CAM messages in winding roads. Our premise is that this deficiency could cause a failure in the application layer if the information update is

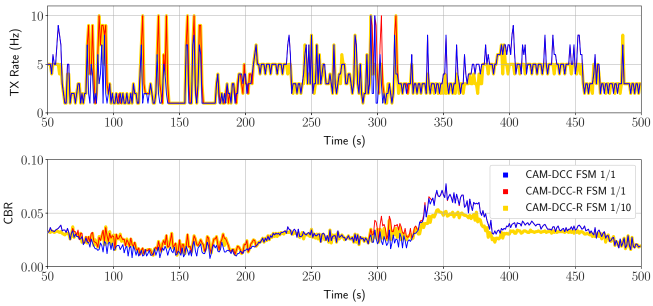

Fig. 5: Study of CBR in the presence of channel load limitations using a 1/10 scaled FSM.

insufficient. Therefore, we propose a triggering condition as a function of the radius of curvature of the road, periodically estimated and used as a risk metric. We have evaluated different radius, and their effect in some real scenarios, for both congestion limited and unconstrained cases, obtaining promising results with regards to extra beaconing and turning awareness.

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