Advisory Speed Estimation for an Improved V2X Communications Awareness in Winding Roads

Juan Aznar-Poveda, Esteban Egea-López, Antonio-Javier García-Sánchez, Joan García-Haro

Department of Information and Communications Technologies

Universidad Politécnica de Cartagena, 30202, Cartagena, Spain

e-mail: {juan.aznar, esteban.egea, antoniojavier.garcia, joang.haro}@upct.es

ABSTRACT

The European Telecommunications Standards Institute (ETSI) establishes a Decentralized Congestion Control (DCC) which triggers the so-called Cooperative Awareness Message (CAM) depending on vehicle kinematics. However, this algorithm hence called CAM-DCC represents a challenge in the triggering rules of these messages. In particular, it lacks (i) awareness of the neighboring vehicles and (ii) efficient use of the channel bandwidth. Consequently, information gaps related to the road environment might give rise to non-compliances in the application layer requirements of the vehicles, which could potentially threaten the drivers' safety, most particularly in hazardous roads. To overcome these flaws, we first study the CAM generation trigger focused on the vehicle heading in risky curves or winding roads. Then, we evaluate both scenarios tuning different triggering thresholds and including additional mechanisms such as the comparison of the current speed respect to the estimated advisory speed over time. Different computer simulations have been conducted in two real road sections to validate our proposal. Results reveal significant better performance in terms of awareness and channel usage.

Keywords: Vehicular networks, Cooperative Awareness Message, Rate control, Winding and curved roads, Congestion, Awareness

1. INTRODUCTION

In recent decades, road accidents involved large mortality ratios [1]. Given the self-evident high importance of the passengers' safety and their protection, many of the technological advances in the vehicular industry are addressed to avoid accidents or reducing their severity through different measures. In general, current safety developments fall into two main groups depending on when they are applied. First, passive systems. They come into play once the accident is unavoidable to minimize the passengers' injuries since they remain passive until some car sensors are triggered. Examples include smart airbags, seat belts, the vehicle body, chassis or headrests. In contrast, active systems are those preventing accidents or crashes anytime while driving, such as adaptive headlights, collision avoidance, lane departure warnings, blind-spot vehicle alerts, electronic stability program (ESP), or antilock brake systems (ABS).

Most of the aforementioned active safety systems are based on data obtained from neighboring vehicles. Data, usually called awareness, are dispatched by periodical broadcast messages denoted as Cooperative Awareness Messages (CAM), also termed beacons, as defined in EN 302 637-2 standard [2] by the European Telecommunications Standards Institute (ETSI). Furthermore, having in mind the road as a highly dynamic environment, a careful periodical beaconing broadcast is required to keep the information updated. For instance, if the beaconing rate is not appropriately allocated, different problems may arise motivated by requirements not satisfied. On the one hand, if the number of messages received is too low, the channel is underused and, therefore, the application layer handles outdated information. This would imply unsatisfactory solutions while driving, especially in risky roads. Conversely, if the load caused by beacons in the wireless channel is high, errors produced by channel congestion must be considered, especially if the event-driven messages from Decentralized Environmental Notification (DEN) service are lost. Under these circumstances, the beaconing rate must be fairly allocated among vehicles. This means that the surrounding traffic situation must be an input parameter in the resource allocation in order to discern those *hazard vehicles*, and thus provide more useful information to their application layer services.

To overcome the overloading case in the ITS-G5 radio channel, the ETSI defined the Cross-Layer Decentralized Congestion Control (DCC) Management Entity [3]. This entity was tested and validated by two pure rate control algorithms: (i) a reactive control, denoted as CAM-DCC [2], where the message rate is controlled by a finite state machine, and (ii) an adaptive linear control, called LIMERIC [4]. In this paper, we focus on reactive control, which manages the congestion issue by calculating the elapsed time from the last beacon sent to restrict the generation of new ones. Regarding the CAM allocation, it is fairly prioritized and controlled by certain generation rules based on vehicle dynamics. However, these rules lack clear motivation and, in the absence of abrupt vehicle dynamic variations, few or even no additional beacons are generated. This low number of beacons may entail underestimating the risk on certain roads.

In this paper, we contribute to the two following aspects. Firstly, we evaluate the current behavior of CAM-DCC by tuning the heading threshold. Secondly, in view of the obtained results, a novel triggering condition is designed to improve the awareness in winding roads or sharp bends. Vehicles evaluate the same physical parameters involved in the design of the road, more specifically comparing the current speed of the vehicle with the estimated advisory speed (calculated theoretically during driving), to later set a new CAM triggering condition.
The rest of this paper is organized as follows. In Section 2, we describe in detail the CAM-DCC standard for facilitating the reader's understanding. We discuss the shortcomings of the aforementioned standard to later point out the value of our proposal to achieve better performance in winding roads and sharpen curves. Section 3 validates the model, compares it against the original congestion control algorithm and discusses the obtained results. In Section 4, we summarize this paper and state future research lines.

2. BACKGROUND AND PROPOSAL

Concerning the EN 302 637-2 standard, CAM-DCC triggers a CAM depending on the vehicle dynamics and the channel congestion status. As a rule, the algorithm is executed every *T_CheckCamGen* seconds (typically a low enough value to reach a good time resolution) and sets 1 and 10 Hz as the minimum and maximum reachable beaconing rate. Now, we describe the reactive control mechanism provided by the DCC entity without going into details of the congestion control methodology. A finite state machine (FSM) based on channel busy rate (CBR) measurements regulates the channel congestion by limiting the elapsed time between CAM transmissions (configured by the *T_GenCam_Dcc* variable). Once this condition is satisfied and the elapsed time between transmission is below *T_GenCam_Dcc*, the congestion is controlled. At this moment, the vehicle kinetic is checked just before transmitting a new CAM. In particular, CAM-DCC measures the absolute difference between the current heading, position and speed, and those sent in the previous CAM. If any of these conditions exceeds the values of 4º, 4 m and 0.5 m/s, respectively, a new CAM is then dispatched. On the contrary, if no changes are detected in the vehicle heading, position or speed, a new CAM is generated only if the elapsed time from the last CAM transmission is higher than or equal to the value stored in the *T_GenCam* variable. If this situation of low dynamics remains over time, the algorithm will send *N_GenCam* messages (usually three messages) before setting the minimum rate (1 Hz) to *T_GenCam*. In any other case, when a CAM is transmitted by kinetic rules, *T_GenCam* is set to the elapsed time from the previous transmission. In short, the CAM-DCC algorithm is based on measuring the speed, position, and heading changes over time to decide whether or not a new beacon is transmitted. These premises ignore the risk of the curves, since vehicle dynamics are lower than in other types of roads (e.g. highway), and therefore a lower number of CAMs are transmitted. This entails a poor awareness in scenarios as winding roads or sharp bends.
To consider road risks, we design a novel proposal conceived for enhancing the CAM-DCC. The result is a new triggering condition whose basis are the road design parameters. This new CAM-DCC release is achieved by increasing the number of CAM transmissions for the scenarios under study, and allowing appropriate operation of diverse road safety and traffic efficiency applications, as described in ETSI TR 102 638 [5]. The new triggering condition included in the CAM-DCC algorithm after checking the congestion condition is as follows. If the current speed is higher than 85% of the estimated advisory speed, a new CAM is transmitted. The advisory *speed* will be briefly explained in the following paragraphs.
The Federal Highway Administration, which belongs to the U.S. Department of Transportation, defines different parameters to quantify the risk of a road [6], being the top five: radius, superelevation, tangent speed, vehicle type, and curve deflection angle. These parameters allow us to (i) set the road restrictions and speed limits, and (ii) to be aware of those physical magnitudes that must be measured to provide a better awareness. In particular, a combination of the road radius together with the advisory speed estimation is included in the CAM-DCC algorithm as a priority triggering condition. On the one hand, the radius is the parameter most directly related to the risk of a curve [7]. It is easy to observe that the lower the road radius, the larger the risk. Regarding the advisory speed, it is also an important risk indicative; if this value is exceeded, it could denote a serious accident. There are different methods to determine the advisory speeds of specific stretches of road. The oldest empirical method is the so-called Driver Comfort Speed Method, whose main idea is based on "which causes an occupant of the vehicle to feel an outward pitch" and later refined as "that speed at which the driver's judgment recognized incipient instability." This is a very subjective method and provides inconsistent results. A current method, employed in our proposal, is the called AASHTO (American Association of State Highway and Transportation Officials) Geometric Design Method, which calculates the advisory speed from physical parameters obtained in the traditional highway design process, as described in equation (1):

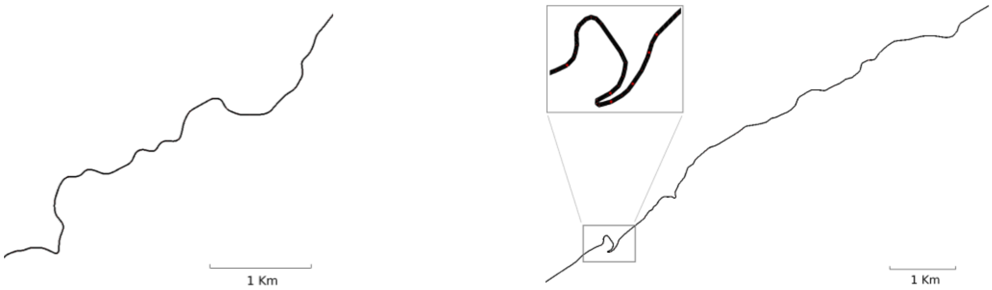
$$V_a = \sqrt{15R(0.01e + f)} \tag{1}$$

where the advisory speed (V_a) is derived from the radius (R), the superelevation (e), and the road friction coefficient (f). Typical values for superelevation and friction coefficient are 0.066 and 0.2, respectively. The radius can be geometrically calculated though the different GPS positions of the vehicle in temporal intervals of

T_CheckCamGen seconds. Since GPS data may be noisy, a bad estimation of the radius may result. To overcome this shortcoming, vehicle positions are computed employing also their initial position, speed, and acceleration vectors. In detail, given an initial position in a given time, we estimate the next position of the vehicle through its speed and acceleration vectors and averaging it with the next GPS position. Once at least three positions have been calculated and stored in the vehicle engine control unit (ECU), the radius is determined and then the estimated advisory speed is obtained by (1).

3. RESULTS

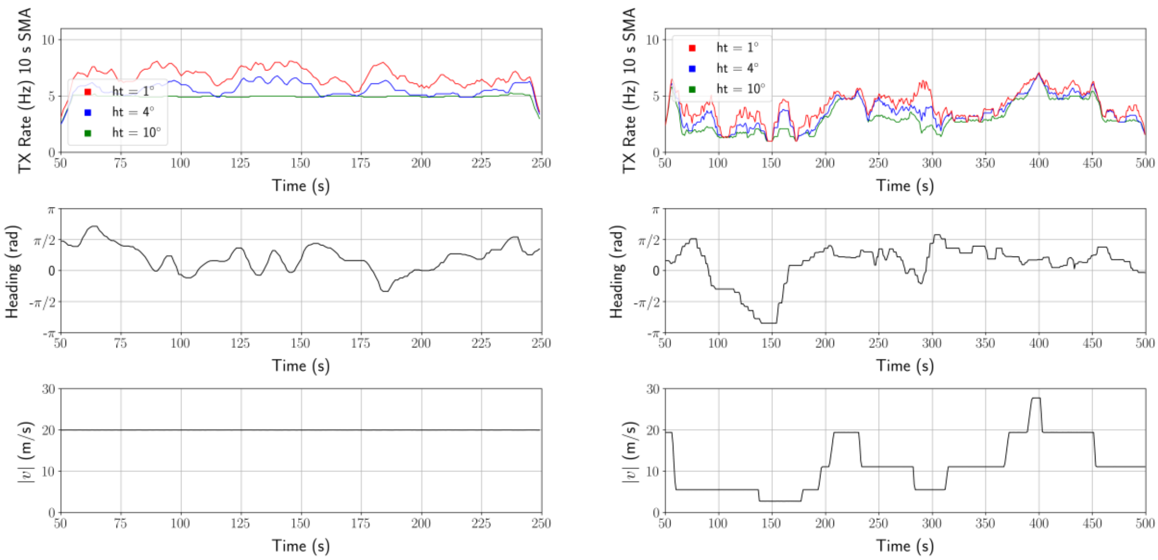
In this section, we evaluate the performance of our proposed mechanism and compare it against the original CAM-DCC. For this purpose, OMNeT++ v5.3 and its INET v3.5 libraries are used to replicate realistic vehicular environments and wireless communications. In particular, INET libraries include the IEEE 802.11p standard module (PHY and MAC layers) comprising, among other features, a realistic propagation and interference model to (i) compute the Signal to Interference-plus-Noise Ratio (SINR) and (ii) determine the packet reception probabilities. Two real winding road sections have been simulated: (i) a section of the State Hwy 22 from Kentucky, US, with a uniform speed of the vehicles of 20 m/s, and (ii) a section of the E-22 mountain road located between Cartagena and Puerto de Mazarrón, Spain, considering the real speed limits of the road. A birds-eye view of both road sections is illustrated in Figure 1.



(a) Hwy 22 Kentucky **(b) E-22 Cartagena**

Figure 1. Birds-eye view of the different road sections under study: (a) State Hwy 22 from Kentucky, US and (b) E-22 Cartagena, where most sharpen bend has been zoomed for a better viewing.

First, we perform tuning of the heading threshold (*ht*) in the original CAM-DCC algorithm, which is set by default at 4º. The speed, heading, and the beaconing rate parameters evolution for a random vehicle that drives through the road section are illustrated in Figure 2. The moving average of the beaconing rate using 10 s intervals has been calculated to remove excessive peaks and easily observe the effect of the tuning in the *ht*.



Hwy 22 Kentucky **E-22 Cartagena**

Figure 2. Tuning of the heading threshold (ht) for values 1º, 4º, and 10º.

As can be observed for both sections, the CAM-DCC algorithm tends to follow the behaviour of the speed magnitude if the *ht* value is too high (i.e. 10º or larger). This is because the heading condition rarely triggers a new CAM, and only the position and speed conditions cause transmissions. Conversely, if the heading threshold is lower than 4º, a higher heading resolution is obtained, and the rate generated by the CAM-DCC algorithm is due to the speed plus some extra transmissions from the heading changes. Following this reasoning, a low *ht* (i.e. 1º) provides a better awareness in winding roads where the speed is lower (and also the rate). The triggering condition based on the advisory speed is depicted in Figure 3, where the tightest curve of the E-22 road (170-180 s period) has been simulated for two speeds: the advisory speed and a much higher value (2.77 m/s and 13.88 m/s). Note that for a lower *ht* value, the mechanism here proposed allows us to obtain a higher information exchange when the advisory speed is exceeded and, therefore, the risk increases. This is why this awareness improvement is not reached only in the curve where the speed has changed to 13.88 m/s, but also in other curves, as can be seen in the intervals 110-130 s, 150-160 s, 200-220 s, and 230-245 s. If we had applied the original CAM-DCC, it would had provided a lower beaconing rate in these curves, just reacting when the speed is drastically varied (170-180 s).

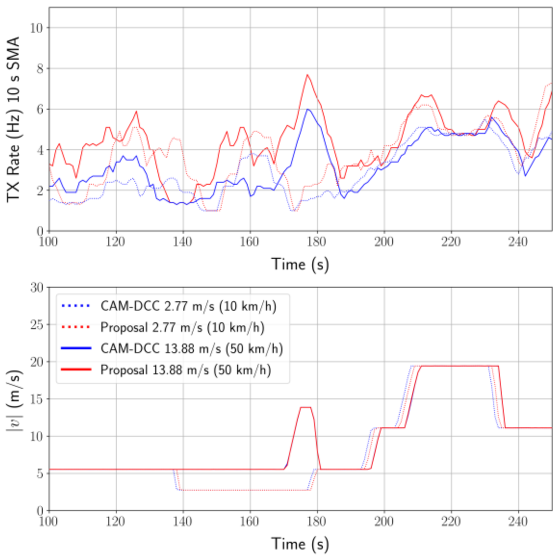


Figure 3. Evaluation of the CAM-DCC for the tightest curve belonging to the E-22 road using the proposed triggering condition.

4. CONCLUSIONS

In summary, the default mechanism of the ETSI standard for generating cooperative awareness messages, i.e. the CAM-DCC, results in low transmissions even in situations that require a higher information exchange. One of these situations are the winding roads since usually imply low vehicle dynamics when curves are traversed. Therefore, this scenario in CAM-DCC underestimates the risk of the curves. To approach this problem and better evaluate the risk while driving, we propose to introduce in the CAM algorithm diverse magnitudes and parameters of the road design instead of vehicle parameters only. Higher awareness and beaconing rate are successfully achieved by adding both the road radius and advisory speed in the triggering conditions. In doing so, the congestion control is not practically affected since it is previously checked according the FSM of the algorithm. Further changes and optimizations have been left for future works.

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