Context-based Communications Dimensioning for Safety Applications in Wireless Vehicular Systems

M. Sepulcre and J. Gozalvez, *Member, IEEE*
Signal Theory and Communications Division
University Miguel Hernández
Elche, Spain
msepulcre@umh.es, j.gozalvez@umh.es

***Abstract*—The use of wireless vehicular communication systems for traffic safety applications imposes a careful and adequate communications dimensioning to ensure the transmission of broadcast safety messages in a timely manner. To date, several studies have proposed an adaptive dimensioning of the inter-vehicle communication protocols based on the particular operating conditions of the transmitting vehicles. This work complements these initial investigations by proposing and demonstrating the need to dimension such communication protocols not only based on the operating conditions but also on the vehicular context. By modifying the communication parameters based on the presence of nearby vehicles, the proposed context-based communications dimensioning reduces the risk of chain collisions.**

***Keywords-component*—Communications dimensioning, context-aware, vehicular communications systems.**

I. Introduction

Wireless vehicular communications have been identified as a suitable technology to improve road safety and provide ubiquitous connectivity while on the move. To exploit its potential, the IEEE established the IEEE 802.11p working group that is actually working on evolving IEEE 802.11 to define a standard for the vehicular environment, usually referred as Wireless Access in Vehicular Environments (WAVE) [1], addressing both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. The WAVE standard evolves the IEEE 802.11a system and covers the physical and MAC (Medium Access Control) layers of the protocol stack. The WAVE proposal is based on seven, ten-megahertz channels consisting of one Control Channel and six Service Channels in the 5.9GHz band. While the service channels are used for public-safety and private services, the control channel is used as the reference channel to initiate and establish any type of communication links by means of short broadcast messages. As shown in [2], V2V communications can help improve road safety at intersections through the exchange of information related to the vehicle's position, speed and acceleration. V2V communications also allow for the establishment of Vehicular Ad-hoc Networks (VANETs) that help reducing collisions among nearby vehicles through the quick propagation of broadcast safety messages [3].

Wireless V2V communication schemes need to be carefully dimensioned to meet the strict latency and reliability QoS (Quality of Service) requirements of traffic safety applications. The adequate dimensioning of V2V communication protocols also faces significant technical challenges derived from the vehicles high mobility, the fast VANET topology changes and their decentralized communication management. In this context, previous studies ([4] and [5]) demonstrated the need and benefits derived from adapting the communication parameters (e.g., transmission power and packet rates) to the particular operating conditions (e.g., vehicles speed and traffic density). Although such studies provided valuable insights into the correct dimensioning of V2V communications for collision avoidance, they did not consider in the protocols dimensioning the potential impact on surrounding vehicles of sudden actions from a driver caused by the late reception of a broadcast safety alert. The importance of considering the vehicular context in the communications protocol dimensioning can be illustrated through the intersection scenario where a vehicle is alerted of a potential collision a short time before reaching the intersection. Although this vehicle might avoid the accident at the intersection by immediately decelerating after the broadcast safety message reception, its sudden deceleration might cause an accident with the vehicles following it if those did not have sufficient time to react. This chain collision situation could have been avoided if the communications system was dimensioned so that the first vehicle approaching the intersection received the broadcast safety message not only with sufficient time to decelerate before reaching the intersection, but also with sufficient time to allow for a smooth deceleration that would not result in sudden actions that can cause chain collision accidents. In this context, this work proposes a novel context-based wireless vehicular communications dimensioning policy for safety applications that avoids propagation of an accident among surrounding vehicles by adapting the communication parameters based on the presence of surrounding vehicles.

This work was supported in part by the Spanish *Ministerio de Fomento* under the project T39/2006, by the *Generalitat Valenciana* under research grant BFPI06/126 and by the University Miguel Hernández under the 2005 Young Researcher Award received by Dr. Javier Gozalvez.

II. TRAFFIC SAFETY VEHICULAR CONTEXT SCENARIO

To analyse the context-based V2V communications dimensioning proposed in this work, we consider the urban intersection scenario without visibility illustrated in Fig. 1. This scenario has been selected since it represents a difficult radio propagation environment in which an adequate V2V communications dimensioning will have a major impact on the traffic safety efficiency of wireless vehicular systems. The intersection scenario was also selected based on US studies showing that about 26% of vehicles collisions occur at intersections. In any case, it is important to note that the methodology proposed in this work can be extended to other wireless vehicular scenarios.

Based on the scenario reported in Fig. 1, we define the critical distance CD as the minimum distance to the intersection at which vehicle A_1 needs to receive a broadcast safety message from vehicle B to avoid their potential collision at the intersection. Considering a uniform deceleration model, the critical distance can be computed as follows:

$$CD = v \cdot RT + \frac{1}{2}\frac{v^2}{a_{\max}} \tag{1}$$

where v represents the vehicle's speed, RT the driver's reaction time and a_{max} the vehicle's emergency deceleration. The work presented in [4] proposed the use of adaptive dimensioning schemes to ensure the correct reception of a broadcast safety message before reaching CD based on the specific operating conditions. Although sufficient to avoid a collision between vehicles A_1 and B, the dimensioning policies discussed in [4] do not consider the possibility of a chain collision between vehicles A_i resulting from the sudden deceleration of A_1 caused by the late reception of the first broadcast safety message from vehicle B. To avoid these chain collisions, this work proposes to extend the dimensioning policies analysed in [4] through a contextual approach that also adapts the communication parameters (e.g., the transmission power) based on the presence of surrounding vehicles, the distance between vehicles, the driver's reaction time and the time needed to propagate a safety alert among nearby vehicles. In this case, the minimum distance to the intersection at which vehicle A_1 receives the first broadcast safety message from vehicle B needs to be extended so that the sudden decelerations that can result in chain collisions are avoided. To estimate such distance extension, we consider that the N-1 vehicles, A_2, A_3,…A_N, following vehicle A_1 are uniformly spaced by distance IVS (Inter-Vehicle Spacing). To estimate the required extra distance (ED) for this contextual communications dimensioning, we consider that the distance to the intersection $d_i(t)$ of each vehicle A_i can be defined with the following equations[1]:

[1] While the first relation in equation (2) corresponds to the case in which a vehicle is not yet decelerating, the second one represents a uniform deceleration scenario.

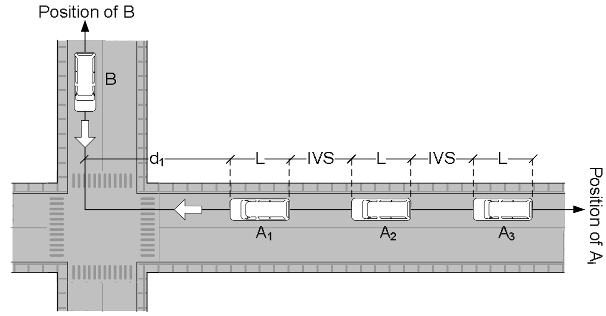

Figure 1. Intersection scenario

$$d_i(t) = \begin{cases} -vt + CD + ED + (i-1)(L+IVS) \\ \qquad if \quad t < RT + (i-1)PT \\ \frac{1}{2}a_i(t - RT - (i-1)PT)^2 - vt + CD + ED + (i-1)(L+IVS) \\ \qquad if \quad t > RT + (i-1)PT \end{cases} \tag{2}$$

where a_i is the deceleration of vehicle A_i, L is the vehicle's length and PT is the propagation time of a broadcast safety message from vehicle A_i to vehicle A_{i+1}. In terms of the propagation time, two scenarios can be envisaged. In the first scenario, a broadcast safety message received by vehicle A_1 is propagated to vehicle A_2 through a visual alert using the vehicle's brake lights. In this case, PT is equal to the driver's reaction time (RT). In the second scenario, the vehicles moving along the same street have established a VANET they use to propagate the reception of broadcast safety alerts. The use of VANETs to propagate broadcast safety alerts between nearby vehicles can significantly reduce the PT. As reported in [3], the PT for this second scenario varies between 0.1 and 0.4 seconds.

To establish equation (2), the time origin has been set at the moment at which vehicle A_1 receives the first broadcast safety message from B. At this instant, vehicle A_1 is located at distance $d_1(0)=CD+ED$ from the intersection. After RT seconds, A_1 starts to decelerate in order to avoid a collision at the intersection. Similarly, vehicle A_2 receives the broadcast safety message from vehicle A_1 at $t=PT$ and starts decelerating at $t=RT+PT$. Consequently, vehicle A_i would receive the broadcast safety message from vehicle A_{i-1} at $t=(i-1)PT$ and start decelerating at $t=RT+(i-1)PT$. To avoid chain collisions, the maximum deceleration of vehicle A_i depends on the deceleration of vehicle A_{i+1}. As a result, establishing ED requires computing the maximum deceleration a_i for each vehicle. To this end, we have assumed that the last vehicle in the chain stops with a deceleration a_{max} given that its sudden action would not affect any following vehicles. The value of a_i can then be obtained solving recursively, and in a descending order, the equation $d_i(t)<d_{i+1}(t)-L$ for $i=(N-1)$ to 1[2]:

[2] The analytical development resulting in the extraction of a_i is not shown due to space limitations and to concentrate on the required communications dimensioning when considering the vehicular context.

$$a_i = \begin{cases} \dfrac{0.5v^2}{vPT + \dfrac{0.5v^2}{a_{i+1}} - IVS} & if \quad 0.5vPT \le IVS \\ \dfrac{a_{i+1}(t^* - RT - 2PT)^2 + 2IVS}{(t^* - RT - PT)^2} & if \quad 0.5vPT > IVS \end{cases} \tag{3}$$

where

$$t^* = \frac{2IVS}{PTa_{i+1}} + 2PT + RT \tag{4}$$

Once a_i has been obtained, ED can be computed using equation (2), and considering that vehicle A_1 stops at the intersection ($d_1=0$) and that the time needed to stop from the moment that vehicle A_1 receives the broadcast safety message from B is equal to v/a_1+RT:

$$d_1\left(\frac{v}{a_1} + RT\right) = 0 \tag{5}$$

Equation (6) shows, as an example, the distance ED computed for the scenario in which $N=2$ and $0.5vPT > IVS$:

$$ED = \frac{1}{2}v^2\left[\frac{\left(\dfrac{2IVS}{PTa_{\max}} + PT\right)^2}{a_{\max}\left(\dfrac{2IVS}{PTa_{\max}}\right)^2 + 2IVS} - \frac{1}{a_{\max}}\right] \tag{6}$$

It is important to note that although the parameter N is not part of the equations shown, the dependence of the ED parameter with regard to N is implicit in the recursive calculations needed to compute a_i.

Fig. 2 shows the impact of the vehicle's speed and the distance between vehicles on the ED parameter considering the scenario in which the broadcast safety alert is visually propagated ($PT=RT$). The obtained results show that the distance at which a broadcast safety message needs to be received from the potentially colliding vehicle can be defined as CD (i.e. ED = 0) under fluid traffic conditions and low vehicular speeds. On the other hand, the ED distance required to avoid chain collisions can be quite significant at high speeds and at dense traffic conditions (short IVS distances). The results shown in Table 1 also highlight the strong dependence of the ED distance with PT and the number of nearby vehicles. In fact, Table 1 emphasizes the difference between a visual and a radio alert propagation scheme since the use of VANETs to propagate broadcast safety alerts can significantly reduce the needed ED distance to avoid chain collisions.

III. Context-based V2V communications dimensioning

The previous section has highlighted the need to consider the vehicular context when establishing the distances at which a broadcast safety message needs to be received. By considering this vehicular context, V2V communications

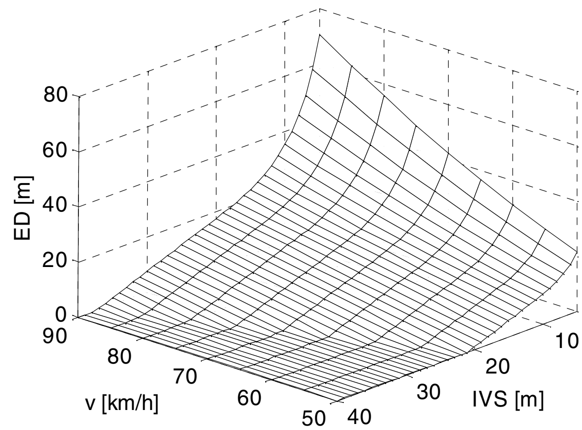

Figure 2. ED vs. the vehicular speed and the IVS distance ($N=2$ vehicles and $RT=PT=1.5s$)

TABLE I. ED for $V=70KM/H$, and $IVS=5M$.

	RT=0.75s		RT=1.5s	
PT (s)	**N=2**	**N=5**	**N=2**	**N=5**
0.1	0.0	0.0	0.0	0.0
0.4	2.8	11.1	2.8	11.1
(=RT)	10.6	42.5	42.5	170.1

would be able to assist a driver to avoid a potential collision while minimizing the potential negative impact in nearby vehicles caused by the driver's reaction to a collision alert. After quantifying under varying operating conditions the required extra distance to avoid such negative effects (in our scenario, chain collisions), this section studies the impact of this vehicular context on the dimensioning of V2V communications protocols.

A. Simulation platform

This work has been conducted using a V2V communications simulation platform implemented in ns2. The platform simulates the urban intersection scenario illustrated in Fig. 1 with the parameters reported in Table 2; the parameters have been established following the WAVE recommendations and [3]. To avoid a potential collision at the intersection, vehicles periodically transmit broadcast safety messages in the ad-hoc WAVE Control Channel. Messages are transmitted at 6Mpbs following the 1/2 QPSK transmission mode defined for the WAVE Control Channel.

A detailed urban micro-cell propagation model developed in the WINNER project [6] has been considered to model the radio transmission effects defined in terms of pathloss, shadowing and multipath fading. Despite not considering V2V communication scenarios, the operating conditions of the urban micro-cell WINNER are, to the knowledge of the authors, those that currently best fit the V2V communications scenario[3]. It is also important to note that despite the interesting work currently underway to model the V2V propagation channel [7], no complete V2V communication propagation model for system level investigations has yet been published.

The WINNER propagation model differentiates between LOS (Line of Sight) and NLOS conditions. The NLOS and LOS pathloss expressions are defined as follows:

$$PL_{NLOS} = PL_{LOS}(d_1[m]) + 20 - 12.5n_j + 10n_j \log_{10}(d_B[m]) \quad (7)$$

$$n_j = \max(2.8 - 0.0024d_1[m], 1.84) \quad (8)$$

and

$$PL_{LOS} = \begin{cases} 22.7\log_{10}(d_1[m]) + 41 + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d_1 < R_{bp} \\ 40\log_{10}(d_1[m]) + 41 - 17.3\log_{10}(R_{bp}) + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d_1 \geq R_{bp} \end{cases} \quad (9)$$

$$R_{bp} = 4\frac{(h_1 - 1)(h_B - 1)}{\lambda} \quad (10)$$

with d_1 and d_B representing the distances of vehicles A_1 and B to the intersection, and h_1 and h_B their respective antenna heights.

The shadowing is modelled through a log normal distribution with a zero mean and a standard deviation equal to 3dB and 4dB for LOS and NLOS conditions respectively. To model the spatially correlated nature of the shadowing, the simulation platform also implements the shadowing correlation through the Gudmunson model [8]. Finally, the fast fading effect resulting from the reception of multiple replicas of the transmitted signal at the receiver has also been implemented. In particular, the multipath fading is modelled through a Ricean distribution, with the K parameter depending on the distance, for LOS conditions, and with a Rayleigh distribution under NLOS conditions.

To reduce the complexity of system level simulations, the effects of the physical layer resulting from the probabilistic nature of the radio environment have been included by means of the Look-Up Tables (LUTs) shown in Fig. 3 [9]. These LUTs, extracted from link level simulations, map the Packet Error Rate (PER) to the experienced channel quality conditions expressed in terms of the effective Signal to Interference and Noise Ratio (SINR), E_{av}/N_0.

B. V2V communications dimensioning

Fig. 4 plots the required broadcast transmission power for vehicles A_1 and B to detect each other's presence at distances CD or $CD+ED$ before reaching the intersection. While receiving a broadcast safety message at CD would help avoiding a collision between vehicles A_1 and B, only receiving such message at $CD+ED$ would also help preventing a potential chain collision between vehicles A_i derived from a sudden driver's reaction after receiving a broadcast safety receiving with little time to react. The represented transmission powers have theoretically been obtained considering the WINNER pathloss model and a target PER of 3%. As depicted in Fig. 4, high traffic densities and large alert propagation times require significantly increasing the transmission powers to not only avoid a collision at the intersection but also prevent potential chain collisions. In fact, the obtained results also emphasize the important communication dimensioning benefits (i.e. low transmission powers) derived from the use of VANETs with low propagation times.

Fig. 5 also represents the transmission power for various target probabilities of correctly receiving a message before the distance CD or $CD+ED$, but estimated through the implemented simulation platform. First of all, it is important to stress the significant differences resulting from the use of a simplified estimation methodology or a more realistic system and channel modelling. It is also interesting to note that targeting a higher transmission reliability significantly affects the communication parameters when considering the proposed context-based wireless vehicular dimensioning policy. This is the case because of the probabilistic nature of the wireless radio channel that significantly hinders the possibility to guarantee a high and sustained signal level quality level.

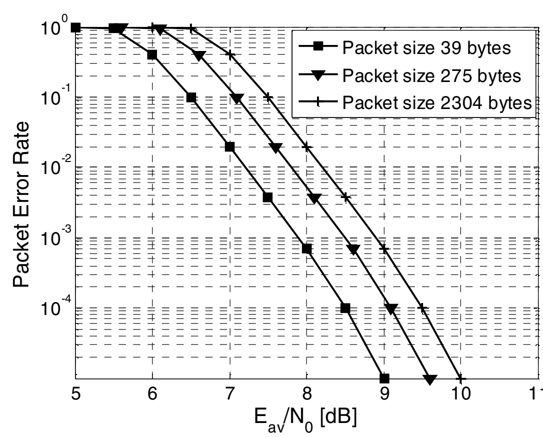

Figure 3. Packet Error Rate for the WAVE Control Channel

TABLE II. SIMULATION PARAMETERS

Parameter	Value
Speed, v, [km/h]	50, 70, 90
Inter-vehicle spacing, IVS [m]	5, 10
Reaction time, RT, [s]	0.75, 1.5
Length of vehicles, L, [m]	4
Emergency deceleration, a_{max}, [m/s^2]	8
Packet size [bytes]	100
Packet transmission rate [packets/sec]	10
Data rate [Mbps]	6
Background noise, N_o, [dBm]	-90

[3] The WINNER model considers a transmission height of 5m and a frequency range between 2GHz and 6GHz.

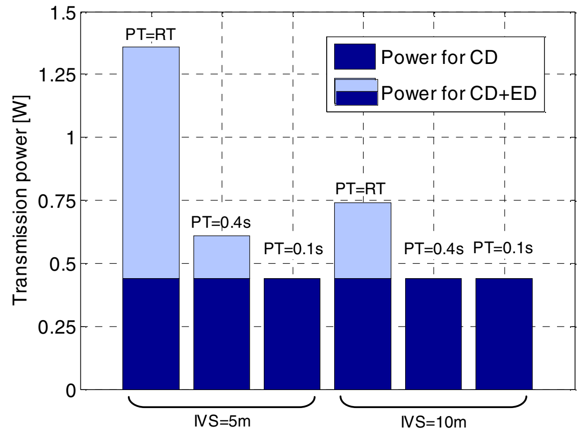

Figure 4. Theoretic broadcast transmission power (v=70km/h, N=2 vehicles, RT=0.75s and a target PER of 3%)

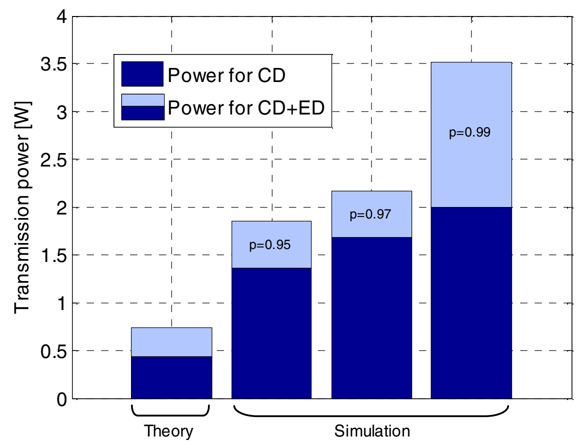

Figure 5. Simulated broadcast transmission power (v=70km/h, N=2 vehicles, RT=PT=0.75s and IVS=10m)

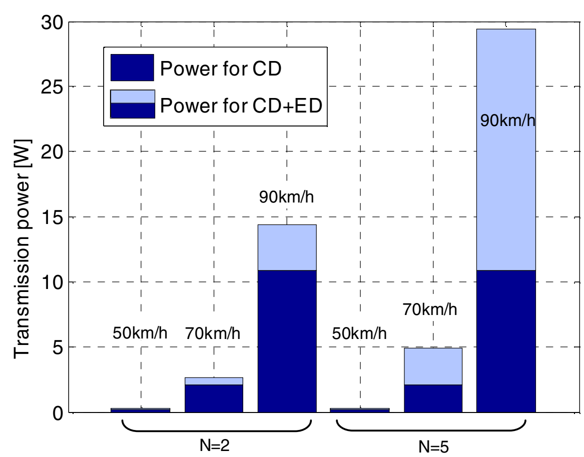

Figure 6. Dimensioning the broadcast transmission power under various operating conditions (IVS=5m, TR=1.5s, TP=0.4s, and PER target of 1%)

Finally, Fig. 6 analyses the dimensioning of the broadcast transmission power under various operating conditions. This figure highlights the notorious impact of the vehicular speed on the communications parameters to prevent chain collisions[4]. The results illustrated in Fig. 6 also indicate that the number of nearby vehicles moving along the same street should strongly be considered to dimension the V2V communication protocols.

IV. CONCLUSIONS

This work has proposed and demonstrated the need to dimension V2V communication protocols based on the specific applications needs, the operating conditions and the vehicular context. In particular, the conducted research has highlighted the need to modify the communication parameter settings (in this case, the transmission power) to prevent chain collisions derived from the driver's reaction to the exchange of broadcast safety messages. The modifications required can be quite considerable for dense traffic conditions, high vehicular speeds and when not considering the use of VANETs to propagate collision avoidance alerts. On the other hand, the conducted research has highlighted the important benefit derived from the use of VANETs with low propagation times to reduce the required transmission power in the proposed context-based wireless vehicular communications dimensioning policy.

REFERENCES

[1] IEEE P802.11p/D0.21, "Draft Part 11: WLAN MAC and PHY Specifications: Wireless Access in Vehicular Environments (WAVE)", *IEEE Standards Association*, June 2005.

[2] Y. Liu U. Ozguner and E. Ekici, "Performance evaluation of intersection warning system using a vehicle traffic and wireless simulator," *Proc. of the Intelligent Vehicles Symposium*, June 2005, Las Vegas, USA, pp. 171–176.

[3] S. Biswas, R. Tatchikou, and F. Dion, "Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety", *IEEE Communications Magazine*, January 2006, pp 74-82

[4] M. Sepulcre and J. Gozalvez, "Dimensioning WAVE-based inter-vehicle communication systems for vehicular safety applications", *Proc. of the International Symposium on Wireless Communications Systems*, September 2006, Valencia, Spain, pp 312-316.

[5] M. Torrent-Moreno, S. Corroy, F. Schmidt-Eisenlohr and H. Hartenstein, "IEEE 802.11-based one-hop broadcast communications: understanding transmission success and failure under different radio propagation environments", *Proc. of the International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, October 2006, Torremolinos, Spain, pp 68-77.

[6] WINNER, "D1.1.1. WINNER II interim channel models", *Public Deliverable*, https://www.ist-winner.org/index.html

[7] D.W. Matolak, I. Sen, W. Xiong, and N.T. Yaskoff, "5 GHZ wireless channel characterization for vehicle to vehicle communications", *Proc. of the Military Communications Conference (Milcom)*, October 2005, pp 3016-3022.

[8] M. Gudmundson, "Correlation model for shadow fading in mobile radio systems", *Electronic Letters*, 27(23), November 1991.

[9] Y. Zang, L. Stibor, G. Orfanos, S. Guo and H. Reumerman. "An error model for inter-vehicle communications in highway scenarios at 5.9GHz", *Proc. of the International Workshop on Performance evaluation of wireless ad hoc, sensor, and ubiquitous net-works*, October 2005, Quebec, Canada, pp 49-56.

[4] The WAVE control channel transmission power limits are reached for high vehicular speeds, in which case, other alternative solutions, like the deployment of road infrastructure, would have to be considered.