ReviewersôComments and Authors Response

Paper number: ADHOC-D-13-37
Paper title: Reverse Back-off Mechanism for Safety Vehicular Ad Hoc Networks
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The authors would like to thank the area editor and the reviewers for their precious time and invaluable comments. We have carefully addressed all the comments. The corresponding changes and refinements made in the revised paper are summarized in our response below.

Reviewer #2: This paper has a potential to be accepted, but some important points have to be clarified or fixed before we can proceed and a positive action can be taken.

We here summarize this points:

1. It is really unclear to me the vehicular scenario that the authors take into consideration. This is an important point before we can start to reason about the proposed method seriously. We need to understand precisely if the proposed mechanism is able to face with the following:

- different vehicles may have different transmission ranges and receiver sensitivities depending on the hardware devices they mount,

The observations of the reviewer are exact; the contention window (CW) is only one of the parameters that can be adjusted in a vehicular environment. In a complete framework, such as the one described in the ETSI Decentralized Congestion Control architecture, parameters such as the transmission power and/or receiver sensitivity will also be adapted. However, the goal of this paper is to isolate and understand the impact of CW on the losses experienced by Cooperative Awareness Messages, therefore no other parameter is modified in this study. Nevertheless, the reverse back-off mechanism is compatible with a framework such as the ETSI DCC and the following paragraph has been added in the paper to reflect this point:

Section 3: ñThroughout this study, we consider all the vehicles use the same values for parameters relevant to MAC layer congestion control, with the exception of the contention window. This means that the beaconing frequency, the transmission rate and power, or the receiver sensitivity are the same for all nodes. While this assumption does not hold in practice, it allows us to focus in this work on the impact of the back-off mechanism on the reception of vehicular safety messages.ñ

- transmission ranges between a pair of vehicles can be asymmetric: that is, it may happen that vehicle a can receive packets from vehicle b, but not vice versa,

- all this may be exacerbated by the fact that, with the passage of time, transmission ranges can vary due to a number of reasons, such as intervening obstacles and physical propagation effects (including multi-path and fading).

While the analytical model does not take into account physical layer issues, in order to remain tractable, the simulation study includes physical propagation effects, such as multi-path, shadowing and fast fading. The radio propagation model used in the simulation is explained in Section 5.2, and it has the particularity of a fast fading factor which depends on the vehicular density, a property which has been demonstrated by field tests. Link asymmetry and non-isotropic radio propagation are also considered in the simulation study.

2. The authors seem to disregard or neglect some important results that have been recently achieved in this specific field. For example authors should not ignore the following: A. Amoroso, G. Marfia, M. Roccetti, ``Going Realistic and Optimal: A Distributed Multi-Hop Broadcast Algorithm for Vehicular Safety", Computer Networks, Elsevier, vol. 55, n. 10, July 2011, pp. 2504-2519. We need to understand how the proposed approach is related with this result.

3. Authors should revise better and more the current literature in the field. For example a good survey can be found here: M. Di Felice, L. Bedogni, L. Bononi, "Group Communication on Highways: An Evaluation Study of Geocast Protocols and Applications", 2013 Elsevier Ad Hoc Networks.

We would like to thank the reviewer for pointing out these very interesting works. Nevertheless, the two papers in question tackle the problem of *multi-hop broadcasting*, and propose mechanisms that adapt the contention window in order to optimize information dissemination in such a multi-hop scenario. Our work is focused instead on *single-hop broadcasting*, which is a complementary but different problem. While solutions for *multi-hop broadcasting* mainly focus on selecting the value of CW that avoids the broadcast storm problem and reduces the end-to-end delay, in *single-hop broadcasting,* the main goal is to increase the delivery ratio in the geographical area close to the transmitter. In a vehicular scenario, *multi-hop broadcasting* is used to disseminate Decentralized Environmental Notifications (DEN), while *single-hop broadcasting* is used for Cooperative Awareness Messages (CAM). As our study is focused on CAM, an investigation of DEN solutions does not seem judicious, but we agree that the different meanings of the word ñbroadcastò can lead to confusions, therefore the following paragraph has been added for clarification purposes:

Section 2.3: ñAlso in a vehicular context, a lot of effort has been dedicated to the design of back-off mechanisms that would optimize the delivery of messages, especially DENMs, over a certain geographical area [24]. In this form of multi-hop broadcast, the objective is to set the smallest back-off time to the best forwarding nodes, in order to minimize the information propagation delay. However, this problem is fundamentally different from the single-hop broadcast optimization we focus on.ò

[24] A. Amoroso, G. Marfia, M. Roccetti, *Going Realistic and Optimal: A Distributed Multi-Hop Broadcast Algorithm for Vehicular Safety*, Computer Networks, vol. 55, no. 10, pp. 2504-2519, July 2011

4. I have many concerns about the style of this paper. I think that if the authors wish this paper is well considered by experts in the vehicular field, more attention should be devoted to discuss the application scenario. In essence the paper is too long and boring with a large use of mathematics that is often used without without clarity and sufficient motivations. I suggest to simplify it or better explain with realistic examples.

While we understand the reviewer's concern regarding the structure of the paper, we would like to point out that the original analytical model represents one of the main contributions of the paper, hence the ñboringò mathematics. Of course, we would appreciate any specific example that could help us improve the clarity of the model.
As for the motivation of this analytical framework, please note that it allows us to prove an important property, namely that the optimal contention window for broadcast traffic with temporal constraints does not follow the classical IEEE 802.11 models, and, on the contrary, it decreases when the node density increases.

Finally, concerning the application scenario, the safety beaconing studied in this paper will be the building block for multiple safety applications, such as Intersection Collision Warning, Lane Change Assistant, Emergency Vehicle Warning, etc (a very detailed list of such applications can be found in the deliverables of the EU Prevent project). All these applications require a high beaconing reception ratio and a small number of consecutively lost beacons, hence the metrics used to measure the performance of the reverse back-off mechanism. However, we need to point out that this paper is focused on medium access control issues and we evaluate the performance of a MAC layer mechanism; the design and evaluation of traffic safety applications is clearly a complementary work, but not at all our focus in this study.
The following paragraph has been added to clarify the application scenario interested in the performance of Cooperative Awareness Messages:

Section 2.1: ñIn this paper, we focus on the delivery of safety beacons in the one-hop neighborhood of a vehicle. The reception ratio and the inter-reception time of CAMs represent essential performance metrics for multiple envisioned vehicular safety applications, such as Intersection Collision Warning, Lane Change Assistant, or Emergency Vehicle Warning.ò

5. The provided simulative results are not completely convincing to me. Again they are too vague and generic. Again I suggest to take inspiration from the following paper where real on-field experiments were carried out.

We would appreciate if the reviewer could provide more precise examples of unconvincing and vague results. We would also like to point out that this study is focused on congestion control issues in vehicular networks, and real experiments are practically impossible for these scenarios (sadly the reviewer forgot to provide the example he was talking about). Even the largest field tests, such as the ongoing simTD project, are far from meeting the number of equipped vehicles needed for a congestion control study.

Provided the above questions are answered and problems are fixed, the paper can be reconsidered for publication.

Reviewer #3: In this paper, the authors investigate the compatibility of the IEEE 802.11 medium access control protocol with the requirements of safety vehicular applications. Using an analytical framework, they study the performance of the back-off mechanism and the role of the contention window on the control channel of a vehicular network. Based on these findings, they propose a reverse back-off mechanism, specifically designed for road safety applications. The efficiency of the proposed enhancement scheme is proved through a simulation campaign.
The overall level of the paper is good: even if it is quite simple, it is well written and some important considerations are highlighted.
Moreover, the proposed mechanism seams to be an enhancement for high-density vehicular networks.

In the following, there is a list of questions that the authors should answer:
1) The system model is trivial because it is suitable only for linear vehicular networks. Is it possible to extend the model for, at least, 2-D networks?

The reasons for using a linear network in our study are twofold. First of all, we would like to note that we are not aware of any study showing that a 2-D network is a better model for a vehicular network than a 1-D network. With the exception of intersections, vehicular networks are generally linear, as the road width is negligible compared with the communication range. Moreover, recent

small scale field tests (e.g. F. Martelli et al. ñA Measurement-based Study of Beaconing Performance in IEEE 802.11p Vehicular Networksò, Proc. IEEE Infocom 2012, pp. 1503-1511) showed the fast degradation of vehicular radio signals in non-line of sight conditions, meaning that, even in the case of urban intersections, the linear network assumption, while far from perfect, is more accurate than a 2-D network model.
The second argument is that our principle is to use an analytical model to gain insight in the functioning of the MAC layer, and double this with extensive simulations. Restricting the analytical model to a linear network allows us to keep the model tractable and to quickly provide numerical results, which uncover the important relationship between back-off time and node density in a vehicular network. However, we do not limit our study to these theoretical results, and provide simulation results that confirm these findings. Our simulation scenarios use several real maps and no longer make the assumption of a linear network, complementing the mathematical results.

2) The hypothesis that at most 2 nodes can be involved in a collision is strong, in particular in case of high-density vehicular networks. It should be better try to relax it.

We would like to point out that the assumption of only 2 colliding nodes is not central to the analytical model. The system can be just as easily solved for different values of $E[n_i]$, but this would not change the general trend of the results. We have measured $E[n_i]$ in our simulations, obtaining a value of 2.11, which confirms the fact that collisions rarely involve more than two stations. This information has now been added to the paper to clarify this point:

Section 3.1: ñThis equation can be solved for any values of N_{col} and n_i, for example for experimentally determined values. In the simulation study described in Section 5, we found $E[n_i]$ =2.11, meaning that, in the vast majority of cases, there are only two nodes involved in a collision, an intuitive result in the case of a road constrained vehicular topology. Based on these results, in the following we make the simplifying assumption of n_i å2ñ

3) The authors should explain better the curves in Figures 3, 4 and 5. It is not clear why the curves are so different passing from 125 to 200 vehicles/km.

We thank the reviewer for pointing out this problem. The three curves, for 125, 150 and 200 veh/km, are actually very similar, the problem coming from the fact the curves are cropped at a contention window between 1 and 450. Let us take the example of Fig. 3 and 4. In both cases, the curves begin with a phase where the collision probability is not affected by the contention window. However, this phase is not visible for a density of 200 veh/km as, for such a high density, the first phase would appear for negative values of the contention window, which make no sense in reality. The second phase, where the collision probability decreases with the increase of the back-off time, is visible for all the three curves, but is shifted at different values of the contention window. Finally, the third phase is the increase of the collision probability as nodes try to transmit before the beaconing expiration deadline. This phase is not visible on the curves for a density of 125 veh/km, as in this case the third phase starts for a value of the contention window higher than 450. The following paragraph was modified to better explain the evolution of these curves:

Section 3.5: ñFrom the figure, the behaviour of P_{cs} can be divided in three phases. In the first phase, increasing the contention window has no impact whatsoever on the collision probability. However, the interval of the contention window over which this uniform behavior can be observed decreases when the vehicular density increases, and it becomes negligible for n_c=200. In the second stage, the number of collisions decreases steadily, until reaching a minimum where the third phase, a slower increase, begins. It is noteworthy that, because we only show results for a contention window up to 450, the third phase for n_c=125 is not visible in the figure, as it starts at a higher value of the contention window.ò

4) The caption of Figure 5 is wrong. It does not concern 160 vehicles/km only.

We thank the reviewer for this observation; the problem has been fixed.

5) In section 5.2 the authors describe the simulation scenario. In particular, they specify that the statistics are computed using the final 5 minutes of the simulation, when the system already reached a steady-state. It is not clear if the authors are talking about the simulated or the real time. If they intended the simulated time, the simulation risks to be too short to capture the dynamic of a vehicular network.

The 5 minutes we refer to represent the simulated time. We understand the reviewer's concern, and it is true that we did not try to find an optimal simulation time in our study. However, we verified that the vehicular density varies both in time and in space during these 5 minutes. Moreover, recent studies on the structure of vehicular networks (e.g. D. Naboulsi and M. Fiore ñOn the Instantaneous Topology of a Large-Scale Urban Vehicular Network : the Cologne Caseò, Proc. ACM MobiHoc 2013, pp. 167-176) indicate that the dynamics of the vehicular traffic take place at a smaller time-scale than the 5 minutes used in this study. Nevertheless, we believe the observation of the reviewer is important, and we plan to study the optimal simulation time problem in a more detailed manner in the future.

Reviewer #4: -The paper entitled "Reverse Back-off Mechanism for Safety Vehicular Ad Hoc Networks" studies the performance of the 802.11p MAC protocol for vehicular environment through an analytical model. It also proposes a new back-off mechanism that is shown using simulation study to result in better performance in vehicular environment.

-The paper is well written. The Introduction and Background sections provide useful information for the readers.
Nevertheless some information presented is not accurate. For example, in Section 2.1, the authors assume when a new beacon is available while a previous one is still waiting in the queue, the old beacon needs to be dropped. This assumption is used later at the end of Section 2 as an argument for not adopting oCSMA.
Actually, The approach described by the author is one possible option for queue handling. However, this is a chipset implementation issue not specified in the WAVE standard. Alternative options are possible and might be adopted where the old beacon is not flushed.

From our knowledge, the ETSI ITS architecture clearly requires dropping expired messages from the MAC layer queue. The currently ongoing discussion focuses on whether the back-off should be stopped following this expiration or the remaining time should be used for the new message. However, it is commonly accepted that expired messages contain useless information and should not be transmitted on the wireless media. If the reviewer is aware of any other option in this sense, we would be grateful to learn about it.

-Moreover, in Section 2.2, the authors argue that low speed vehicle is not necessarily due to increased road traffic. However, adaptive beaconing frequency schemes based on velocity assume that vehicles running at low speed do not need a high frequency of status update.

Our argument is that, although low speed vehicles might not need a high update frequency, these vehicles might have neighbors that run at much higher speeds, who require a higher beaconing frequency. There are many situations in real life (left turn, traffic jam in one direction, stop signs, traffic lights), where low speed and high speed vehicles coexist, meaning that adapting the vehicular frequency simply based on one's velocity cannot work.

Also, the authors relate beaconing frequency reduction only to the vehicle speed. However, several schemes were proposed where beaconing frequency is made a factor of different parameters such as channel contention.

We thank the reviewer for pointing out that we did not discuss adaptive solutions based on the estimation of channel busy ratio (CBR). The problem with CBR estimation is that the relationship between the channel busy ratio and the number of contending stations ceases to exist in high density scenarios. For example, a recent study by T. Tielert et al. (ñJoint Power/Rate Congestion Control Optimizing Packet Reception in Vehicle Safety Communicationò, ACM VANET 2013, pp. 51-60) shows that, from a density of 100 veh/km, the CBR remains constant, at a value close to 0.9. This means that CBR-based techniques cannot distinguish between a situation with 125 veh/km and 200 veh/km, two very different scenarios, as shown by our study.
Moreover, adaptive solutions that use CBR, such as ATB (C. Sommer et al. ñTraffic Information Systems: Efficient Message Dissemination via Adaptive Beaconingò, IEEE Com.Mag. 49 (5), pp. 173-179), lead to a beaconing period of more than 3 seconds, a value which is incompatible with the requirements of safety applications. The following paragraph has been added in the paper to address this point:

Section 2.2: ñ Other studies propose to adapt the beaconing frequency based on the measured channel busy ratio (CBR) or some other indicator of channel quality [11]. However, the use of the CBR as an estimator for the vehicular density is only accurate for low vehicular densities. Once the vehicular density is important enough, the CBR remains stable at a value around 0.9 even if more nodes are added to the network. Using the results provided in [12], we estimate that, in a scenario similar to ours, the CBR allows distinguishing only between vehicular densities lower than 100 veh/km. Moreover, trying to keep the channel quality above a certain threshold by reducing the CAM frequency leads to very large beaconing periods (more than 3 seconds in [11] for a target CBR of 0.7).ñ

[11] C. Sommer, O. Tonguz, F. Dressler, *Traffic Information Systems: Efficient Message Dissemination via Adaptive Beaconing*, IEEE Communications Magazine, vol. 49, no. 5, pp. 173-179, May 2011
[12] T. Tielert, D. Jiang, H. Hartenstein, L. Delgrossi, *Joint Power-Rate Congestion Control Optimizing Packet Reception in Vehicle Safety Communication*, Proceedings of the 10th ACM International Workshop on Vehicular Ad Hoc Networks (VANET 2013), pp. 51-60, Taipei, June 2013

-In Section 3, the authors mention only two references for analytical model in VANETs. Several studies were omitted such as:
C Campolo, A Molinaro, A Vinel and Y Zhang, "Modeling Prioritized Broadcasting in Multichannel Vehicular Networks", IEEE Transactions on Vehicular Technology 61 (2), 687-701.

A. J. Ghandour, M. Di Felice, H. Artail and L. Bononi, "Dissemination of Safety Messages in IEEE 802.11p/WAVE Vehicular Network: Analytical Study and Protocol Enhancements", Pervasive and Mobile Computing Elsevier, http://dx.doi.org/10.1016/j.pmcj.2013.03.003

J. Misic, G. Badawy and V. Misic, "Performance Characterization for IEEE 802.11p Network with Single Channel Devices", IEEE Transactions on Vehicular

Technology, 68(4), pp. 1775-1789, 2011.

We acknowledge that the discussion of related work on analytical models was incomplete. We have now added several bibliographical references, as follows:
- K. A. Hafeez et al. ñPerformance Analysis of Broadcast Messages in VANETs Safety Applicationsò, Proc. IEEE Globecom 2010, pp. 1-6.
- C. Campolo et al. ñModeling Prioritized Broadcasting in Multichannel Vehicular Networksò, IEEE Transactions on Vehicular Technology 61 (2), pp. 687-701.
- H. Chong et al. ñAnalytical Study of the IEEE 802.11p MAC Sublayer in Vehicular Networksò, IEEE Transactions on Intelligent Transportation Systems 13 (2), pp. 873-886.
- M. Di Felice et al. ñDySCO: A Dynamic Spectrum and Contention Control Framework for Enhanced Broadcast Communication in Vehicular Networksò, Proc. MobiWac 2012, pp. 97-106.

These papers either fail to consider expired messages (Hafeez, Chong), or consider expired messages only in the context of channel switching, as implied by the WAVE standard. In our study, we consider a radio is always switched on the control channel, as required by the ETSI ITS architecture, therefore the expiration of safety messages needs to be treated differently. Moreover, the two studies that consider beaconing expiration (Campolo, Di Felice) make much stronger assumptions than our model: they require that all the vehicles are in each other's transmission range, ignoring the effect of hidden nodes, which is shown to be essential in our study.

Regarding the two other papers proposed by the reviewer, while we consider them very interesting, we believe they have a different scope from our study. Ghandour et al. focus on the complementary problem of DEN dissemination, and the model they use is just a simple adaptation of the Bianchi model, which we discuss in detail in our paper. On the other hand, Misic et al. propose an EDCA-like model for unicast traffic, as they assume the exchange of RTS/CTS messages, impossible in the case of broadcast safety messages. This model is very useful for the study of non-safety applications in the case of channel switching, but the target is clearly different from ours.

The following paragraphs have been added to reflect this improved discussion on analytical models:

Section 3: ñThe complexity of a VANET, where vehicular traffic and special network properties need to be considered, makes the analytical study of MAC layer performance in a vehicular environment. Previously proposed unicast frameworks based on Markov chain analysis have been extended to a vehicular context by Ma et al. [25] and Vinel et. al [26], but fail to take into account essential properties of the safety beaconing, such as the limited lifetime of the messages. The impact of expired messages is not considered even in some models specifically designed for the performance analysis of vehicular safety applications (e.g. [27], [28]).

The two studies we are aware of that take into account the expiration probability of safety beacons are those described by Campolo et al. [29] and Di Felice et al. [30]. However, both these studies focus on single radio devices that need to periodically switch between the control channel and one service channel, and the beaconing expiration is the result of such a switching. Unlike these analytical frameworks, the one we propose considers a radio that permanently remains on the CCH, as foreseen by the ETSI ITS architecture. While the ongoing debate between the proponents of the two functioning modes is out of the scope of this paper, we would like to point out that the two systems are highly different from a MAC layer point of view, hence the need for a different analytical model.

Moreover, it is noteworthy that both [29] and [30] make much stronger assumptions than the model proposed in the present work. Two important examples are the hypothesis that all the vehicles are in each other's transmission range (meaning that hidden nodes are ignored), and the requirement that the communication range is equal to the carrier sense range. Neither of these properties holds in reality and, as shown by our analysis, the impact of hidden nodes is quite important and cannot be ignored.ñ

[27] K.A. Hafeez, L. Zhao, Z. Liao, B.N. Ma, *Performance Analysis of Broadcast Messages in VANETs Safety Applications*, Proceedings of the 53rd IEEE Global Telecommunications Conference (GlobeCom 2010), pp. 1-5, Miami, December 2010
[28] C. Han, M. Dianati, R. Tafazolli, R. Kernchen, X. Shen, *Analytical Study of the IEEE 802.11p MAC Sublayer in Vehicular Networks,* IEEE Transactions on Intelligent Transportation Systems, vol. 13, no. 2, pp. 873-886, June 2012
[29] C. Campolo, A. Molinaro, A. Vinel, Y. Zhang, *Modeling Prioritized Broadcasting in Multi-channel Vehicular Networks*, IEEE Transactions on Vehicular Technology, vol. 61, no. 2, pp. 687-701, February 2012
[30] M. Di Felice, L. Bedogni, L. Bononi, *DySCO: A Dynamic Spectrum and Contention Control Framework for Enhanced Broadcast Communication in Vehicular Networks*, Proceedings of the 10th ACM International Symposium on Mobility Management and Wireless Access (MobiWac 2012), pp. 97-106, Paphos, October 2012

-A major assumption made in the manuscript is that number of nodes involved in a collision is two. This assumption needs to be verified especially in high density nodes where collision between multiple nodes is highly probable at low values of contention window.

Please refer to the comment above. As explained, this is only a simplification required in order to obtain numerical results, and the model can support any value for this parameter.

-The slot definition in the proposed model is different from 802.11p which results in large confusion for the reader.
The slot value is set to 66.7us in Section 3.5 without justification. This confusion yields to an ambiguity in the definition of "duration of a beacon in slots N_s".

The slot value of 66.7µs is simply obtained by dividing the size of the beaconing period (100ms) by the number of slots in such a period, chosen to be 1500. Both these values are provided and explained in Section 3.5.
We would like to point out that the definition of a temporal slot different than the one used in the IEEE 802.11 standard is common in analytical models. In fact, most analytical models, starting with the classical Bianchi model, give new definitions to the term ñslotò compared to the 802.11 standard. The problem comes from the fact that IEEE 802.11 uses a slotted mode only during back-offs, while the transmissions are unslotted, a behavior which is very difficult to model mathematically. While other studies avoid presenting results in terms of ñslotsò because of this problem and use different parameters, we preferred showing the impact of the number of slots, as we focus on the optimal size of the contention window, although the meaning is different from the one proposed in the standard. We believe the results are important from a qualitative point of view, and that quantitative problems are addressed by the simulation study, which uses a detailed implementation of the standard.

-A major concern about the proposed reverse back-off mechanism is its performance in low to medium traffic scenarios.
These scenarios are the dominant on the road. In the proposed scheme, whenever the vehicle senses the channel to be busy and enters back-off, a high delay will be incurred prior to the beacon transmission. This delay might be in the order of several milliseconds in a low to medium traffic scenario which results in a low channel utilization.

It is true that a delay in the order of milliseconds can be introduced by the reverse back-off in low traffic scenarios. However, the fact that a higher back-off reduces channel utilization in low density scenarios is only true under the assumption of saturated traffic, as proposed by Bianchi-like models. It is quite simple to see that in an unsaturated traffic, such as the one created by safety beacons, there is no impact on the channel utilization.

To explain this, let us take the example of 2 stations transmitting one beacon each every 100ms. The probability that one station would try accessing the medium during a transmission from the second station is pretty low (0.67% using the values in Section 3.5), meaning that the two stations will transmit with no back-off whatsoever (the back-off state is entered only if the channel is sensed busy, or in the case of a non-empty waiting queue, which is only true for saturated traffic). Moreover, even if the back-off would happen, the second station would transmit the message several milliseconds later, but with no effect on channel utilization: 2 messages transmitted during a 100ms beaconing period.

-Several studies such as the one below present enhancement to the existent back-off mechanism. It is important to discuss these studies and compare their performance with the "reverse back-off scheme".
M. Di Felice, A. J. Ghandour, H. Artail and L. Bononi, "On the Impact of Multi-channel Technology on Safety-Message Delivery in IEEE 802.11p/1609.4 Vehicular Networks", 21st IEEE International Conference on Computer Communication Networks (ICCCN 2012), July 30 - August 2, 2012, Munich, Germany.

We wish to thank the reviewer for bringing this paper to our attention; we discovered this work with a lot of pleasure. The mechanism proposed in this paper is really interesting, and we will surely investigate its performance with close attention in the future. However, there are some important differences between our approach and the one proposed by Di Felice et al., as follows:
- the study is focused on the problem of calculating the optimal back-off in a scenario with channel switching between the control channel and service channels, while we focus on functioning on the control channel, with no switching, resulting in a different scenario.
The discussion regarding which functioning mode (with or without switching), if any, will prevail can lead to an endless debate. As explained above, we believe the WAVE series of standard to be the result of many misconceptions and misunderstandings, one of them being channel switching. This idea has already been refuted by field tests and by regulators in both US and Europe, meaning that the CCH in Europe and the channel 172 in US have to be permanently monitored and 1609.4 would only apply to a second, optional radio used for non-safety applications.
- the solution proposed by Di Felice et al. needs an estimation of the channel busy ratio. As discussed, the CBR is equal to 0.9 for any density higher than 100 veh/km, as also shown by Tielert et al.
- the authors of the indicated study propose to increase the contention window with the vehicular density, as indicated by classical 802.11 models. However, we show that this assumption is false and, on the contrary, the value of CW should decrease in these conditions.

The following discussion has been added to the paper:

Section 2.3: ñFrom our knowledge, the only contention window adaptation mechanism taking into account the expiration probability of safety beacons is the one proposed by Di Felice et al. [23]. The authors propose a two-phase adaptation: in a first step, the contention window increases with the channel busy ratio while, in a second time, the back-off value is refined based on the time remaining before message expiration. However, this solution is designed to solve the problem of message accumulation at the beginning of a CCH period in the case of channel switching between service and control channels. In this case, the back-off time is computed for all enqueued CAMs at the beginning of the CCH period, a different scenario from the one considered in this paper, where a radio is always switched on the control channel and the contention time is computed as soon as the message reaches the MAC layer, in agreement with current radio hardware. Moreover, a mechanism such as the one proposed in [23] assumes the channel busy ratio is a good estimator of the vehicular density, a property which is not true in high density scenarios, as discussed above.ñ

[23] M. Di Felice, A. Ghandour, H. Artail, L. Bononi, *On the Impact of Multi-channel Technology on Safety-Message Delivery in IEEE 802.11p-1609.4 Vehicular Networks*, Proceedings of the IEEE 21st International Conference on Computer Communications and Networks (ICCCN 2012), pp. 1-8, Munich, August 2012

-Receiver Sensitivity and SINR values in Table 1 are not compatible with the literature.

We are not aware of any standard value for these parameters. As a matter of fact, we have tested different values for the receiver sensitivity and proposed an adaptive mechanism for the carrier sense threshold (R. Stanica et al. ñPhysical Carrier Sense in Vehicular Ad-Hoc Networksò, Proc. IEEE MASS 2011). While the receiver sensitivity has a clear impact on the reception ratio, and can be used as a congestion control parameter on its own, we have not noticed any qualitative impact of this threshold on CW-based solutions. From our experience, the choice of these two parameters largely depends on the used simulator. In this case, our choice was made based on the results shown in Fig. 7, where one can see the reception ratio without any interference. The two curves match the experimental results we are aware of, meaning that the choice of the parameters is compatible with these field tests results.