Smart Adaptation of Beacons Transmission Rate and Power for Enhanced Vehicular Awareness in VANETs

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Abstract— In this work, we are interested in periodic beacons transmission, the main cause of the Control Channel (CCH) congestion and the major obstacle delaying the progress of safety messages dissemination in VANETs. In order to offload the network, solutions that range from transmit rate adaptation to transmit power adaptation including hybrid solutions have been proposed. Although some of these solutions have managed to successfully reduce the load on the wireless channel, none, to the best of our knowledge, have considered the impact of the applied adaptation scheme on the overall level of awareness among vehicles and its quality. ETSI TS released a technical specification stating a limit for the minimum beacons transmit frequency in order to maintain a good level of awareness among vehicles and ensure a certain accuracy in VANET applications. In this paper, we propose to jointly adapt both transmit rate and power in a novel smart way that guarantees a strict beaconing frequency as well as a good level of awareness in closer ranges, while reducing the beacons collision rate and keeping the channel at a good level of utilisation. First, the transmit rate is adapted to meet the channel requirements in terms of collision rate and busy ratio; then, once the minimum beacon transmit frequency, set by ETSI, has been reached, transmit power is adapted in a way that guarantees a good level of awareness for closer neighbours. The simulation results show a significant enhancement in terms of the quality as well as the level of awareness.

I. INTRODUCTION

Vehicular Ad Hoc Networks (VANETs) is an emerging technology that has aroused great interest worldwide in the last decade. This simple yet very efficient technology, consisting in enabling wireless communications between vehicles, has attracted a lot of attention from both research and industry communities. A large set of applications has been designed to this end as they promise to solve many of today's road traffic problems, like enforcing the security of the road users, significantly shortening their trip times and enhancing their driving experience. However, this particular type of wireless networks has some distinguishing characteristics. The first main characteristic is the absence of a central entity that monitors the state of the network and keeps track of vehicles' information like their density, speeds, positions or their headings. This absence needs to be compensated by some

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periodic presence messages, also called BSMs or beacons. These short single hop messages, sent by all vehicles, aim at providing vehicles with information about their neighbours and act like a pulse for the surrounding vehicles. It is widely accepted in the vehicular networking community that the use of beacons is crucial for any application whether it is a safety or a non-safety one. The second characteristic is the highly dynamic environment of VANETs. In fact, the high mobility of vehicles leads to a rapid expiration of the beacons content, and therefore more updates about the state of the network are compulsory in order for VANET applications to function properly. In addition, the more up to date the beacon is, the more accurate the information used in the application will be. This is why it is mandatory for the vehicles forming the wireless network to exchange beacons as often as possible. According to the National Highway Traffic Safety Administration and the Crash Avoidance Metrics Partnership [1], most safety applications cannot guarantee accurate results with a beaconing frequency lower than 10Hz, while some of them require a beaconing frequency up to 50 Hz to run smoothly and efficiently.

One important thing which is worth mentioning is the limited radio resource that is expected to carry all this data. VANETs usually operate around the 5.9GHz frequency band which is divided in 10MHz channels. The IEEE 802.11p WAVE Standard [2] defines six service channels (SCH) in the US while four channels has been allocated in Europe by ETSI TS [3]. On the other hand, both standards agreed on attributing a single control channel (CCH) that will serve for carrying safety related information, context aware information and service announcements. There is no doubt that these three types of messages are a bit bulky to be carried by a single CCH channel, especially the second type since the beacons are broadcasted with a very high periodicity in some cases. These beacons, aside from being crucial for all safety and non-safety applications, are the main source of congestion of the CCH channel. Such congestion might have devastating consequences on the performance of safety applications and might even endanger the safety of the road users.

Many researchers have focused in the recent years on proposing and designing efficient ways to control the load generated by beacons and therefore the load on the CCH channel. Some of the solutions propose to deal with this issue by controlling the transmission frequency of the beacons while some others suggest limiting the transmission power and therefore the number of vehicles reached with every beacon transmission. Each of these approaches has its own

advantages and limitations, and might be more beneficial in some specific scenarios and less useful in some others. A hybrid solution might be a good tradeoff between the two, but without a perfect understanding of what the drawbacks of each of them are, it is really difficult to meet the safety applications strict messaging requirements. In this work, we asked ourselves the following questions:

- What are the rate adaptation advantages, what are the most suitable scenarios for its usage, and what are its limitations?
- What are the power adaptation advantages, what are the most suitable scenarios for its usage, and what are its limitations?
- What is the best way to leverage the strengths of these two approaches while overcoming their respective limitations?

To answer these questions, we propose SuRPA (Successive Rate and Power Adaptation), a new solution that jointly adapts the transmission rate and power in a new smart way that will ensure the required minimum level of context awareness for the vehicles (i.e. respecting the minimum beacons transmission rate), necessary for safety applications, and allow reaching the needful vehicles (i.e. using sufficient transmit power) when required. First, the rate adaptation is applied, until the minimum required rate is reached. This rate adaptation reduces the number of messages exchanged but not the number of vehicles exchanging them within the awareness region, while adapting the transmit power reduces the number of vehicles in the awareness region. This might lower the awareness level because some vehicles needing the beacons information will not receive it. This is why we chose to adapt the rate of beacons first.

Once the rate adaptation limit has been reached and the density of vehicles still increasing, the power adaptation is performed. In this case of higher density, it is acceptable to reduce the power and thus the geographic area covered by the beacons since the vehicles density within that area will be higher, and the number of vehicles covered in this reduced awareness region will be sufficient to ensure the required awareness level. This new combination helps to better understand the mechanics of rate and power adaptations and paves the way for new perspectives and a new family of solutions.

The remainder of this paper is organized as follows. In section II, we will briefly present the standards and the most significant solutions for the studied problem. Section III will provide a detailed description of the proposed solution, including our inspirations and motivations. The performance evaluation, the simulation scenario and results are presented in section IV , and finally we conclude in section V.

II. RELATED WORKS

As stated earlier in the previous section, numerous works have been proposed to deal with the network overload generated by the periodic transmission of beacons in vehicular networks. These works fall under one of the two categories: rate adaptation approaches and power adaptation approaches.

As an example for the first category, ATB [4] proposes to reduce the beaconing rate based on two key metrics: message utility and channel quality. Another example is DynB [5] which follows a similar approach but introduces the effects of shadowing caused by both buildings and cars on the wireless channel load. The main challenge for not only these two solutions but all of the transmit rate control based solutions is that they cannot, in some high density situations, meet the strict messaging requirements specified in standards like IEEE WAVE or ETSI ITS G5 due to the limited radio channel. In fact, if we consider a minimum allowed frequency of 10 Hz and a CCH Interval (CCHI) of 48 Milliseconds (excluding the guard interval); if one beacon transmission takes approximately 1 Millisecond according to [6] and given that the maximum channel usage cannot exceed 60% of the CHHI according to [5], the CCH channel cannot allow more than 28 vehicles transmit within each other's range.

As an example for the second category (i.e. transmit power adaptation approach), [7] selects the transmit power according to the utility of the beacon to be transmitted. The authors in [8] follow a completely different criterion and propose to randomly select the transmit power of vehicles following a given probability distribution. In both works, the authors have shown the potential improvement of this approach in terms of channel load control and the achieved vehicle awareness level, especially in closer ranges. The main issue with this class of solutions, however, is the poor quality of awareness in farther ranges. Indeed, in a highway scenario where the speed of vehicles can be very high, the response time of drivers is shrunken and therefore, high level of awareness is required even in farther ranges.

Some researchers have proposed hybrid solutions like [9]-[11] where the transmit rate and power are adapted jointly. Building on these approaches and others, ETSI ITS G5 has released a technical specification introducing DCC [12] (Decentralized Congestion Control). The idea is to combine transmit rate and power adaptations with other kind of adaptations like the Carrier Sense Threshold. Many efforts have followed like [13] and [14] which mainly focus on analysing the performance of DCC, but the results show many flaws and confirm the poor performance produced by this version of the standard.

In [15], the authors have proposed a joint rate/power adaptation to cope with the wireless channel load problem, by analysing a wide range of transmission (Tx) parameters and came to the interesting conclusion that the transmit rate should depend on the channel load while the transmit power should depend on the target region. However, it is unclear how this target region is defined; besides, there is no guaranty the strict beaconing frequency requirement will be respected. Due to all these reasons invoked above, we take the opportunity to design SuRPA, a novel algorithm that deals in a smart way with the channel load problem taking into account the strict beaconing frequency and the quality of awareness requirements, while keeping the collisions and channel busy rates at an acceptable level.

III. The proposed solution

A. Rate/power adaptation: key principle

We will talk in this subsection about the rate adaptation (i.e. adapting the beacon Transmit Rate: TR) and the power adaptation (i.e. adapting the beacon Transmit Power: TP) as a whole for the sake of clarity; we will explain later in this section how we combine them together in an efficient way in order to optimise the CCH usage while minimizing the number of collisions.

Our algorithm is inspired from the "divide and conquer" family of search algorithms and the "binary search" [17] algorithms as we observed many similarities between the problem studied in this paper and that solved by this class of algorithms. The binary search consists of parsing the position of a value in a sorted set of data by setting upper and lower bounds and updating them in multiple iterations. The initial bounds are the first and the last values in the data set, which represent the smallest and the biggest values respectively if the values are sorted in an ascendant order. After each iteration, the value located in the middle index of the set is compared with the sought value X. If this current value is lower than X then the position of this latter within the data set is certainly located between this middle and the last values of the set, and, therefore, the lower bound is updated to the middle index of the data set. On the other hand, if the current value is larger than X then the position of this sought value is certainly located between the first and the middle values of the set, and thus the upper bound is updated to the value with the middle index while the lower bound will remain unchanged. With a complexity of $O(\log(n))$, this algorithm is the fastest and most efficient way for locating a given value in a sorted set of data. This algorithm can be further optimised if more information about the distribution of values in the dataset is available. A weighted interpolation can be performed to pick a different index in the set instead of always picking the middle value to compare against.

The problem investigated herein, which can be summarised in "quickly finding and constantly updating the optimal channel utilisation rate that would minimize the probability of collisions", can relate to the binary search problem as both aim at locating a value in a sorted set of values. In our case, the value X that is being sought is the optimal channel busy ratio in the interval between min_busy_ratio and max_busy_ratio ([0 %, 100 %]). The optimal busy ratio can be described as a channel busy rate which would result in an acceptable collision rate (i.e. below a certain threshold). This optimal busy ratio can be obtained by controlling the beacons TR/TP, and that is where our joint rate/power adaptation takes place. In other words, looking for the optimal busy ratio amounts to locating the optimal TR/TP (depending on the collision rate observed), since this former is strongly positively correlated with the latter.

By applying the binary search algorithm technique, we will be able to locate a near-optimal channel busy rate value and apply it to the nodes (vehicles) in the network by adapting their beacons TP/TR. A single iteration in the binary
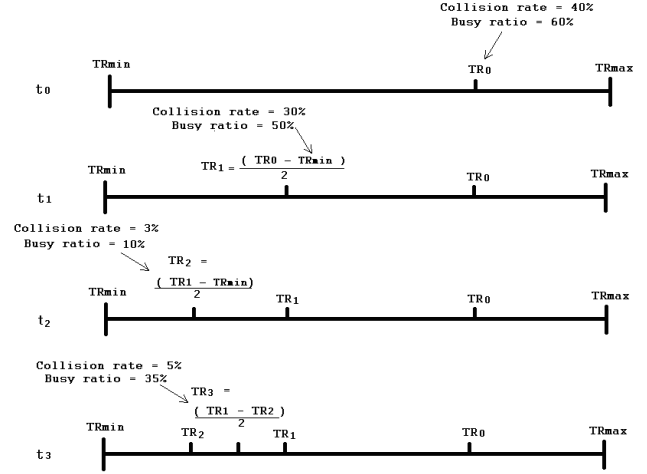

Fig. 1. Illustration of the key principle of our solution

search algorithm corresponds to one CCH Interval (CCHI) in our case as one new TR/TP value is selected after each CCHI. The main two parameters used for beacons TR/TP adaptation in our scheme are the collision rate and the busy ratio as all three strongly depend on each other.

The collision rate is read out by checking the beacons sequence numbers on the MAC header, if the sequence {3, 4, 8, 9} is received from a vehicle V, the receiver of these beacons will conclude that beacons {5, 6, 7} were lost. This method has previously been used in many works including [16]. The busy ratio, on the other hand, can be retrieved by sensing the channel and adding up the time periods each vehicle spent in the state receive. By constantly sensing the CCH and retrieving information related to beacons collision and channel busy ratio, this latter can be controlled by adapting the transmit rate/power of beacons. That is to say, our algorithm looks for, and sets the channel utilisation to the value that would lead to an acceptable collision rate, by adapting TR/TP parameters, and updates this value after each CCHI, in a way to quickly and aggressively converge towards a near-optimal solution.

By setting a minimum and a maximum busy rate values, and an acceptable collision rate value (e.g. 5%) our algorithm adapts the TR/TP accordingly with the observed channel busy and collision ratios. First, it picks a TR/TP value in the interval between the minimum and the maximum values of TR/TP. At the next CCHI, it observes the channel parameters (busy and collision ratios) and decides whether this new TR/TP value will become the new upper or the lower bound. If the collision rate is still higher than the acceptable collision rate, a lower transmit rate/power in the interval between the minimum and the last observed busy ratios is picked. A value in the interval between the last observed and the maximum busy ratios is picked otherwise. Fig. 1 explains this concept for TR adaptation. The same mechanism applies for TP adaptation as well.

As stated earlier in this section, this algorithm can be optimised using a weighted interpolation. In our case, there

is a strong positive correlation between the collision rate and the busy ratio; and between the latter and the picked TR/TP values. It is well known that a higher TR/TP is more likely to result in a higher busy ratio, which in turn will lead to a higher collision rate. We leverage this correlation to pick the next TR/TP values. In fact, instead of always picking the middle value in the interval of min and max TR/TP as the next value; we pick a value that is more likely to narrow down the scope of our search. In other words, instead of always dividing this value in half (multiply by 0.5), the TR/TP is determined by multiplying the previous TR/TP value to a weight, which in turn is set based on the Euclidian distance between the current busy/collision ratios and their desired/acceptable values. This weight and the adaptation is further detailed in the next subsection.

Algorithm 1 Successive TR and TP adaptation SuRPA

Input:

    GI: gradual_increase_rate

    CI: confidence_interval

    C_{ac}: acceptable_collision_rate

    B_{op}: optimal_busy_ratio

    C_c: current_collision_rate

    B_c: current_busy_ratio

1: At the end of each CCHI do:
2: **if** (C_c - C_{ac} < CI) **then**
3:    *Reinitialise TR_{max} and TP_{max}*
4:    *Reinitialise TR_{min} and TP_{min}*
5:    Exit
6: **end if**
7: **if** (C_c < C_{ac} && B_c < B_{op}) **then**
8:    **if** ($TP == TP_{max}$ && $TR \leq TR_{max}$) **then**
9:      $TR_{min} = TR$
10:      $TR = Min$ (TR * [Min (1 + (B_{op} - B_c), GI)], TR_{max})
11:    **end if**
12:    **if** ($TR == TR_{min}$ && $TP \leq TP_{max}$) **then**
13:      $TP_{min} = TP$
14:      $TP = Min$ (TP * [Min (1 + (B_{op} - B_c), GI)], TP_{max})
15:    **end if**
16: **end if**
17: **if** (C_c > C_{ac}) **then**
18:    **if** ($TP == TP_{max}$ && $TR > TR_{min}$) **then**
19:      $TR_{max} = TR$
20:      $TR = Max$ (TR * [1 - (C_c - C_{ac})], TR_{min})
21:      Exit
22:    **end if**
23:    **if** ($TR == TR_{min}$ && $TP > TP_{min}$) **then**
24:      $TP_{max} = TP$
25:      $TP = Max$ (TP * [1 - (C_c - C_{ac})], TP_{min})
26:      Exit
27:    **end if**
28: **end if**

B. Combined rate/power adaptation mechanism

In section II, we presented the most significant works in the literature dealing with beacons congestion control problem and highlighted their limitations. Afterwards, we explained, earlier in this section, the connection between different transmission parameters (rate/power) and channel conditions (collision rate/busy ratio), and how they are correlated. we also gave a preview on the method we will follow to locate and select Tx parameters accordingly with the channel conditions. In this subsection, we will demonstrate why the transmit rate and power should be adapted in a certain way and order, and how a rigorous choice of these parameters is a must in order to neither over utilise the channel nor underutilise it, and ensure successful and frequent enough beacons transmissions. Relying on transmit power adaptation only may lead some vehicles within a certain distance to miss a lot of beacons, this is not tolerable especially in highways where vehicles speed is very high and, therefore, the distance traveled by a vehicle before reacting to any other vehicle on the road can be quite high. This is why it is mandatory for beacons to reach even far away vehicles in this case. On the other hand, relying on the rate adaptation only can result in a less frequent update of beacons which is not tolerable in a highly dynamic network like VANETs, especially in highly congested scenarios, where context aware information should be exchanged as often as possible (a minimum of 10 times a second according to [1]).

The good news is that these two scenarios (high speed and low congestion, or low speed and high congestion) can only happen coupled together. In fact, it is very unlikely to be in a situation where there is a low density of vehicles traveling at a low speed or the opposite, a very high density of vehicles traveling in a very high speed. Taking this rule of thumb into account, we propose to combine TR and TP in a novel way to cope with the two previously identified problems, i.e. transmitting beacons as often as possible (10Hz) in highly dynamic low speed scenarios, and reaching vehicles as far as possible in high speed scenarios.

It is well known that most VANET applications require a minimum beacons rate of 10Hz. It is thus mandatory to respect this constraint no matter what the channel conditions or the density of vehicles on the road are. In other words, the rate adaptation should not go below this threshold at the risk of compromising the accuracy and the efficiency of VANET applications, particularly the safety ones. Once this minimum threshold has been reached, no further rate adaptation should be allowed. Beyond this threshold, power adaptation might take place under some conditions.

In fact, in scenarios where only beacons generation rate is adapted, the interval between beacon transmissions is increased as the vehicles density increases (i.e. reducing the beacon generation rate). This increase in vehicles density comes along with a decrease in vehicles speed. Therefore, power adaptation is possible and adequate since it is acceptable, in this case, to reach closer vehicles only without endangering other vehicles on the road. Furthermore, even

if the vehicles speed is still relatively high when the 10Hz threshold is reached in rate adaptation, and given that the minimum required beacon generation rate, it is more rational to reach closer vehicles first as they have more priority over the farther vehicles to receive the transmitted beacon.

Both rate and power adaptations can be considered as limited resources, and the question here is to find out how and when to use them in the most efficient way. A good rational solution is to adapt the beacons generation rate as long as we still have not reached the critical threshold, then once this resource has been exhausted; it is still possible to exploit the power adaptation resource and, therefore, switch to this mode.

Our solution combines the rate and power adaptations in a novel smart way allows respecting the strict beaconing frequency requirements of safety applications, while compromising on the power adaptation when possible. If the communication overhead increases and, consequently, the collision rate; we first adapt the beacons generation rate in a way to reduce the busy ratio and, therefore, the collision rate. Then, if the 10Hz threshold is reached and the collision rate is still high, we switch to the power adaptation mode in a way to keep reducing the busy rate and consequently the collision rate.

C. The proposed algorithm

In this subsection, we will explain under which circumstances each of the two Tx parameters is adapted, and how this adaptation is performed. Since our adaptation is made based on two parameters, we set an order of priority between the collision rate and the busy ratio, in other words, which of the acceptable/desirable ratios we are trying to achieve first. We all know the devastating effect of packets loss on the performance of any safety or non-safety application in vehicular networks. Therefore, we gave more priority to achieving the acceptable collision rate regardless of the channel busy ratio. Once the collision rate is below this threshold, we switch to the second objective, which is achieving the desired channel busy ratio as long as the collision rate is still acceptable.

Algorithm 1 shows how our adaptation is performed. This algorithm is performed at the end of each $CCHI$ and is node-centric i.e the adaptation is carried out in each vehicle and based on the channel conditions observed at a vehicle level.

First, we check the collision and the channel busy ratios to decide whether we should increase the values of TR/TP or decrease them. If the current collision rate indicates that it is higher than the acceptable collision rate, we should *decrease* either the transmit rate or the transmit power according to what is available to be adapted. On the other hand, if the collision rate is below the acceptable collision rate, we can look at the busy ratio in this case and *increase* our selected Tx parameter to increase the busy ratio if this latter if it is lower than the optimal rate.

Once the decision about increasing or decreasing Tx parameters has been made, we look at TR and TP values to pick which one of them should be adapted. If TR is high

TABLE I
SIMULATION PARAMETERS

PHY	Frequency band	5.9 GHz
	Bandwidth	10 MHz
	Transmission range	260m
	Max/Min Tx Power	19.03/5 dBm
	Receiver sensitivity	-45 dBm
	Noise	-105 dBm
LLC	Bit rate	6 Mbits/s
	CW	[3, 7]
	AIFSN	2
SuRPA	Data message size	256 bytes
	Max/Min beacons freq	50Hz/10Hz
	Acceptable collision rate	0.05
	Desired channel load	0.3
	Gradual increase rate	1.2
DCC	Relaxed/Active/restrictive	19.03/15/-10 dBm
	Relaxed/Active/restrictive	25Hz/2Hz/1Hz
	Max /Min Channel load	0.4/0.15

enough (i.e. higher than the minimum allowed) so that it can still be adapted, we reduce it first; otherwise, if TR has already reached its minimum allowed value but TP is still flexible, we adapt TP.

The third step consists in adapting Tx parameters according to the above conditions. The adaptation is then made by increasing or decreasing the selected Tx parameter by a certain amount at each step (CCH Interval). This amount is determined using the Euclidian distance between the current channel conditions (i.e. collision rate and channel busy ratio) and the acceptable/ desired values, as long as we do not exceed Tx parameters minimum and maximum values. Equations in Algorithm 1 show the adaptation made on TR by decreasing and increasing it in lines 10 and 20 respectively; and TP as well by reducing and expanding it in lines 14 and 25.

The upper and lower bounds (TR_{max}/TR_{min}, TP_{max}/TP_{min}) are updated at the end of each $CCHI$ as well and right before the adaptation itself is performed; by setting the previous corresponding Tx parameters as a new bound. These bounds are reinitialised with the maximum/minimum TR/TP values if the difference between the current and the acceptable collision rate is smaller than an amount CI that we set beforehand. This means that the near-optimal Tx parameters have been found and the adaptation is skipped in that step.

Note that in case of TR or TP increase, a gradual increase rate is applied as a maximum increase at each step (i.e. $CCHI$). This is done to avoid an excessive increase that would compromise the collision rate.

IV. PERFORMANCE EVALUATION

In this section, we will show the substantial gain obtained when applying our scheme. To do so, we compared our solution to three different variants of ETSI's DCC namely TRC (Transmit Rate Control), TPC (Transmit Power Control) and full DCC with both TRC and TPC enabled.
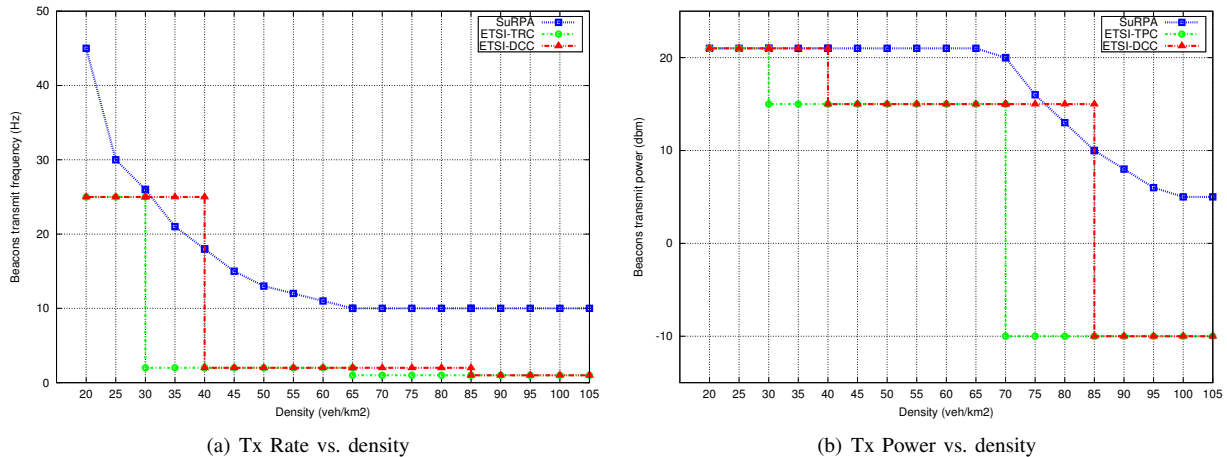
(a) Tx Rate vs. density (b) Tx Power vs. density

Fig. 2.   Impact of vehicles density on beacons Tx parameters: SuRPA vs. ETSI schemes

A. Simulation setup

We took a special care to conduct our tests study in a realistic simulation environment. For a realistic vehicular mobility model, we used HINTS [18], a platform that couples the road traffic simulator SUMO with the network simulator NS-3, and allows them to exchange information about vehicle movements at runtime. We also used the Corner propagation loss model [19] to capture the shadowing effects caused by buildings.

Ns-3 with its accomplished protocol stack offers a large range of parameters and allows building an accurate vehicular communication model. For our simulations, we used the IEEE 802.11p Medium Access Control model (MAC) with 10MHz wide channels. We only considered the CCH channel to get rid of the effect caused by switching between channels. Furthermore, we only used one access category (AC) AC_VO since all beacons use the same AC. We chose a data rate of 6 Mbit/s and starting values of 19.03 dBm for the transmit power to reach approximately 260 meters, and 50 Hz for the beaconing frequency. Note that these values are the maximum values and are adapted dynamically in our scheme based on the channel conditions. We set the starting transmit power to 19.03 dBm for ETSI schemes as well to achieve the maximum desired transmission range that is representative of vehicular networks. The full list of simulation parameters for both SuRPA and the DCC is given in Table I.

Building on this simulation configuration, we implemented all three variants of DCC and our scheme. We picked a road map composed of two 1km long roads with 3 lanes in each direction, intersecting in the middle. This scenario includes a wide range of vehicle types with different lengths and shapes. Several runs were performed in order to obtain more accurate results.

B. Results

First, we wanted to show the variation of Tx parameters versus the density of vehicles in SuRPA against ETSI schemes. Figure 2 shows this variation with 2(a) the transmit rate of frequency of beacons and 2(b) their transmit power.

In 2(a) we see the gradual decrease in the beacons transmit frequency for our scheme as opposed to TRC and DCC. In addition, our scheme does not go below the limit of 10Hz and stabilises at this value in a density around 65 veh/km^2, while the two other schemes go down to 1Hz as the density of vehicles increases and the communication overhead with it. In 2(b), the transmit power for our scheme is stable and at the maximum value since, up to a density of 65 veh/km^2, the rate adaptation is activated. Beyond this density, the transmit power starts to decrease gradually to reach a value of 5dBm. In contrast, the ETSI schemes drop sharply and reach the bottom value of -10 dBm.

This first set of results reveals two important things: first, the gradual evolution of Tx parameters in our scheme means a better adaptation and adjustment to the channel conditions. Second, the higher values of our Tx parameters means a more up-to-date context information for vehicles in 2(a) as beacons are exchanged more frequently; and a higher level of awareness in 2(b) since the transmission range is higher and the awareness region is larger. We notice that Tx parameters are higher in DCC at densities between 30 and 40 veh/km2 in 2(a), and between 75 and 85 veh/km^2 in 2(b); but this leads us to the second set of our results shown in Figure 3, which are the collision rate and the busy ratio versus the density of vehicles.

Figure 3(a) shows the collision rate of SuRPA against ETSI schemes. Our solution shows the lowest collision rate among all four schemes and is the more stable as this collision rate remains below 10% during the whole simulation. In contrast, the ETSI schemes achieve worse results as they approximate 20% collisions in medium and high densities for TRC and DCC and beyond that in all the simulation duration for TPC. We also notice a lot of fluctuation for the DCC schemes; this is due to the violent change in Tx parameters when switching between the DCC states. We refer the reader to [12] for more details about DCC schemes. The busy ratio is shown in Figure 3(b) As the plotted results show, our scheme achieves higher busy ratios, varying between 20 and 25%, compared to TRC and DCC. Even though our
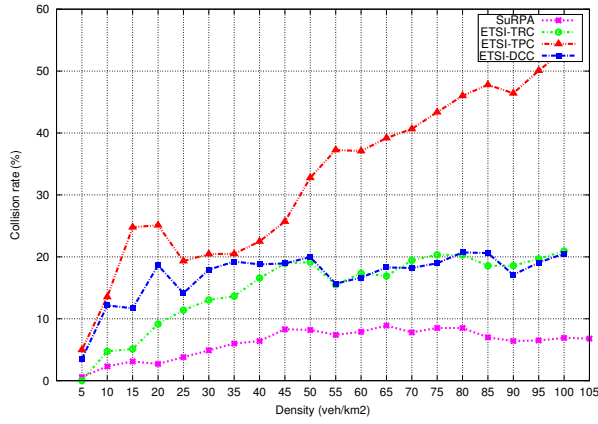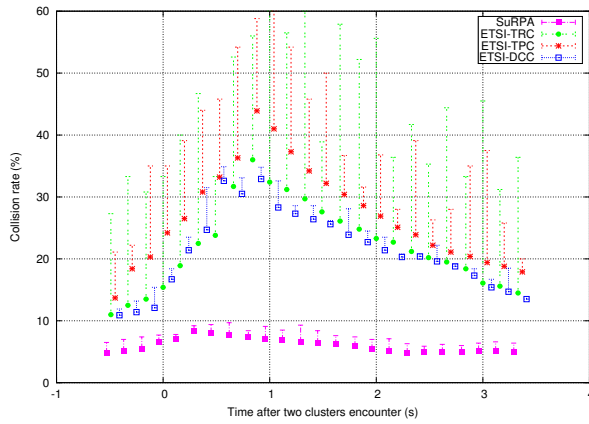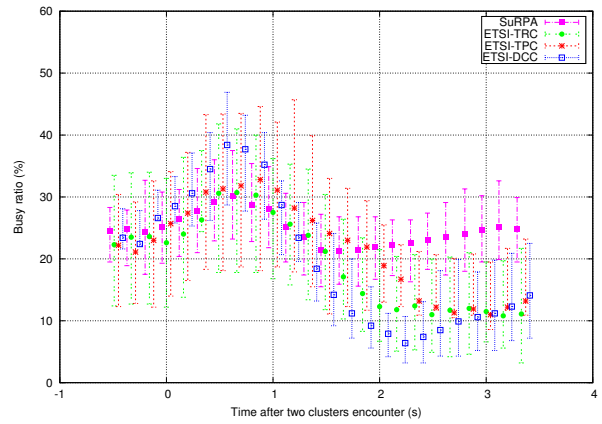
(a) Collision Rate vs. density
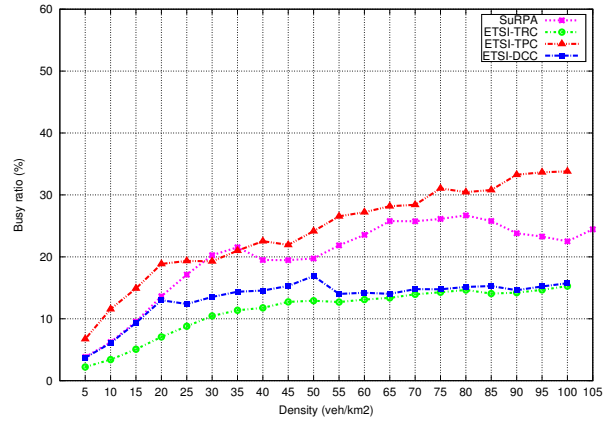
(b) Busy ratio vs. density

Fig. 3. Impact of vehicles density on the achieved collision rate and channel busy ratio: SuRPA vs. ETSI schemes

(a) Collision Rate vs. time

(b) Busy ratio vs. time

Fig. 4. Tx parameters adaptation efficiency: SuRPA vs. ETSI schemes

scheme outperforms these two schemes in terms of collision rate, TPC achieves slightly higher channel utilisation at the detriment of the collision rate.

It is crucial here to point out the importance of a low collision rate to achieve a higher level of awareness in vehicular environment. In fact, DCC having higher Tx parameters (first set of results) for a short period does not mean it achieves a higher awareness level since more beacons are lost (twice the value of collision rate in our scheme). That being said, the under utilisation of the channel is not desired either as this channel needs to remain at a good level of utilisation in order to meet the requirements in terms of awareness level. According to our findings and those presented in [5], the adequate channel busy ratio in vehicular networks, that guarantees a marginal collision rate, is around 25%.

The third set of results show the reaction time of each of the considered schemes to the detected changes in the channel conditions. Figure 4 shows the variation of the collision rate and the busy ratio after two groups of vehicles meet (in an intersection for example) in 4(a) and 4(b), respectively. SuRPA achieves a collision rate of 5% with a slight increase right after the two groups of vehicles encounter, but gets

back to its normal rate after approximately one second. This collision rate is maintained all through the merge of the two vehicle clusters without an important drop in busy ratio (above 20% at the lowest point). The ETSI schemes show an important increase in collision rate after second 0, then take more time to get back to their respective normal rates. The variation in busy ratios shows the instability of these schemes as their respective values rise during second 1 after the vehicles encounter and drop significantly in the third second due to the inappropriate adaptation of Tx parameters (see Figure 2).

It is clear that our scheme allows a faster reaction and adaptation to the channel conditions variation, and it also shows that these variations are softer than the three other schemes considered in this study. To summarise, SuRPA ensures a negligible collision rate thanks to the smoother adaptation of Tx parameters; it guarantees a higher awareness level than the three other considered schemes with more up to date context aware information and a larger covered area. Finally, the reaction time of our scheme is lower. Such an aggressive reaction allows more stable collision rate as well as the busy ratio. The channel is kept at a good level of

utilisation in a way to exploit it better, and leave enough free channel time in case an incident occurs on the road and emergency messages are triggered.

V. CONCLUSION

In this paper, we presented SuRPA, a new solution where the transmit rate and power are adapted successively in order to control the channel load and ensure a better level of awareness among vehicles. We achieved these goals by combining rate and power adaptations in an original smart way that allows respecting the strict beaconing frequency requirement and ensuring a high level of awareness, especially in closer ranges. We conducted simulations under realistic channel conditions and vehicles mobility. The obtained results have proven the efficiency and effectiveness of the proposed scheme and confirmed our claims about a smart transmit rate and power combination. The findings of this work will help the research community to move one step forward and gain deeper understanding of the rate and power adaptation mechanics, open up new prospects for more innovative ways to control the channel load in VANETs, and brings up new challenges that we will address in future works.

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