Analysis of Adaptive Beaconing Protocols for Intersection Assistance Systems

Guillem Boquet, Ivan Pisa, Jose Lopez Vicario, Antoni Morell and Javier Serrano
Department of Telecommunications and Systems Engineering
Universitat Autònoma de Barcelona
Email: {guillem.boquet, ivan.pisa, jose.vicario, antoni.morell, javier.serrano}@uab.cat

***Abstract*—Cooperative vehicular applications require severe to moderate requirements of accuracy and latency according to their purpose. Those applications mainly rely on the periodic exchange of information directly causing congestion problems on the communication channel and thus obtaining unreliable information at the application level. Adaptive and reactive beaconing tries to overcome that fact adapting transmission parameters to different criterions such as channel load, application requirements or specific situations to improve the overall performance of the vehicle network. Nevertheless, it has not yet been determined to date if the information disseminated by these protocols is suitable for the implementation of specific applications. In this context, we analyze the system behavior in a realistic simulated high dense intersection where the probability of packet reception becomes unpredictable and analytical models become inaccurate. We present a critical analysis on the performance of four relevant state-of-the-art protocols with different aims and approaches while their performance is evaluated with respect to position accuracies required by different kind of RSU-based applications.**

I. Introduction

Currently, there is a need for vehicular safety applications that are to be implemented in the coming years to have accurate, continuous and updated information because of their strict requirements. Those applications mainly rely on the periodic broadcasting of Cooperative Awareness Messages (CAM) on the ETSI ITS-G5 Control Channel (CCH) [1]. However, current standards and proposed solutions suffer severe congestion problems in the communications channel when the number of nodes, i.e. vehicles, grows within the network [2]. These problems result in large packet losses and, therefore, in a delay of the information that nodes eventually receive, which entails a deterioration in the performance of the applications and even a limitation for their implementation. The main reason that causes this problem is the need to comply with the requirements of the so-called cooperative awareness that requires the periodic exchange of vehicle status information through latencies of the order of 100 ms. Consequently, to alleviate this problem, standardization bodies and researchers propose protocols to adapt mainly the frequency, power and speed of transmission depending on, for example, the load of the channel, the traffic density, the dynamics of the vehicles, specific situations or application requirements. Two surveys on adaptive beaconing can be found in [3] and [4].

The most relevant trend that is being followed is to adapt the beaconing frequency as a function of the channel load so as not to exceed a threshold considered optimal with respect to the throughput of the channel, which in turn leaves capacity to receive messages that promptly inform of specific events. This type of protocols are named congestion control protocols which, in addition, most of them are based on the fairness postulation, i.e. that all vehicles must have the same performance and the same opportunities within the network. Two of these examples are LIMERIC and PULSAR currently considered by ETSI [5] to be included in the ITS-G5 vehicular standard together with their DCC mechanism and the CAM triggering conditions. Despite this, the aforementioned approaches are not optimal at the application level [6] [7] [8] since each vehicle has different needs at each instant of time to meet the requirements of the applications. For example, authors of [7] mention that current state-of-the-art congestion control mechanisms are not able to support Intersection Assistance Systems (IAS) adequately so they propose the use of a situation-based rate adaptation algorithm by allowing temporary exceptions for vehicles in dangerous situations relying on their Intersection Collision Probability metric. On the other hand, awareness control protocols aim to adequately support cooperative vehicular applications and traditionally have been designed and evaluated separately from congestion control protocols [9]. Therefore, [9] propose INTERN, a beaconing protocol that integrates a congestion control process as a function of the channel load and an awareness control process which aims to adapt the power to the minimum necessary so that the messages are received with certain reliability at an individual warning distance. However, none of these protocols take into account the position accuracy at the application level, which is a relevant metric for most safety applications like in [10], [11] and [12], and moreover their application requirements are based on the assumption that vehicles information is up to date and has no error.

The three main scenarios mentioned in the VANET literature and where vehicular safety applications acquire more relevance are: highway and urban and rural intersections because of its unique characteristics. Likewise, packet reception affects critically the performance of the applications and is determined by a number of influencing factors, such as radio wave propagation and interferences issuing from simultaneous transmissions. Therefore, we focused on intersections where scalability is a major problem due to the high density traffic in peak hours leading to high collision probabilities. As said, the probability of reception is based on a plurality of factors.

ISBN 978-3-903176-02-7 © 2018 IFIP

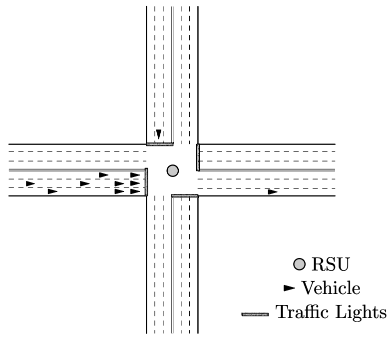

Fig. 1. Intersection layout.

For example, IEEE 802.11p MAC contentions, the capturing effect and the hidden terminal problem all effect message reception but are very difficult to express analytically [13]. Thus, we empirically analyze the system behavior in a high dense intersection where the probability of packet reception becomes unpredictable and models become inaccurate.

Vehicle-to-Infrastructure (V2I) applications considered by ETSI are many such as: intersection collision warning, wrong way driving, traffic condition warning, signal violation warning, traffic light management and optimal speed advisory, traffic information and recommended itinerary. Those applications have different requirements but required position accuracies can be grouped into three scales for better evaluation: low (10-20 or even 30 m), medium (1 to 5 m), and high (a meter or sub-meter) [14]. Then, we evaluate the performance of four relevant beaconing protocols with respect to intersection application requirements from the point of view of a Road Side Unit (RSU) to see if the information provided by state-of-the-art protocols is accurate enough to support RSU-based applications.

Summarizing, we make a critical analysis about why some protocols with different aims and approaches perform better or not into the chosen scenario and then we compare the results with the aforementioned scale accuracies required by applications. To do this, first we make a semi-analytic analysis of the position error derived either by lost packets or by vehicle dynamics. Then, this analysis helps us to understand how different protocols perform. The main contributions of this paper are:

- a semi-analytic analysis of the position error behavior,
- and a performance evaluation of state-of-the-art beaconing protocols under the considered scenario in a realistic simulation environment (Veins [15]).

This work is organized as follows. The scenario considered is described in Section II and then the error behavior analysis is derived under Section III. Protocols considered are listed and briefly described in Section IV while their evaluation is done under Section V. Finally, conclusions and future work are exposed in Section VI.

TABLE I
PERCENTAGE (ρ) OF VEHICLE TYPES TOGETHER WITH THEIR LENGTH (L), ACCELERATION (a), DECELERATION (d), AND MAX SPEED (v_{max})

Class	ρ	L $[m]$	a $[m/s^2]$	d $[m/s^2]$	v_{max} $[m/s]$
A	0.29	4	2.6	4.6	$\sim \mathcal{N}(44, 0.1)$
B	0.7	5	2	4.2	$\sim \mathcal{N}(33, 0.1)$
C	0.01	15	1	3	$\sim \mathcal{N}(22, 0.1)$

II. Scenario Description

The selected scenario is an unobstructed intersection with a RSU that is responsible for the real-time monitoring of all vehicles, Intersection Collision Avoidance (ICA) and traffic management. Figure 1 shows the topology of the scenario which consists of an intersection regulated by traffic lights of four 500 m long roads with six lanes each, three in each direction. The RSU is located in the middle of the intersection maximizing Line-Of-Sight (LOS) at a height of 5 m. We assume that all nodes in the network communicate according to the IEEE 802.11p standard. CAMs are periodically broadcasted by vehicles on the ITS-G5 CCH with a Best Effort Access Category (AC_VE) [16], which results in the listening period (Arbitration Inter-Frame Space, AIFS) and Contention Window (CW) mentioned in Table II together with other relevant IEEE 802.11p PHY and MAC parameters.

Three different vehicle classes are generated with different dynamics, lengths and probabilities of appearance, because these values affect the behavior of the vehicles. Vehicle speeds are normally distributed to achieve realistic car following behavior. Table I values result in a speed distribution where 95% of the vehicles drive between 80% and 120% of the maximum speed allowed. Only high density traffic emulating realistic rush hours is considered in this work because low and medium densities where simulated in [17] under the same scenario showing no relevant differences w.r.t. position accuracy. Figure 7 shows the evolution of the vehicle number across time in an area of 19.5 km^2. Note that vehicles stop appearing at $t = 160$ s. All vehicles move according to the default SUMO *Krauss* driver model and the vehicle arrival process for each road follows a $\mathcal{B}(160, 0.25)$ with a trial every second which approximates a Poisson distribution.

The radio signal attenuation is modeled as a function of path, shadowing and fading effects, Figure 2. The Two-Ray Interference model is used to capture radio signal attenuation over distance and ground reflection effects because transmissions experience either constructive or destructive interference with its own ground reflection [18]. The small scale and the large-scale fading are both represented by the Nakagami model with $m = 3$ for distances between 0 to 50 m (approximating Rician distributed channel conditions where a LOS path exists), $m = 1.5$ from 50 to 150 m and $m = 1$ for distances above 150 m [19]. Also as there is a substantial impact of shadowing on the performance of congestion control protocols, radio shadowing effects caused by other vehicles are modeled using [20].

ISBN 978-3-903176-02-7

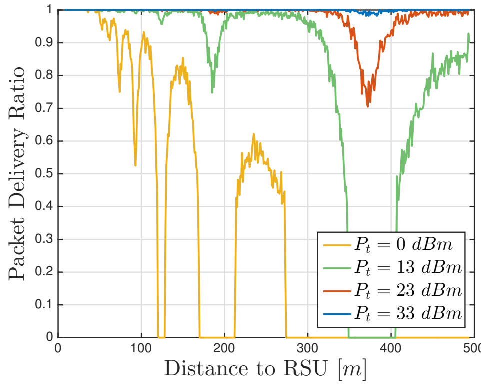

Fig. 2. Simulated probability of packet reception for different transmission powers computed for one vehicle alone using the channel model described in Section II.

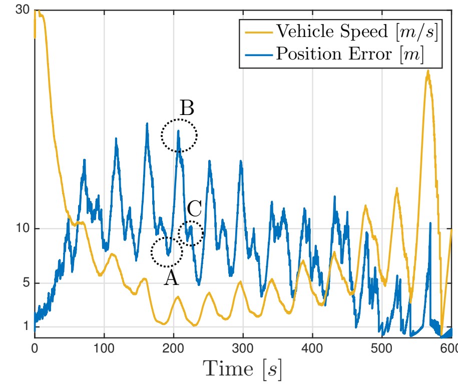

Fig. 3. Average position accuracy at the RSU and speed of vehicles.

TABLE II
DEFAULT IEEE 802.11P PHY & MAC PARAMETERS

Parameter	Value
ITS-G5 Channel	CCH (5.9 GHz)
Bandwidth	10 MHz
Data Rate (R)	6 $Mbps$
Beacon Size (L)	300 B
Transmission Power (P_t)	23 dBm
Sensitivity (CS_{th})	-95 dBm
$AIFS$, CW_{min}	110 μs, 15 $slots$

III. Error Behavior Analysis

We evaluated the performance of static beaconing in order to understand how the system model behaves in the defined scenario where dynamics and network behavior are highly unpredictable. Due to these qualities the purely mathematical analysis of the position error becomes highly complex and, therefore, we present a semi-analytical analysis. 10 Hz beaconing was selected as was originally suggested by ETSI for cooperative awareness applications to meet the 100 ms requirement. The main metric analyzed in this section is the position accuracy because safety applications have strict requirements in terms of awareness reliability and latency. It is defined as the error between the current vehicle's physical position and the last reported position to the RSU which implicitly entails the requirement of latency. Hereafter it is assumed that the positioning of the vehicles is error free because we are interested in the error contribution from the performance of the protocols not in the node positioning of itself.

Firstly, assuming ideal channel conditions, a constant vehicle speed v and uniformly distributed events of looking up the position during a fix beaconing interval t_b, the average position error at the receiver can be expressed as half the minimum plus the maximum position errors as [12]:

$$\bar{e} = vt_{tx} + \frac{v(t_b - t_e)}{2}, \tag{1}$$

where t_{tx} is the transmission time of the beacon and t_e is the time between the position look up and the next beacon reception.

However, the reception of the next beacon depends on several factors as a packet may not be received due to low SINR (i.e., collision) or low SNR (i.e., reception power below the receiver's sensitivity). This can be seen in Figure 3 where the average position error at the RSU increases as the average speed of vehicles drops while congestion occurs, contrary to (1). Considering this and neglecting the error contribution of t_{tx} (cm-order), the maximum instant position error of a vehicle can be estimated as

$$\hat{e}_k = v_k E\{t_b{'}\}, \tag{2}$$

where $t_b{'}$ is the actual time between two consecutive beacons and, therefore, it is a random variable. Its expectation can be expressed as the number of consecutive tries needed to receive a beacon multiplied by the beacon interval, $E\{t_b{'}\} = E\{\#tries\}t_b$ where (assuming that packet losses are independent across time)

$$E\{\#tries\} = \sum_{i=1}^{\infty} i \; P_{col}^{(i-1)}(1 - P_{col}). \tag{3}$$

Note that in our scenario the probability of a collision can be estimated as $P_{col} \approx 1 - PDR$ because packet losses due to SNR represent the 0.6% of the total packet losses.

The error defined in (2) is a function of the vehicle dynamics, which roughly depends on traffic conditions and vehicle characteristics, and of the probability of packet reception (i.e., Packet Delivery Ratio, PDR), which roughly depends on the channel load, channel attenuation and hidden nodes. Thus, we divide the error analysis of the scenario into two parts:

- the error component due to vehicle dynamics
- and the error component due to packet losses.

A. *Influence of vehicle dynamics*

Looking at Figure 3, it can be seen that the error follows two different patterns as a function of time as stated in (2). On the one hand, there are periodic fluctuations in the error similar to

ISBN 978-3-903176-02-7

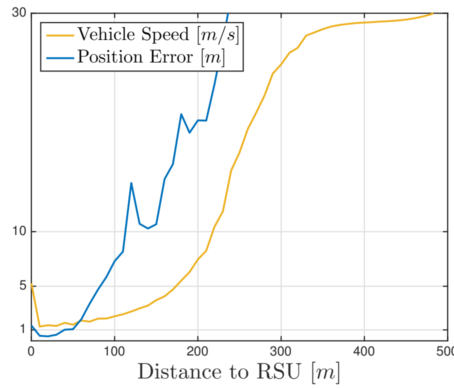

Fig. 4. Average spatial distribution of the position error and vehicle speed.

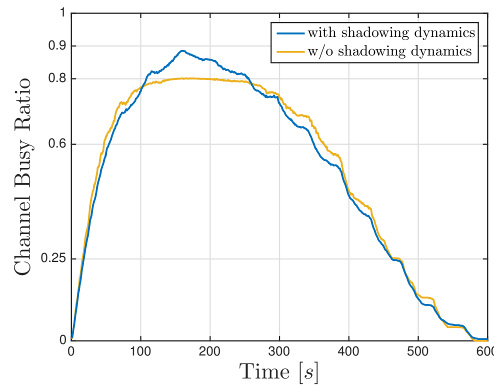

Fig. 5. Impact of shadowing dynamics on the average CBR.

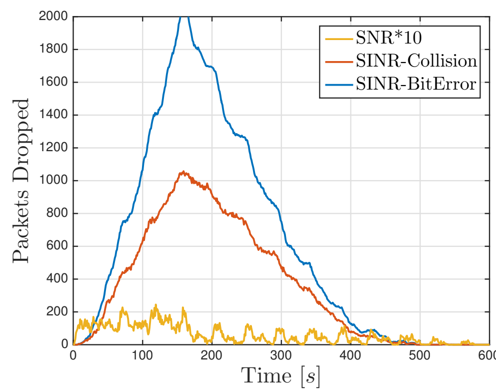

Fig. 6. Average number of packets dropped across time. The number of packets dropped due to SNR is multiplied by 10 to increase its visibility.

the evolution in time of the average speed. These are due to the behavior of vehicle traffic at the intersection. For example in point A of Figure 3, one of the time instants in which the error is minimal, corresponds to when immediately traffic lights turn green: vehicles in queue are stopped and those at the beginning start to accelerate, therefore the average speed of vehicles is much lower and the resulting error as well. Once the traffic light has turned green, the vehicles accelerate until reaching the maximum speed to leave the intersection, point B in Figure 3. In addition, vehicles that previously stood in the queue move towards the traffic light. All of these increases the average speed and consequently decreases the position accuracy. Finally, the same phenomenon can be perceived at point C with vehicles that were on turn lane, although it is less scaled because the number of vehicles is smaller and the traffic light time is also shorter. The worst case scenario can be found, looking at Figure 4 and at the evolution of the error in space, at larger distances from the RSU where higher speeds are found.

This shows that beaconing frequency and communication parameters should be adapted to the dynamics of the vehicles, mainly because stopped vehicles near the RSU saturate the channel with redundant information that does not improve the accuracy, raise the probability of a collision and are the least likely to contribute to an accident.

B. Influence of packet losses

On the other hand, the error grows similar to the evolution of the number of vehicles but attenuated by the decrease in the average speed when congestion occurs. There are collisions in almost all instants of time due to the periodic transmission of beacons. Losses due to attenuation of the channel are negligible compared to those due to collisions. Figure 6 shows the number of packets dropped at the physical layer: considered as noise due to low SNR, discarded as collision due to low SINR during preamble reception or discarded due to bit errors caused by low SINR at some point during the reception. The problem worsens as the number of vehicles increases coinciding in $t = 160\ s$ the greatest number of collisions with the maximum number of vehicles. This translates to a low PDR near 30%, Figure 7, which roughly corresponds to a 70% chance of a collision. Therefore, high density traffic infer a high collision probability between transmissions arising the well-known scalability problem of the IEEE 802.11p MAC protocol which precisely congestion control protocols try to avoid [2]. Besides, the high number of vehicles also increases the effect of radio signal shadowing dynamics increasing the probability that some packets are not received due to a low SNR but, more importantly, increasing the problem of the hidden node during which the collision avoidance mechanism of CSMA is not involved. Thanks to the shadowing of the vehicles the range of distance at which another vehicle is sensed is diminished and is more likely that two hidden nodes try to transmit at the same time generating a collision. Another thing that can be seen in Figure 6 is that when vehicles stop appearing ($t = 160\ s$) packet losses due to SNR follow the same pattern as the speed. This is not due to the speed but to the distance in which the cars are located because it coincides that they have the highest speed at further distances from the RSU.

The hidden node and collisions problem can also be seen looking at the evolution of the Channel Busy Ratio (CBR) over time in Figure 5. The CBR is computed at the RSU as the amount of time that the channel is sensed as busy during a second. The theoretical CBR limit in CSMA/CA without any collision can be computed as the total number of beacons that

ISBN 978-3-903176-02-7

Fig. 7. Average PDR and vehicle number (jointly with 2 times the standard deviation and divided by 400 to fit the figure).

can be fitted in a second, N_l, multiplied by the duration of a beacon transmission, t_p. In addition, N_l can be deduced as the inverse of the packet duration plus the predetermined listening period (AIFS) like:

$$N_l = \frac{1}{AIFS + t_p} \tag{4}$$

where t_p can be expressed as the duration of L bytes transmitted at a data rate R plus the duration of the predetermined 802.11p PHY header ($t_h = 40\ ms$) [21]:

$$t_p = t_h + \frac{8L}{R}. \tag{5}$$

Substituting first in (5) and then in (4) the values mentioned in Table II and multiplying by t_p leads to a CBR limit of 0.8. However, as shown in Figure 5, the CBR is close to 0.9 exceeding the threshold of 0.8 mainly due to the shadowing introduced by the vehicle dynamics. This result indicates that the behavior of the medium access protocol CSMA/CA converges to an ALOHA process where a node chooses a random transmission time without sensing the medium. This finding is aligned with the work in [2], which mentions that to obtain a 90% ALOHA one needs near 400 vehicles within the carrier sensing range of a node. So, at these densities, the network tends to behave like an ALOHA protocol even though a back-off mechanism is in place.

In conclusion, periodic beaconing increase transmission collisions resulting in catastrophic position accuracies. In fact, position error is not improved when the CBR is below or near to 0.6, which [22] states that this is the CBR value that maximizes the throughput or number of successful messages exchanged per second. Therefore, this indicates that congestion control protocols are not suitable alone. Furthermore, adaptation of power transmission is needed to overcome shadowing effects that exacerbate the hidden node problem and to avoid the capturing effect, because vehicles near the RSU with slow speeds interfere with vehicles far away with larger speed and prone to larger errors. Finally, at application layer level, one way to overcome channel losses would be to adopt a trajectory predictor at the receiver to minimize the uncertainty between beacons.

TABLE III
STATES AND PARAMETERS OF THE ETSI DCC STATE MACHINE

State	CBR	T $[ms]$	P_t $[dBm]$	R $[Mbps]$	CCA_{th} $[dBm]$
Relaxed	< 0.3	100	33	3	-95
Active1	$0.3 - 0.4$	200	23	6	-85
Active2	$0.4 - 0.5$	300	23	6	-85
Active3	$0.5 - 0.6$	400	23	6	-85
Restrictive	> 0.6	500	13	12	-65

IV. CONSIDERED PROTOCOLS

We considered four relevant state-of-the-art beaconing protocols (for specific details the reader is referred to [22], [23], [26], [1], [9] and [17]). All protocols were adapted to the specific scenario conditions and to the following safety application requirements: maximum frequency of 10 beacons per second, a target latency of 100 ms and 0.5 m tracking accuracy [1] [24] [25]. All parameters were adapted following the guidelines provided by the corresponding authors. Default values of Table II were adopted for parameters not considered by the protocols.

A. LIMERIC [22] + PULSAR [23]

Beacon frequency is linearly adapted following the LIMERIC protocol in combination with CBR information exchange provided by PULSAR, such that all vehicles converge to the same beacon rate and to a desired channel load level $CBR_{max} = 0.6$. As the vehicle number is not constant, we implemented the gain saturation approach [22] in which vehicles adapt their frequency linearly as a function of the previous frequency plus the difference, limited by a threshold $X = 0.005$, between CBR_{max} and the global CBR, that is the maximum CBR between the one locally sensed and the one reported by the neighbors during two hops CBR_{2-hop}. The constant variables of the linear model used are $\alpha = 0.1$ and $\beta = 1/150$ [22]. The local CBR was computed using a low pass filter as in [23]. The CBR computing time window was set to 250 ms, thus the rate adaptation occurs every 750 ms to account for the information dissemination delay. Finally, we considered the unsynchronized case, i.e., all vehicles do not check the CBR at same time.

B. ETSI DCC [16] [26] + CAM [1]

Beacon frequency is adapted to vehicle dynamics following the CAM triggering conditions and the packet interval T_GenCam_DCC provided by DCC. On the other hand, transmission power, data rate and the Clear Channel Assessment threshold CCA_{th} are adapted using a state machine with parameters listed in Table III to react to the global CBR which is obtained using the PULSAR approach. The state machine interval check was set to 100 ms and $timeUp$ and $timeDown$ constants were set to 1 and 5 seconds respectively [5]. All vehicles are unsynchronized like in the LIMERIC case.

ISBN 978-3-903176-02-7 © 2018 IFIP

C. INTERN [9]

Beacon frequency is adapted as $T_f = R \pm \Delta T_f$ to achieve fairness at the application level, i.e., vehicles apply similar increments ΔT_f to the required beacon frequency $R = 10\ Hz$. In addition,

$$\Delta T_f = \Delta T_f^T \frac{CBR_{max}}{CBR_{2-hop}} \tag{6}$$

is dynamically adapted to CBR_{max}, the maximum CBR experienced within two hops CBR_{2-hop} and the minimum ΔT_f reported by its neighbors ΔT_f^T, both obtained following the PULSAR approach. Then, frequency is decreased only if $CBR_{2-hop} > CBR_{max}$. We considered minimum and maximum ΔT_f values of 3 Hz and a 100 ms CBR window time. Besides, the transmission power is set to the minimum power level needed to ensure that the demanded beacon frequency r is guaranteed at the application's warning distance d_w [9]. Under this scenario, the application requirement aims to provide accurate position information to the RSU at distances from 0 to 500 m. Thus, the transmission power is adapted like

$$P_t[mW] = 4.932\ e^{(0.012\ d_w)}, \tag{7}$$

as the minimal power that ensures a mean PDR of 0.99 with a standard deviation of 0.01 for the aforementioned distances plus a compensation for the reduced PDR resulting from the channel congestion [9], following an exponential function obtained experimentally using a regression model because no analytical model fitted the scenario.

D. TPM [27] [17]

Beacon frequency is adapted using data properties involved in the considered network traffic with the aim of reducing redundant information transfer while satisfying the accuracy application's requirement. The simplest approach of this protocol applied to a V2I scenario was used [17]. A beacon is sent when the comparison between the predicted position using a constant velocity model and the actual position known by the vehicle, i.e., the position error, exceeds a user-defined threshold $\delta_{th} = 0.5\ m$. Accordingly, on the RSU's side runs the same prediction model for every vehicle on the scenario. The position error interval check was set to 10 ms.

V. Performance Evaluation

The performance of Section IV protocols was evaluated using Veins 4.6 and SUMO 0.29 on the scenario and parameters described in Section II and IV. All results shown in this paper were averaged over 10 simulation runs and the fix-period beaconing of Section III was considered as the Baseline.

The following metrics were taken into account (*max* and *min* in Table IV are the maximum and minimum values seen by the RSU):

- Position Errors (defined in Section III) are computed and averaged at the RSU for each vehicle every 10 ms. The mean of the position error is calculated averaging all time instants and σ_e in Table IV is computed as the mean of the standard deviations of every time instants.
- PDR is computed as the ratio between the number of packets received and sent within 1 second windows for every vehicle. The mean and σ_p in Table IV are calculated averaging all time instants for all vehicles.
- Channel Footprint is defined as the total channel resources consumed at the RSU in time and space, i.e. the integral of CBR from 0 to 600 seconds [8] [28]. max value is the maximum value of CBR experienced at the RSU.

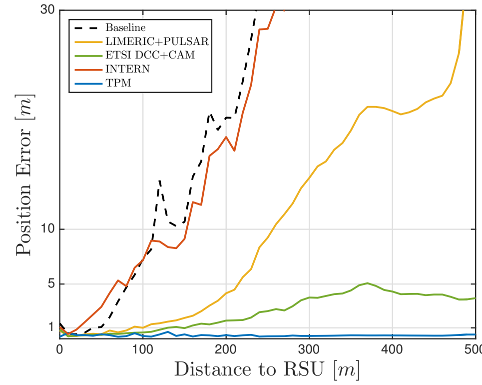

Fig. 8. Average spatial distribution of the position error.

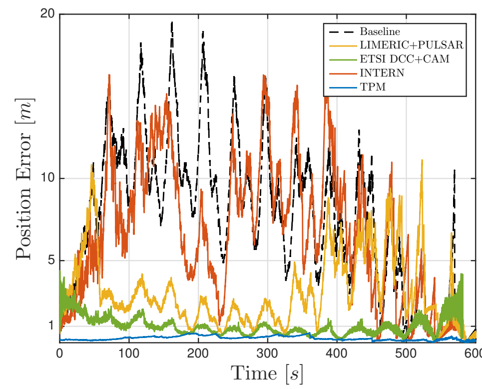

Fig. 9. Average position error across time.

Figure 8 should be taken into account at the time of implementing an application based on a RSU which needs position information of vehicles approaching the intersection. TPM could support applications that require in average high scale accuracies up to distances from 500 m while ETSI up to 150 m, LIMERIC up to 100 m and Baseline and INTERN near 50 m. Regarding medium accuracies: Baseline and INTERN would comply with the requirement up to distances of approximately 80 m, LIMERIC up to 210 m and ETSI up to 500 m. On the low accuracy requirements, Baseline would meet the requirement within distances between 0 and 240 m, INTERN up to 250 m and LIMERIC up to 490 m.

Figure 9 shows the average position errors across time where it is clearly seen the congestion adaptation effect on

ISBN 978-3-903176-02-7 © 2018 IFIP

TABLE IV
STATISTICAL PERFORMANCE OF PROTOCOLS IN TERMS OF POSITION ERROR, PACKET DELIVERY RATIO AND CHANNEL FOOTPRINT OVER TIME.

		Baseline	LIMERIC+PULSAR	ETSI DCC+CAM	INTERN	TPM
Position Error $[m]$	$mean$	7.01	2.88	1.02	6.83	**0.26**
	σ_e	28.09	12.97	1.99	23.24	**1.62**
	max	566	546.1	227.6	511.9	**139.3**
Packet Delivery Ratio	$mean$	0.72	0.69	0.95	0.67	**0.997**
	σ_p	0.21	0.17	0.11	0.26	**0.03**
	min	0.1	0.1	0.13	0.1	**0.33**
Channel Footprint	$mean$	0.52	0.48	0.25	0.49	**0.03**
	σ_f	0.031	0.031	0.009	0.01	**0.004**
	max	0.9	0.82	0.49	0.86	**0.09**

TABLE V
REQUIRED POSITION ACCURACY FOR ITS APPLICATIONS GROUPED INTO LOW (10-30 m), MEDIUM (1-5 m), AND HIGH (0.5-1 m) SCALES [14].

Technique	Position Accuracy		
	Low	Medium	High
Routing	x		
Data Dissemination	x		
Map Localization	x		
Coop. Cruise Control		x	
Coop. Intersection Safety		x	
Blind Crossing		x	
Platooning		x	
Coll. Warning System			x
Vision Enhancement			x
Automatic Parking			x
Autonomous Vehicle			x

the error. Speaking about LIMERIC, ETSI and INTERN, the error decreases drastically as the frequency is adapted to the saturated channel. Nevertheless, the error keeps following the same pattern as vehicle dynamics because there is no adaptation in reference to this term. Also Figure 9 shows that the error grows once the traffic density decreases. This is due to the fact that the reaction time of the protocol is slow compared to the dynamics of the scenario and because the criteria used for adaptation is no longer optimal since in these time instants the error component due to dynamics is more relevant (channel is less congested). Regarding the application requirements, most of the time the position error is maintained within the medium accuracy. Contrary, TPM on average always stays within high accuracy.

Now, considering an average vehicle width of about 2 m an overall accuracy of 1 m is needed in order to locate a vehicle in a particular driving lane. Therefore, taking a look at values from Table IV it can be deduced that maximum errors and standard deviations are too large to consider implementing a critical safety application relying on the information proportioned only by these protocols at the RSU.

LIMERIC and INTERN protocols rely on the fairness postulation and therefore their adaptation is mainly conditioned by other vehicles. LIMERIC aims to achieve a target CBR while INTERN aims to achieve a desired frequency under the target CBR but vehicle dynamics are neglected. LIMERIC linear parameters, which define the convergence stability, speed and time, were set to constant values but the protocol performance would be improved if those were dynamically adapted to the number of vehicles because of the fast varying density traffic of the scenario. Also keep in mind that it does not use any power adaptation. INTERN's error pattern is similar to the baseline as its adaptation focus on achieving the desired frequency adapted to: (i) CBR measures which are not accurate enough due to shadowing dynamics and (ii) strongly to the minimum frequency increment reported by neighbors (see (6)) which equals to 0 for vehicles measuring CBR levels below CBR_{max} and close to the desired frequency. Note that in the scenario the desired frequency is the same for all vehicles to meet the 100 ms latency which in turn is the same as the baseline and the maximum allowed by ETSI. INTERN's power adaptation implies that distant vehicles transmit with greater power, however, it is not optimal since it also implies similar signal strength of packets received at the RSU, which in case of interference none can be received correctly because of poor SINR values.

ETSI's protocol not only relies on the channel load to adapt the beacon frequency. In fact, the periodic component of the beacon frequency is adapted to the channel load but the other frequency component is derived from vehicles dynamics (CAM triggering conditions). Thus, as the channel becomes more saturated, the protocol decreases the beacon frequency and the later component acquire more relevance improving the position accuracy. As said in Section III, vehicle dynamics are a key component in the position accuracy and, because of this, protocols aiming to adapt the beacon frequency to dynamics achieve a better position accuracy. This can be seen looking at the TPM performance. TPM focuses on adapting the beacon frequency only to vehicle dynamics and reducing the maximum redundant information from the channel. Therefore, it achieves the best position accuracy, a reduced channel load and almost near maximal PDR values (Table V). In turn, these also leads to better opportunities to succeed for other kinds of messages like Decentralized Environmental Notification Messages (DENM). However, as TPM does not use any mechanism to overcome channel losses, if a packet is lost the next packet will be sent when the predictor error exceeds the threshold. This derives in large values of maximum error and standard deviation which do not cope with high accuracy position requirements of the critical applications. In addition, another drawback of TPM —although this problem is alleviated as the RSU is the one regulating the intersection— could be that new vehicles appearing inside the RSU range do not receive updated information about vehicles that already sent their beacon and that their model is predicting correctly.

VI. Conclusions & Future Work

We presented a critical analysis on the performance of four state-of-the-art protocols derived first from a semi-analytic study of the position error behavior through an RSU-based application's point of view. Their performance was evaluated and compared with three different accuracy scales required by vehicular applications. It was deduced that congestion control controls perform well with respect to the channel capacity management and that translates into an increase in the accuracy of the position. However, it became clear that these protocols do not guarantee that the information is sent when needed as the position accuracy is strongly influenced by vehicle dynamics. Neither of them account directly for the hidden node problem and the capturing effect which are of high relevance in the considered scenario and needs to be addressed to achieve low uncertainty. Also, it was seen that adaptation of power transmission is needed to overcome shadowing effects which awareness control protocols partially solve while trying to meet the application requirements. Finally, it was concluded that communication parameters need to be adapted to the dynamics of the vehicles and to application requirements if high accuracy and reliable awareness is needed.

Future work will propose an enhanced protocol considering the analysis and results obtained and presented in this paper.

Acknowledgment

This work is supported by the Spanish Government under Projects TEC2014-53656-R and TEC2017-84321-C4-4-R.

References

[1] *Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service*, ETSI EN 302 637-2 V1.3.2, 2014.

[2] T. V. Nguyen, F. Baccelli, K. Zhu, S. Subramanian, and X. Wu, "A performance analysis of CSMA based broadcast protocol in VANETs," in *INFOCOM, 2013 Proceedings IEEE*. IEEE, 2013, pp. 2805–2813.

[3] K. Z. Ghafoor, J. Lloret, K. A. Bakar, A. S. Sadiq, and S. A. B. Mussa, "Beaconing approaches in vehicular ad hoc networks: a survey," *Wireless personal communications*, vol. 73, no. 3, pp. 885–912, 2013.

[4] S. A. A. Shah, E. Ahmed, F. Xia, A. Karim, M. Shiraz, and R. M. Noor, "Adaptive beaconing approaches for vehicular ad hoc networks: a survey," *IEEE Systems Journal*, 2016.

[5] *Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium; Validation set-up and results*, ETSI TR 101 613 V1.1.1, 2015.

[6] S. Joerer, B. Bloessl, M. Segata, C. Sommer, R. L. Cigno, and F. Dressler, "Fairness kills safety: A comparative study for intersection assistance applications," in *PIMRC IEEE International Symposium*. IEEE, 2014, pp. 1442–1447.

[7] S. Joerer, B. Bloessl, M. Segata, C. Sommer, R. L. Cigno, A. Jamalipour, and F. Dressler, "Enabling situation awareness at intersections for IVC congestion control mechanisms," *IEEE Transactions on Mobile Computing*, vol. 15, no. 7, pp. 1674–1685, 2016.

[8] M. Sepulcre, J. Gozalvez, and B. Coll-Perales, "Why 6Mbps is not (always) the Optimum Data Rate for Beaconing in Vehicular Networks," *IEEE Transactions on Mobile Computing*, 2017.

[9] M. Sepulcre, J. Gozalvez, O. Altintas, and H. Kremo, "Integration of congestion and awareness control in vehicular networks," *Ad Hoc Networks*, vol. 37, pp. 29–43, 2016.

[10] G. Bansal, H. Lu, J. B. Kenney, and C. Poellabauer, "EMBARC: Error model based adaptive rate control for vehicle-to-vehicle communications," in *Proceeding of the tenth ACM international workshop*. ACM, 2013, pp. 41–50.

[11] H.-H. Nguyen and H.-Y. Jeong, "Crosslayer beaconing design toward guaranteed cooperative awareness with contending traffic," in *Vehicular Networking Conference (VNC), 2015 IEEE*. IEEE, 2015, pp. 131–134.

[12] R. K. Schmidt, T. Leinmuller, E. Schoch, F. Kargl, and G. Schafer, "Exploration of adaptive beaconing for efficient intervehicle safety communication," *IEEE network*, vol. 24, no. 1, 2010.

[13] M. Killat and H. Hartenstein, "An empirical model for probability of packet reception in vehicular ad hoc networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 2009, no. 1, p. 721301, 2009.

[14] F. A. Santos, A. T. Akabane, R. S. Yokoyama, A. A. Loureiro, and L. A. Villas, "A Roadside Unit-Based Localization Scheme to Improve Positioning for Vehicular Networks," in *Vehicular Technology Conference (VTC-Fall), 2016 IEEE 84th*. IEEE, 2016, pp. 1–5.

[15] C. Sommer, R. German, and F. Dressler, "Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis," *IEEE Transactions on Mobile Computing*, vol. 10, no. 1, pp. 3–15, January 2011.

[16] *Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 4; Sub-part 2*, ETSI TS 102 636-4-2 V1.1.1, 2013.

[17] G. Boquet, J. L. Vicario, A. Correa, A. Morell, I. Rashdan, E. M. Diaz, and F. P. Muller, "Trajectory Prediction to Avoid Channel Congestion in V2I Communications," in *PIMRC IEEE International Symposium*. IEEE, 2017.

[18] C. Sommer, S. Joerer, and F. Dressler, "On the applicability of two-ray path loss models for vehicular network simulation," in *Vehicular Networking Conference (VNC), 2012 IEEE*. IEEE, 2012, pp. 64–69.

[19] *Intelligent Transport Systems (ITS); STDMA recommended parameters and settings for cooperative ITS; Access Layer Part*, ETSI TR 102 861 V1.1.1, 2012.

[20] C. Sommer, S. Joerer, M. Segata, O. K. Tonguz, R. L. Cigno, and F. Dressler, "How Shadowing Hurts Vehicular Communications and How Dynamic Beaconing Can Help," *IEEE Transactions on Mobile Computing*, vol. 14, no. 7, pp. 1411–1421, 2015.

[21] *Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band*, ETSI EN 302 663 V1.2.0, 2012.

[22] J. B. Kenney, G. Bansal, and C. E. Rohrs, "LIMERIC: a linear message rate control algorithm for vehicular DSRC systems," in *Proceedings of the Eighth ACM international workshop on Vehicular inter-networking*. ACM, 2011, pp. 21–30.

[23] T. Tielert, D. Jiang, Q. Chen, L. Delgrossi, and H. Hartenstein, "Design methodology and evaluation of rate adaptation based congestion control for vehicle safety communications," in *Vehicular Networking Conference (VNC), 2011 IEEE*. IEEE, 2011, pp. 116–123.

[24] *LTE; Service requirements for V2X services (3GPP TS 22.185 version 14.3.0 Release 14)*, ETSI TS 122 185 V14.3.0, 2017.

[25] *Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Definitions*, ETSI TR 102 638 V1.1.1, 2009.

[26] *Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part*, ETSI TS 102 687 V1.1.1, 2011.

[27] A. Boukerche, C. Rezende, and R. W. Pazzi, "Improving neighbor localization in vehicular ad hoc networks to avoid overhead from periodic messages," in *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*. IEEE, 2009, pp. 1–6.

[28] Q. Chen, D. Jiang, T. Tielert, and L. Delgrossi, "Mathematical modeling of channel load in vehicle safety communications," in *Vehicular Technology Conference (VTC Fall), 2011 IEEE*. IEEE, 2011, pp. 1–5.