Dynamic Beaconing using Probability Density Functions in Cooperative Vehicular Networks

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Keywords: Beacon Messages, Cooperative Road Safety Applications, Dynamic Beaconing Strategy, Probability Density Functions, Vehicular Scenario Characteristics.

Abstract: Vehicular networks comprise vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications based on wireless radio access technologies. These networks require the periodic exchange of beacon messages between neighboring vehicles, to support cooperative road safety applications. The regular broadcast of beacon in the common control channel (CCH) using the IEEE 802.11p standard can lead to interference and recurrent packet collisions. This issue impacts negatively in the quality and freshness of the beaconing information which is essential to detect and mitigate potentially dangerous traffic situations on time. In this paper, we evaluate the performance of a dynamic beaconing strategy where both beacon rate and transmit power are assigned by means of probability density functions (PDFs). The idea is to know which PDF is more convenient to increase the system's performance according to vehicular scenario characteristics. We investigate four types of PDFs, attending to four different performance metrics, in four distinct vehicular scenarios, using the well established Veins (Vehicles in network simulation) framework. The simulation results show that a beaconing strategy based on uniform PDF is convenient in scenarios with high vehicle density and low relative speed, whereas a beaconing strategy based on normal PDF is suitable in scenarios with high relative speed and low vehicle density.

1 INTRODUCTION

Vehicular networks include vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications using the IEEE 802.11-OCB[1] radio access technology in the 5.9 GHz frequency band (IEEE, 2016). Cooperative awareness is the core of several active road safety and traffic efficiency vehicular applications (Boban and d'Orey, 2016). The main premise is that, knowing the status of neighboring vehicles, the active road safety systems will be able to detect and mitigate potentially dangerous traffic situations on time, and successfully coordinate the traffic in certain points or sections of a road. In order to make others aware of its presence, each vehicle periodically transmits one-hop broadcast messages, called *beacons*, containing its position, speed, acceleration, and heading (ETSI, 2014). This process, known as *beaconing*, occurs on the so called control channel (CCH) and allows the receiver vehicles to create a Local Dynamic Map (LDM) based on surrounding environment information, which is essential for the proper performance of cooperative awareness vehicular applications.

Different beaconing algorithms have been proposed in the literature to support cooperative awareness applications (Shah et al., 2017). These adapt the beacon transmission parameters, using distinct strategies, to control the channel load and meet the communication requirements of the applications. The algorithm proposed in (Sepulcre et al., 2016) integrates a congestion and awareness control process. First, the packet transmission rate of each vehicle is configured taking into consideration the minimum required by the application, plus certain margin. Then, the transmission power is set to the minimum power

[1]The Outside the Context (OCB) mode allows vehicles that are not member of a Basic Service Set (BSS) to transmit/receive data without preliminary authentication and association.

Bolufé, S., Azurdia-Meza, C., Céspedes, S., Montejo-Sánchez, S., Souza, R., Fernandez, E. and Estevez, C.
Dynamic Beaconing using Probability Density Functions in Cooperative Vehicular Networks.
DOI: 10.5220/0006816206360642
In *Proceedings of the 4th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2018)*, pages 636-642
ISBN: 978-989-758-293-6

level needed to ensure the demanded packet reception rate at the application warning distance. In the proposal of (Aygun et al., 2016), the algorithm adjusts the beacon transmission power in order to reach a desired awareness ratio at the target distance, while controlling the communication channel load by adjusting the beacon transmission rate to keep the current channel busy ratio below certain threshold. The work in (Kloiber et al., 2012) proposes to mitigate recurring interferences by randomly selecting the transmit power, while using a fixed beacon transmission rate. Such randomization reduces the chances that a vehicle is found in the common packet collision area from multiple senders.

In this paper, we evaluate the performance of a dynamic beaconing strategy where both beacon rate and transmit power are assigned by means of probability density functions (PDFs). The goal is to know which PDF is more suitable to increase the system's performance according to traffic characteristics of vehicular scenarios. Randomizing the beacon transmission parameters has the following benefits: **1)** reduces the probability of recurring packet collisions; **2)** provides local and global fairness; **3)** implicit congestion control; and **4)** adjustment of the quality of cooperative awareness according to applications requirements or vehicular context. We explain these benefits in more detail in the subsequent section.

The main contributions of this paper are the following: ***i)*** to model the beaconing process adjusting both beacon rate and transmit power by means of PDFs; ***ii)*** to evaluate the impact of PDFs based beaconing strategy on system's performance, when the same distribution (Constant, Uniform, Normal or Triangular) is used to control the beacon rate and transmit power; ***iii)*** to evaluate the PDFs based beaconing in four distinct vehicular scenario (Spider, Manhattan, Highway, and Urban) using a realistic simulation framework; and ***iv)*** to set a relationship between the use of certain PDF and the traffic characteristics of vehicular scenario.

The remainder of this paper proceeds as follows. In Section 2 we present the beaconing process based on PDFs. Section 3 describes the simulation setup, including vehicular scenarios, simulation parameters, and performance metrics. The results are discussed in Section 4. Finally, conclusions and future works are given in Section 5.

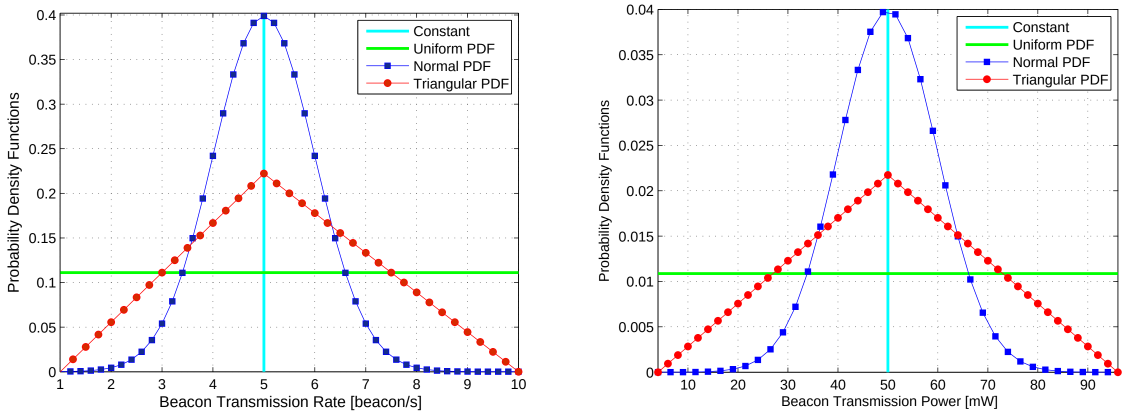
2 DYNAMIC BEACONING USING PROBABILITY DENSITY FUNCTIONS

The regular broadcast of beacon messages provides updated information in real time of the transmitting vehicle status (Boban and d'Orey, 2016). Through this process, receiving vehicles obtain accurate information of the surrounding environment, being able to avoid accidents on time and coordinate the traffic on the road. One of the main issues of the beaconing process is the high load it can generate on the communication channel. In scenarios with high vehicle density, the beaconing load can lead to channel congestion, increasing significantly packet collisions (Zemouri et al., 2014). As a consequence, the degradation of cooperative awareness due to recurring packet collisions impacts negatively on the system's performance.

The random dynamic beaconing is based on using a certain PDF to set beacon transmission parameters. The vehicles compute the beacon rate and transmit power by means of PDFs over a certain valid range on each beacon transmission. Fig. 1a and Fig. 1b show the concept of random distribution of beacon rate and transmit power for four different PDFs. In the normal and triangular distributions, the values close the mean (5 beacon/s in Fig. 1a and 50 mW in Fig. 1b) present a higher chance of occurrence. The benefits of random transmit power selection are described in (Kloiber et al., 2012). Next, we present the main benefits when both beacon rate and transmit power are assigned randomly.

• **Reduction of Recurring Packet Collisions:** randomize the beacon rate and transmit power by means of a symmetric PDF can significantly decrease recurring interferences. In scenarios with high vehicle density and low relative speed, the periodicity of beacon transmission leads to recurring packet collisions. Random selection of beacon transmission rate decreases the probability that two or more vehicles transmit at the same time, whereas random selection of beacon transmission power decreases the probability that a vehicle is in the interference area of multiple senders.

• **Local and Global Fairness:** one of the goals of the beaconing process is to achieve local fairness among neighboring vehicles in the contribution to cooperative awareness, and to achieve overall fairness among all the vehicles of the network in the contribution to communication channel load. PDFs harmonize the access to channel resources, and guarantee equity in selection of beacon rate and transmit power of vehicles. For example, vehicles that broadcast beacons



(a) (b)

Figure 1: Representation of probability density functions for the random assignment of: a) Beacon rate, b) Transmit power.

with a higher transmission rate will have a greater use of the communication channel resources, and vehicles that transmit with a high power negatively affect vehicles that transmit with a lower energy level. However, the random selection of beacon transmission parameters avoids such unfairness, for an extended period of time, providing local and global fairness.

• **Implicit Congestion Control:** random selection of beacon transmission parameters implicitly controls the communication channel congestion, because the vehicles use on average the mean value of beacon rate and transmit power of the selected PDF. For example, if a vehicle transmits constantly with the maximum beacon transmission rate and power, it will generate the highest possible beaconing load and reach the pre-established maximum communication range. However, with the random selection of the beacon transmission parameters, considering a uniform PDF over the valid range, the effective beacon transmission rate and power are reduced to the PDF mean. Even so, the minimum beacon inter-reception time and the maximum communication range can still be achieved.

• **Quality of Cooperative Awareness:** adjusting the parameters of the PDFs (mean and variance), the quality of cooperative awareness can be adapted dynamically according to communication requirements of different applications or vehicular contexts. For example, the PDF mean can be established to meet a certain target beacon transmission rate and power, and by adapting the variance it is possible to control the way in which selected values are distributed around the mean. Further, it is possible to adapt the limits of the valid range of the PDF according to vehicle speed or vehicular density to improve the cooperative awareness.

3 SIMULATION SETUP

The experiments have been conducted using the Veins[2] framework (Sommer et al., 2011), which couples the OMNeT++ network simulator and the SUMO road traffic simulator.

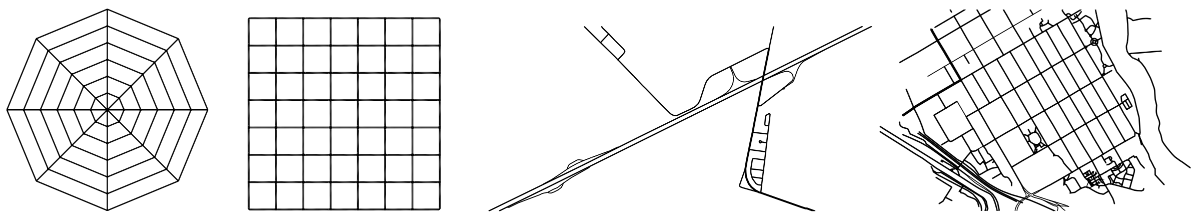
3.1 Simulation Scenarios

The performance of the dynamic beaconing strategy based on PDFs has been evaluated in four different scenarios.

Spider 8x6x100: it consists of 8 axes, which have a length of 1200 m and converge in the center of the scenario, and by 6 regular octagons all spaced at a distance of 100 m (see Fig. 2a). The roads have two lanes in opposite directions and intersections are managed by priority. The speed limit for each street is 70 km/h and the surface has an approximate area of 1 km^2. In this scenario, a traffic flow of 30 vehicles was defined for each principal axis. Therefore, there are eight vehicle flows that move from one end to the other of the axes of the outer octagon at a simulation time of 220 s.

Manhattan 7x7: is composed by a total of 8 horizontal and vertical roads, with a separation between streets of 100 m. The layout of the roads define a total of 49 blocks, which occupy an approximate area of 0.5 km^2 (see Fig. 2b). The intersections are managed by priority, while each road has a speed limit of 70 km/h and two lanes in opposite directions. In this scenario were defined eight traffic flows of 30 vehicles each. The flows move through the four central roads located vertically, four traffic flows from the top

[2]Vehicles in network simulation - http://veins.car2x.org/



(a) (b) (c) (d)

Figure 2: Scenarios seen from SUMO road traffic simulator: a) Spider 8x6x100, b) Manhattan 7x7, c) Highway - Montreal, d) Urban - Ottawa.

to the bottom and the four remaining from the bottom to the top. Each road has two vehicle flows which are moving in opposite direction, in a simulation time of 220 s.

Highway: defined by a real map portion of Montreal city with an area close to 5.1 km^2 (see Fig. 2c). The zone has two main roads, in the opposite direction with a length of 3.4 km. Each road has two lanes in the same direction and a maximum speed limit of 100 km/h. Two traffic flows of 150 vehicles were defined, one by each main road. Therefore, we have two vehicle flows that circulate on parallel roads, one to meet the other, intersect and move away again, in a simulation time of 500 s.

Urban: defined by a real map portion of Ottawa city with an area close to 1 km^2 (see Fig. 2d). The zone has two traffic lights, and roads with speed limits of 60 km/h and 100 km/h. Two traffic flows of 30 vehicles were defined, which move along one of the main roads but in opposite direction. The flows intersect in one of the traffic lights, so that during the time it takes the change of light, vehicles remain clustered. Then the groups disperse, moving away to reach the final destination of the route, in a simulation time of 220 s.

3.2 Simulation Parameters

The vehicles employ the IEEE 802.11p EDCA model (Eckhoff and Sommer, 2012) of the well established Veins framework to represent the MAC/PHY layer. This is an open source model, which fully capture the distinctive properties of IEEE 802.11p radio access technology. The vehicles broadcast beacons messages to the communication channel setting the beacon rate and transmission power by means of PDFs. Table 1 shows the PDFs used to dynamic assign the beacon parameters. The dynamic beaconing process uses the same PDF to adjust both beacon rate and transmit power on every beacon transmission. We used the beaconing approaches proposed in (Kloiber et al., 2012) as a baseline for the evaluation of the beaconing strategies based on PDFs. Table 2 shows the parameters of the two variants of Kloiber's approach that were implemented. The radio signal propagation is modeled with the Two-Ray Interference path loss model (Sommer et al., 2012), using ε_r = 1.02. Based on an extensive set of measurements on the road, this model has been shown to be more exact than Two-Ray Ground and Free-Space model, improving the accuracy of the simulation of radio transmissions, especially in short and medium distances. The communications are established on CCH without considering the effect caused by multi-channel operation. The beacon messages have 250 bytes and are transmitted with a priority corresponding to voice access category (AC_VO). Each vehicle is 5 m long, 2 m wide and has maximum acceleration of 0.8 m/s^2, and deceleration up to 4.5 m/s^2. The antenna height is 1.5 m and data rate is 6 Mbps. Table 3 illustrates the main simulation parameters.

3.3 Performance Metrics

We use four performance metrics to evaluate the cooperative awareness provided by dynamic beaconing strategies based on PDFs.

- **Average Packet Collisions:** number of packet collisions that, on average, is perceived by each vehicle.
- **Average Hidden Nodes:** number of nodes that, on average, are hidden from each vehicle.
- **Average Vehicles in LDM:** number of surrounding nodes that, on average, each vehicle registers in its LDM database.
- **Average Position Error:** average position error computed by a receiving vehicle in real time due to the movement of a surrounding node in the beacon interval.

4 RESULTS AND DISCUSSION

In this section, we present the main simulation results obtained in the different scenarios. Fig. 3 and Fig. 4 illustrate the histogram of the beacon rate and transmit power used by a generic vehicle. In the uniform

Table 1: PDFs Parameters.

PDF	Value
Constant	5 beacon/s, 50 mW
Uniform	a = 1 beacon/s, 4 mW b = 10 beacon/s, 96 mW
Normal	mean = 5 beacon/s, 50 mW variance = 1 beacon/s, 10 mW
Triangular	a = 1 beacon/s, 4 mW b = 5 beacon/s, 50 mW c = 10 beacon/s, 96 mW

Table 2: Parameters of the Kloiber Approach.

Approach	Value
Kloiber - var1	10 beacon/s, uniform (4 mW - 96 mW)
Kloiber - var2	2 beacon/s, uniform (4 mW - 96 mW)

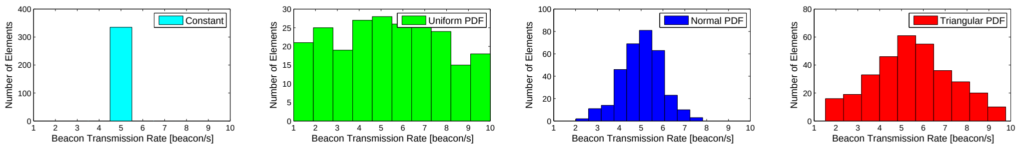
Table 3: Simulation Parameters.

Parameter	Value
CCH center frequency	5.890 GHz
Channel bandwidth	10 MHz
Beacon size	250 bytes
CW	[3, 7]
AIFSN	2
Receiver sensitivity	- 82 dBm
Thermal noise	- 110 dBm
Data rate	6 Mbps
Antenna gain	0 dB
Antenna height	1.5 m
Path loss model	Two-Ray Interference ε_r = 1.02

distribution, the values of the valid interval (1 beacon/s to 10 beacon/s in Fig. 3b and 4 mW to 96 mW in Fig. 4b) have the same chances of occurrence. The result is a fair dynamic assignment of the possible values of beacon rate and transmit power. In the normal PDF, see Fig. 3c (mean 5 beacon/s and variance 1 beacon/s) and Fig. 4c (average 50 mW and variance 10 mW), the values clustered to one and two variance of the mean have approximately 95 % and 65 % chance of being selected, respectively. This causes that the random values of beacon rate and transmit power with more chance of occurrence be clustered on both sides of the mean, and the values that remain at the ends of the valid interval occur with very low frequency (only a 5 % of probability). In the triangular distribution, see Fig. 3d (mean 5 beacon/s) and Fig. 4d (mean 50 mW), the values that most occur are still around the mean. However, these values occur with less probability than in normal distribution. On the other hand, the values that remain at the ends of the valid interval have more chance of occurrence than in the normal distribution.

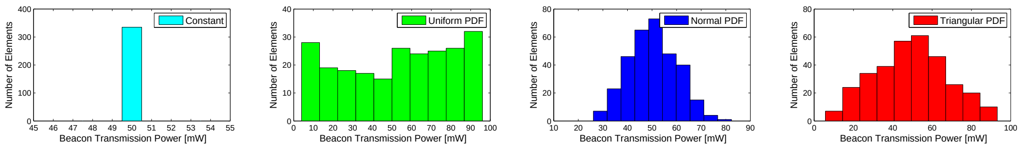
Fig. 5 illustrates the performance of dynamic beaconing strategies based on PDFs in the different scenarios. We also include the two variants of Kloiber's approach (see Table 2). Fig. 5a illustrates that the Kloiber - var1 beaconing approach leads to highest number of average packet collisions in all scenarios, followed by the beaconing strategy with constant transmission parameters. Kloiber - var1 beaconing approach uses a high beacon rate (10 beacon/s), which increases the channel load and recurring packet collisions, especially at low communication distance and in scenarios with high vehicle density. The uniform distribution shows the benefits of randomizing the beacon transmission rate compared to the Kloiber - var1 beaconing approach. The uniform distribution achieves a number of average packet collisions similar to that obtained by the Kloiber - var2 strategy in the different scenarios, spite this Kloiber variant uses a transmission rate of 2 beacon/s all the time. According to these results, the uniform distribution of transmission parameters in the valid range reduces recurring interferences. Randomizing the beacon transmission rate reduces the probability that two vehicles transmit at the same time, while randomizing the transmit power reduces the probability that a vehicle is in the interference area of multiple senders. The normal and triangular distributions have a similar performance in the different scenarios. However, the triangular distribution achieves a lower number of packet collisions (see Fig. 5a) and registers more vehicles in the LDM database (see Fig. 5c) than the normal distribution, but computes a greater number of hidden terminals (see Fig. 5b). According to Fig. 5b and Fig. 5c, both dynamic beaconing based on PDFs and Kloiber's approach compute a similar number of vehicles in LDM and hidden nodes for the Grid, Highway and Urban scenarios.

Fig. 6 and Fig. 7 illustrate the average position error computed by a generic vehicle when the neighbors use dynamic beaconing based on PDFs, in the Highway and Urban scenarios, respectively. On the other hand, Fig. 8a and Fig. 8b illustrate the same situation when the surrounding vehicles use the Kloiber's approach. According to Fig. 6a, the beaconing with constant transmission parameters produces an average position error less than 3 m most of the time in the Highway scenario. However, the high number of packet collisions (see Fig. 5a) results in average position error peaks that can exceed 5 m and 10 m. This behavior is similar in the Urban environment (see Fig. 7a), with the average position error close to 1.5 m due to the low vehicle speeds, but exceeding 4 m in a punctual case. The good performance of the uniform distribution in the previous metrics is degraded in terms of perceived real position error for both scenarios (see Fig. 6b and Fig. 7b). The use of low beacon rates when vehicles move at high speeds leads to a greater average position error. In contrast, dynamic beaconing with normal distribution experiences a lower number of harmful position errors than



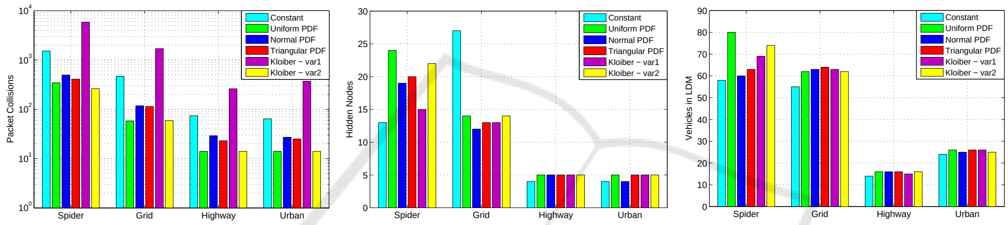
(a) (b) (c) (d)

Figure 3: Distribution of beacon transmission rate of a generic vehicle of the scenario: a) Constant, b) Uniform, c) Normal, d) Triangular.



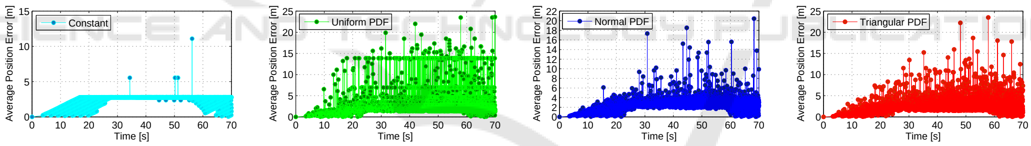
(a) (b) (c) (d)

Figure 4: Distribution of beacon transmission power of a generic vehicle of the scenario: a) Constant, b) Uniform, c) Normal, d) Triangular.



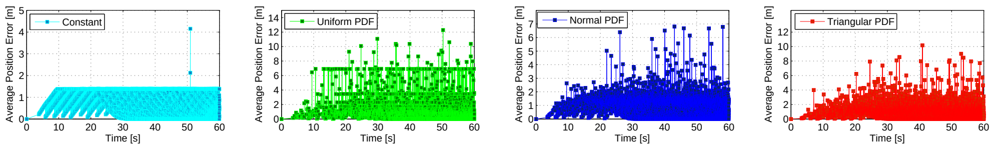
(a) (b) (c)

Figure 5: Performance of the dynamic beaconing strategies in the different scenarios: a) Packet collisions, b) Hidden nodes, c) Vehicles in LDM.



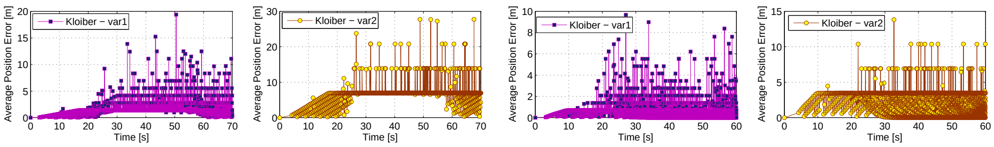
(a) (b) (c) (d)

Figure 6: Average position error computed by a generic vehicle in the Highway scenario: a) Constant, b) Uniform, c) Normal, d) Triangular.



(a) (b) (c) (d)

Figure 7: Average position error computed by a generic vehicle in the Urban scenario: a) Constant, b) Uniform, c) Normal, d) Triangular.



(a) (b)

Figure 8: Average position error computed by a generic vehicle using Kloiber's approaches in: a) Highway, b) Urban.

those obtained with the uniform and triangular distributions in both scenarios. Fig. 6 shows that the normal distribution outperforms the uniform and triangular distribution in terms of maximum average position error and the number of times this position error exceeds 5 m. In the urban scenario (see Fig. 7), the same behavior is observed, with the normal distribution the maximum average position error does not exceed 7 m and the highest number of average position errors is concentrated below 3 m. It could be thought that the use of a fixed transmission rate of 10 beacon/s in the Kloiber - var1 approach would lead to a small average position error. However, Fig. 8a and Fig. 8b illustrate the noxious impact of packet collisions on perceived position error. In both scenarios the recurring packet collisions lead to several harmful position error, computing in the Highway and Urban scenarios a maximum average position error of 19 m and 9 m, respectively. The Kloiber - var2 approach achieves a low number of packet collisions (see Fig. 5a). However, the use of a low transmission rate (2 beacon/s) leads to high average position error in both scenarios, as can be seen in Fig. 8.

5 CONCLUSIONS AND FUTURE WORKS

In this paper, we evaluated the performance of different dynamic beaconing strategies that use PDFs to randomize beacon transmission parameters. The performance of the beaconing strategies was evaluated through a realistic simulation framework in four different vehicular scenarios. The simulation results showed that some PDFs are more convenient than others for certain scenarios. The beaconing strategy based on uniform PDF is convenient in scenarios with high vehicle density and low relative speed, whereas a beaconing strategy based on normal PDF is suitable in scenarios with high relative speed and low vehicle density. The uniform distribution allows to reduce recurring interferences while the low speed of the vehicles does not significantly impact on the real average position error computed by neighboring vehicles. On the other hand, by adjusting the mean in the normal distribution it is possible to reduce the average position error perceived in high speed scenarios, while the low density of vehicles reduces the noxious impact of packet collisions. In future works, we intend to develop an adaptive beaconing algorithm, where PDFs be selected and adjusted, according to the vehicular context and/or the communication requirements of safety applications.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of CONICYT Doctoral Grant No. 21171722; Project ERANET-LAC ELAC2015/T10-0761; FONDECYT Postdoctoral Grant No. 3170021; as well as FONDECYT Iniciación 11140045.

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