Dice the TX Power - Improving Awareness Quality in VANETs by Random Transmit Power Selection

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***Abstract*—Future safety-related vehicular applications require reliable information exchange provided by cooperative Vehicular Ad-hoc NETworks (VANETs). Although the vehicular WLAN standard IEEE 802.11p has been adapted to the challenging vehicular environment, it has not been adapted to the stringent communication requirements imposed by vehicular applications. In particular, broadcast transmissions are mostly periodic and initiated at common TX powers. This makes potential interferences recurring instead of spurious and lowers the performance of medium access for vehicular applications.**

In this paper, we propose to leverage recurring interferences by randomly selecting each TX power following a given probability distribution. Such randomization reduces the chances of recurring interferences, and the probability distribution provides control to the applications regarding the required Awareness Quality, in particular by providing a higher Awareness Quality at close range. This concept also reduces congestions by transmitting less at high distances. It is transparent to the applications, and manages to improve the Awareness Quality in a dense highway by a factor 2 to 20, yet at a factor 2 to 3 lower channel load.

I. Introduction

The new cooperative safety-related applications for Intelligent Transport Systems (ITS) require robust and reliable communications between vehicles. Various standardization bodies (US CAMP, EU ETSI, ISO) have selected a communication technology based on the well known Wireless Local Area Networks (WLANs), IEEE 802.11 [1] with minor modifications for vehicular environments.

The major advantage of the WLAN standard and the reason of its success comes from its flexibility and adaptability. With each new environment could come an extension. For instance, the challenging vehicular environment (strong fading and Doppler effect, high dynamism) justified a new amendment to the WLAN baseline called IEEE 802.11p. Yet, all WLAN extensions still assume the same Internet-type applications. One distinctive aspect of VANET, comes from novel safety-related applications, differing significantly in terms of performance requirements and communication patterns. Most of the cooperative safety-related applications are based on status information of other vehicles in the neighbourhood, usually referred to as *awareness*, and do not require any stable link or a high throughput. Instead, they need from every vehicle to transmit periodically and in a very reliable way a few bytes containing their position, speed, and heading. The more regular such awareness status is received, the higher is the *Awareness Quality*. Moreover, due to wireless access fairness and awareness symmetry requested by these novel applications, each broadcast packet must be sent using a common TX power between immediate neighbours. And although congestion control methods may propose to adjust the TX power to a particular congestion level, most of the approaches [2]–[4] either assume or come to a optimal and common TX power between nodes in immediate vicinity.

The conjunction of periodic broadcast transmissions and common TX power brings the IEEE 802.11p and the WLAN Distributed Coordination Function (DCF) family away from its design framework. As all contention-based approaches, DCF does not guarantee collision-free transmissions but makes collisions spurious to limit their impacts on applications. Unfortunately, periodic transmissions and constant TX power increase the probability of recurring collisions. As such, safety-related applications are creating conditions on the MAC, which are contributing to the degradation of its performance. Part of the VANET community proposed to use a TDMA-like MAC protocol [5] instead, but we believe that the flexibility of the WLAN standard can yet again be used to adapt the IEEE 802.11p to safety-related vehicular applications.

In this paper, we propose to reduce the chances of recurring collisions by avoiding to broadcast at common TX power, and instead randomly select each TX power from a given probability distribution. We maintain fairness by adjusting a common *mean* and *variance* for the probability distribution between all vehicles in the vicinity. Adding randomization in the TX power has multiple beneficial aspects. First, we reduce the probability of collision. Second, by transmitting some awareness status at long distance and some at close distance, we provide a higher quality of awareness at close-distance, where it is critical for the safety-related applications. Third, by adjusting the probability distribution (type, mean and variance) we can dynamically adjust the distribution of the Awareness

Quality as function of the application(s) requirements. Fourth, we contribute to a better usage of the wireless channel by transmitting less where the probability of successful reception is low. We demonstrate the performance of our concept by evaluating it in a dense motorway scenario, and show that we can not only increase the Awareness Quality by a factor of 2 to 20, but we can also reduce the channel load by a factor of 2 to 3, and this, without interfering with any application-level requirements.

The rest of this paper is organized as follows: We provide a detailed problem description in Sec. II, while Sec. III presents our concept and it's advantages. We evaluate the performance of our concept in Sec. IV, and discuss important aspects in Sec. V. While related work is summarized in Sec. VI, Sec. VII finally concludes the paper and gives an outlook for future work.

II. Problem Description

The IEEE 802.11 WLAN standard family is known to be flexible and adaptable. When WLAN has been selected for vehicular communications, a few modifications have been conducted to adapt it to the vehicular environment. Potential short connectivity caused by a short communication range in combination with high speeds justified communicating outside of the context of a BSS (OCB mode). Authentication is controlled after transmission rather than before, but most of the enhancements have been done to adapt the PHY layer to strong multipath and Doppler effects impacting OFDM at 5.9 GHz.

As most of other amendments of the WLAN family, the environment has been changed but not the application characteristics, and the WLAN protocol remains optimized for Internet-type applications. Yet, vehicular applications, in particular the safety-related ones, show totally different patterns and requirements. Their poor performance, typically observed when the medium becomes congested, may be explained by the use of a MAC protocol not adapted to the specific vehicular application requirements. The salient characteristics differing between Internet-type and vehicular safety-related applications maybe summarized as follows (see also Table II):

- **V2I vs. V2V Communication Mode:** Unlike WLAN V2I dominant communication mode, safety-related vehicular communications are mostly dedicated V2V and as such are subject to V2V network topology.
- **Dynamic vs. Stable Network Topology:** Even though the V2I network topology can be very dynamic, the V2V network topology is rather stable. Accordingly, unlike common belief, each vehicle is expected to see its safety-related neighbours over a very long period compared to its periodic broadcast transmit rates.
- **Unicast vs. Broadcast Transmissions:** The predominantly used unicast mode in original IEEE 802.11 networks allows the use of feedback mechanisms to guarantee a reliable link. Safety-related vehicular communication mainly use broadcast or geocast[1] instead, and as such, must assume unreliable communications.
- **Bursty vs. Periodic Data Traffic Pattern:** The WLAN standard has been adapted to Internet-grade *bursty* traffic. Safety-related vehicular applications are instead totally periodic and recurring, which makes the WLAN standard family particularly unadapted.
- **Throughput-centric vs. Information-centric Metric:** Rather than high throughput expected by WLAN users, safety-related applications require the reception of status information consisting of only a few bytes, yet in a very reliable way. The design space of the WLAN family is therefore also unadapted.

Characteristics	Internet	safety-related
Communication Pattern	V2I	V2V
Network Topology	dynamic V2I	stable V2V
Communication Mode	mainly unicast	mainly broadcast
Data Traffic Pattern	bursty	periodic
Metrics	throughput	information (awareness)

TABLE I
Internet-type vs. safety-related vehicular application characteristics considered in a vehicular environment

Initiated in the sensor networks and the MANET community trying to optimize a connected graph from a large distributed network, topology control (i.e. reducing the transmit power to limit the interference level) proposed various solutions to reduce congestion and improve the reliability of broadcast transmissions [6] . Some of these approaches have been later introduced in VANETs as congestion control strategies. Yet their common point is to converge to a locally common transmit power in order to guarantee fairness and efficiency. Considering bursty transmission, these proposals are efficient, but in the case of periodic transmissions, converging to a locally common transmit power has major drawbacks on the medium access.

As illustrated in Fig. 1, the conjunctions of periodic transmissions, slowly changing topology, reduced contention windows, and common transmit power leads to recurring interferences and collisions. Whereas the loss of one broadcast in a while could be acceptable to safety-related applications, the successive loss of multiple broadcast may be dramatic.

Part of the VANET community observed that problem. Bilstrup et al. [5] and others proposed to switch to a Time Division Multiple Access (TDMA) based scheme, which is more adapted to the vehicular applications characteristics described in Table II. However, TDMA also has its drawbacks, such as the decentralized synchronization of the nodes, and the standardization bodies are reluctant of including it before having explored the real performance limits of IEEE 802.11p.

Our approach is to rely on the flexibility of the WLAN standard to adapt the IEEE 802.11p to vehicular applications. Similarly to the contention window management, our proposal

[1] i.e. addressed to a certain geographic region

in this paper is to add a touch of randomization in the selection of the transmit powers by randomly selecting it from a given probability distribution for each periodic transmission and vehicle. Depending on the context or application requirements each vehicle can use an appropriate probability distribution. Our objective is to make interferences more spurious than recurring.

III. Random TX Power Concept

To fully understand the advantages of our random TX power scheme, first some fundamentals about awareness are necessary.

A. Application-level metric: Awareness Quality

Without loss of generality, we assume periodic transmissions of so called Cooperative Awareness Messages (CAMs), which provide updated information about the status of other vehicles in the surrounding [7]. That way, vehicles establish knowledge about other vehicles, which is usually referred to as *awareness*. The up-to-dateness and fineness of that knowledge, we consider as *Awareness Quality*. CAM based applications typically have different requirements on the Awareness Quality, depending on the distance to the transmitting vehicle. Focusing, for example, on safety related applications, the Awareness Quality of an other vehicle should be the higher the closer this vehicle is. This desired behaviour of the Awareness Quality is depicted in Fig. 2 for the one-dimensional case and it shows very well its suitability as an application-level metric.

From a communication perspective, we define the so called *Update Delay* as a representative metric of the Awareness Quality. It measures the delay between two consecutive received CAMs from the same transmitter and, by implication, describes very well the up-to-dateness of information or rather the Awareness Quality. ElBatt et al. and others introduced similar metrics in [4], [8], [9], but we prefer to use the Update Delay and its representation as *Complementary Cumulative Distribution Function (CCDF)*, because of its strong

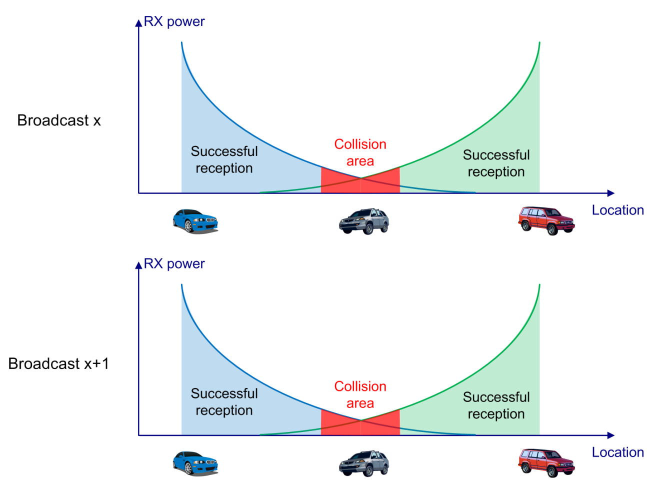

Fig. 1. Problem of recurring collisions due to the periodic data traffic pattern in VANETs in combination with slow relative speeds.

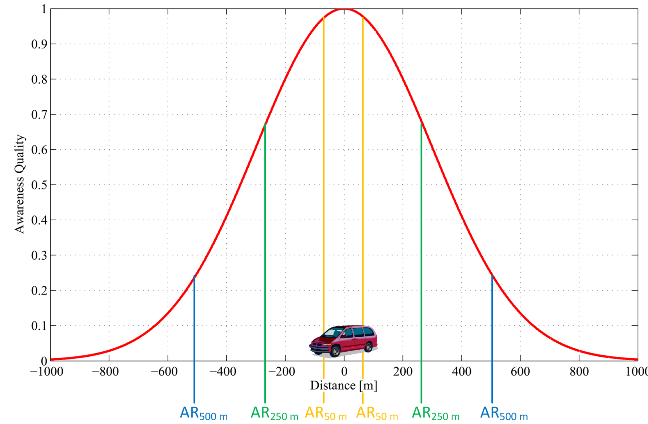

Fig. 2. Desired behaviour of the Awareness Quality over distance: the closer a vehicle, the higher the Awareness Quality of this vehicle.

correlation with Awareness Quality, as described in [10]. The Update Delay itself is a pure time based metric. To reflect an Awareness Range (AR), the Update Delay can be evaluated only for vehicles located within a considered AR, as depicted in Fig. 2.

B. The Random TX Power Mechanism

We propose to increase the Awareness Quality by randomly selecting the TX power for each CAM transmission and vehicle. In theory that means, that each vehicle controls its current TX power by using a certain probability distribution over a valid TX power interval. Fig. 3 illustrates the basic concept by means of an example with three vehicles. It shows the various randomly generated TX power levels for each car over time. Without loss of generality, in this example the random variables are based on the same discrete and uniform probability distribution, and all three cars apply the same transmission rate (CAMs per second).

Using a random TX power selection mechanism is not only simple, but has important beneficial effects, too. They include:

- **Congestion reduction:** The random TX power approach

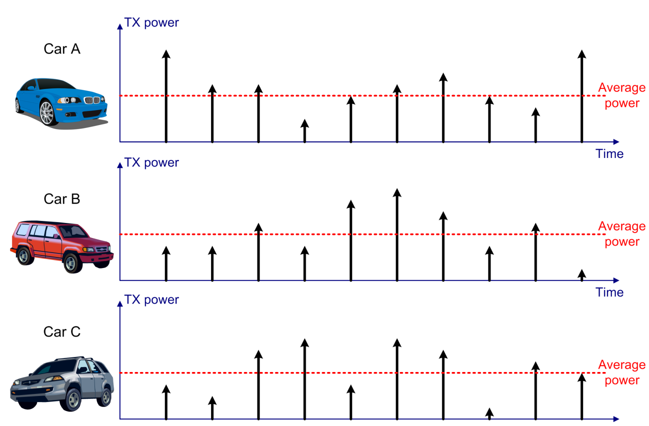

Fig. 3. An example with three vehicles, each using the random TX power selection mechanism.

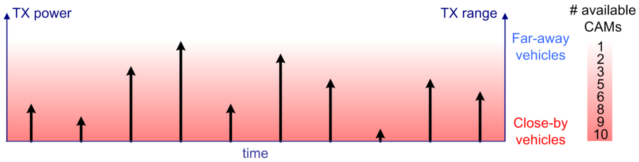

Fig. 4. Whereas close-by vehicles can be reached with low, medium and high TX power, far-away vehicles can be only reached with high power.

can reduce the congestion on the communication channel, because the vehicles are transmitting on average with the mean power value of the probability distribution (see Fig. 3). This statement is only fair if the achieved communication distance is compared as well. For example, if transmitting with constant full power, the maximum intended communication range will be always achieved[2]. Using random TX power selection considering a uniform probability distribution over the TX power interval $[P_{min}; P_{max}]$, the effective TX power has been reduced to the mean of the random variable. But the maximum communication distance can still be achieved, with a certain (reduced) probability.

- **Distance dependent Awareness Quality:** Random TX power selection implicitly performs a prioritization of CAM updates for vehicles closer to the transmitter. This effect is highlighted in Fig. 4. As only the higher TX power values can reach the far-away vehicles, the number of CAM updates is reduced. The number of CAM updates is yet increased for close-by vehicles, as low and high TX power values contribute to the awareness. This implicit prioritization effect addresses very well the desired Awareness Quality over awareness range for most of the cooperative safety applications.
- **High variation of radio propagation conditions:** Random selection of the TX power can mitigate the recurrence of collisions and interferences, caused by the periodicity of CAM transmissions in combination with slow relative speeds (see Fig. 1). Using random TX power selection the radio propagation conditions are shifted with each transmission as well as the collision and interference areas. This effect is shown in Fig. 5, where a collision doesn't reoccur, due to the variation of the randomly selected TX power of both vehicles.
- **Local fairness:** A popular justification for harmonizing the TX power for all vehicles in the same local vicinity is to guarantee fairness.Vehicles transmitting continuously with high power adversely affect vehicles transmitting with less power. Instead of constant fairness by using harmonized TX power, the random power selection mechanism provides statistical fairness as all vehicles use the same probability distribution and thus the same average TX power. Hence, local fairness still remains.

[2]That's only valid in theory, i.e. under perfect conditions, because the communication distance heavily depends on the current radio propagation conditions

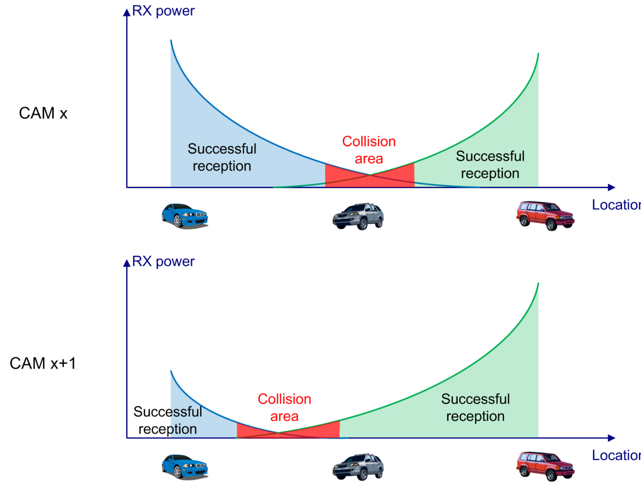

Fig. 5. Shift of the collision area, due to the variation of the randomly selected TX power for both transmitters.

- **Application and context adaptive distribution control:** The probability distribution doesn't have to remain the same all the time. It can be adapted to the current situation and needs. Some example distributions for random TX power selection are shown in Fig. 6. In addition, future vehicles will not only run one cooperative safety application, but several in parallel. Each application can use it's own probability distribution, well adapted to meet the requirements of each application. The joint distribution could control the random TX power selection for CAM transmissions to meet the requirements of all applications. Our concept can also be integrated into current TX power control algorithms, for instance by adapting the mean of the probability distribution, instead of the current TX power value, and is still able to make use of the beneficial effects of random TX power selection.

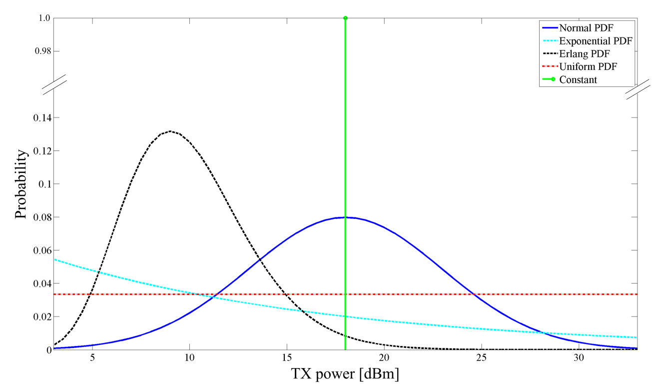

Fig. 6. Various example Probability Density Functions (PDFs) for random TX power selection. Whereas the uniform distribution generates all allowed TX power values with equal probability, the Erlang distribution gives lower power values a higher chance to be selected.

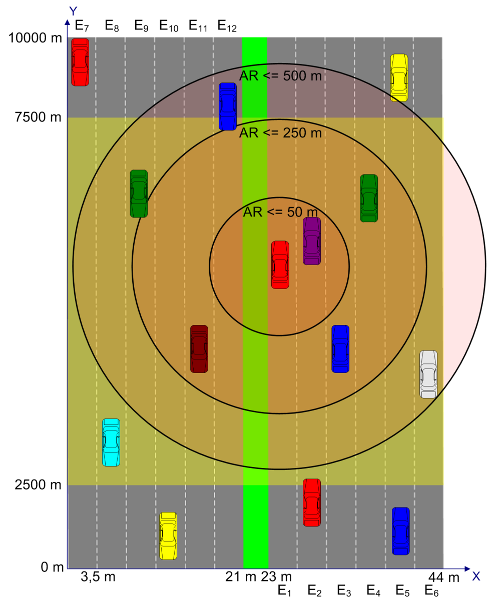

Fig. 7. The simulation scenario is a motorway with 6 lanes in each direction and Erlang distributed vehicle generation at the edges. To remove the border effect, only vehicles within the evaluation section (from 2500 m to 7500 m) are evaluated.

IV. Simulation

This section shows simulation results in a dense motorway scenario for a uniform distributed random TX power pattern, compared with the constant TX power approach, by using the well known network simulator ns-3 [11].

A. Environment and Metrics

To get a real VANET challenging setup, the traffic scenario shown in Fig. 7 has been simulated: a simple motorway with 6 lanes in each direction. Vehicles were generated for each lane, following an Erlang distribution (E_1 to E_{12}) for the timely separation of the vehicles. The mean of these Erlang distributions was set to a value of 2 seconds, which corresponds to the recommended time ahead distance between consecutive vehicles in Germany. Only vehicles within the evaluation section from 2500 m to 7500 m are evaluated, to remove the border effect. Further information on the simulation setup can be found in [12].

In order to simulate the communication, ns-3 was enhanced by ITS-G5, with the possibility of setting the TX power on a per packet basis. The possible TX power values range from 4 dBm to 33 dBm with a 0.5 dB increment. On radio propagation level, the default log-distance model from ns-3 was used, configured to get a maximum communication distance of approx. 1000 m.

To measure the generated communication load on the channel, the simulation environment was enhanced by static measurement stations, placed on the central dividing strip along the evaluation section of the motorway in a distance of 50 m next to each other. These stations measure the Channel Busy Time (CBT) ratio, i.e. the amount of time, for which the channel is detected as busy, with respect to a certain time interval. In our simulations, the CBT ratio was updated each second.

Traffic scenario	10 km motorway with 6 lanes for each direction
Evaluation section	5 km (from 2.5 - 7.5 km)
Vehicle generation process	Erlang distributed (2 s mean)
Speed profile	20 to 40 m/s (4 m/s increase from outer to inner lane)
Access technology	ITS-G5 on Control Channel
Radio propagation model	Log distance (exponent 2.25)
Random TX power distribution	uniform (discrete interval from 4 to 33 dBm with 0.5 dB step size)
CAM TX rate	2 Hz, 10 Hz

TABLE II
Most important simulation parameters.

As already introduced in Sec. III, the applied evaluation metric is the Update Delay and its representation as CCDF, which is shown in Fig. 8. The graph has to be interpreted as follows: The x-axis displays Update Delay values in seconds, the logarithmic scaled y-axis shows the probability $p(ud > UD)$ for exceeding a certain Update Delay value (UD). An example: If an application needs to know the probability for exceeding an Update Delay value of 1 s according to the red curve, it simply has to look for the appropriate value on the y-axis, i.e. approx. 1×10^{-3} in that case.

In order to represent the Awareness Quality as a function of the Awareness Range (AR), we show different Update Delay CCDFs for the same scenario, but with different considered ARs. The considered AR limits the Update Delay evaluation to only vehicles located within a circle with radius AR around the transmitting vehicle. Fig. 2 and Fig. 7 show exemplary the three different considered ARs used for the distance dependent Update Delay evaluation below.

B. Scenarios

Four scenarios have been simulated in total. They are made up of two different TX power approaches in combination with two different CAM TX rates (CAMs per second), for each. The following TX power selection mechanisms have been investigated:

- **Constant full TX power:** All vehicles transmit each CAM with the maximum allowed TX power on the Control Channel (33 dBm).
- **Random TX power:** All vehicles choose randomly the current TX power, based on a discrete uniform probability distribution on the interval $[4\ dBm; 33\ dBm]$ with a 0.5 dB step size (μ = 18.5 dBm).

The CAM transmission rate has been chosen for all vehicles to be 2 Hz in the first case, representing normal communication conditions, and 10 Hz in the second case, representing the worst case according to the maximum value specified in [7]. The latter stresses the channel additionally with respect to the communication load.

Table II summarizes again the most important parameters, used for our simulations.

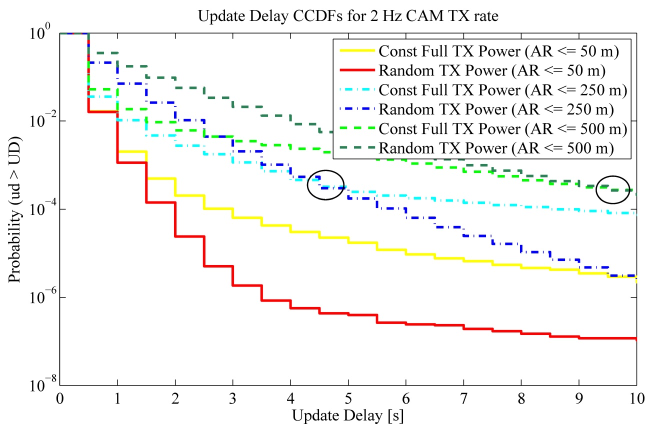

Fig. 8. Update Delay CCDFs for the 2 Hz CAM TX rate scenario: Const. full TX power vs. random TX power, each with respect to a 50 m , 250 m and 500 m AR.

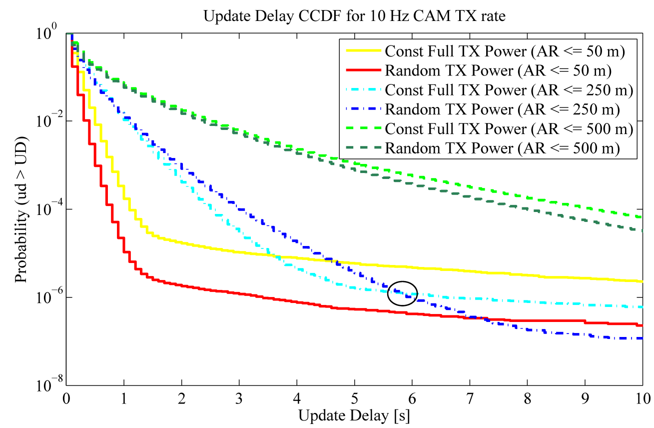

Fig. 9. Update Delay CCDFs for the 10 Hz CAM TX rate scenario: Const. full TX power vs. random TX power, each with respect to a 50 m , 250 m and 500 m AR.

C. Results

We start presenting our results by comparing the Update Delay CCDF for both approaches considering the 2 Hz CAM TX rate scenario, as depicted in Fig. 8.

Considering an awareness range of 50 m, the random TX power approach shows the same performance than constant full power for Update Delay values below 1 s. For Update Delay values of 1 s and more, random TX power clearly outperforms the constant full power approach. The probabilities for exceeding a challenging safety application relevant Update Delay value of 1 s for constant full power and random TX power are 2×10^{-3} and 1×10^{-3}, respectively. That implies a performance increase of factor 2 for the random TX power mechanism.

As the used uniform probability distribution over the interval $[4\ dBm; 33\ dBm]$ is only adapted for a desired AR of 50 m, it is not suitable to do a fair performance comparison for awareness ranges of more than 50 m. The reason is, that a minimum TX power of 19.5 dBm or 26.5 dBm is necessary to fully cover a desired AR of 250 m or 500 m, respectively. By using the same uniform distribution as before, there is a high probability for choosing power values below 19.5 dBm or 26.5 dBm, which indeed lowers the Update Delay performance if an AR of 250 m or even 500 m is considered. Instead the Update Delay curves for the 250 m and 500 m AR are just for showing the desired Awareness Quality behaviour over distance, i.e high quality for close-by vehicles and less quality for far-away vehicles, compared to constant full TX power as a reference approach. The figure shows indeed, that we improve Awareness Quality for close-by vehicles (AR $\leq$ 50 m) but loose quality for far-away vehicles, which is not a problem, because they are still too far away for causing any imminent danger.

Fig. 9 shows the same graph for the 10 Hz CAM TX rate scenario. Here, the random TX power approach clearly outperforms constant full power for all Update Delay values, considering an awareness range of 50 m. In that case, the exceedance probability of a 1 s safety application relevant Update Delay value are 2×10^{-4} for constant full power and 1×10^{-5} for random TX power. That means a performance increase of factor 20 by using random TX power selection.

Also in that case, the Update Delay curves for 250 m and 500 m ARs are not suitable for fair performance comparison, but rather for showing the desired behaviour of the Awareness Quality over distance compared to the full TX power reference approach, as described above.

An important side effect of the random TX power approach is the congestion reduction on the communication channel, caused by the average effective transmission power, which is only 18.5 dBm.

This benefit is presented in Fig. 10, which shows the different CBT ratios along the motorway, averaged for each approach. In case of the 2 Hz CAM TX rate scenario, the random power mechanism is able to reduce the load by approx. two-thirds, but having a better Awareness Quality in the immediate vicinity, i.e. up to 50 m desired AR. A reduction by half can also be achieved in the 10 Hz CAM transmission rate scenario, if random TX power selection is used. The flat

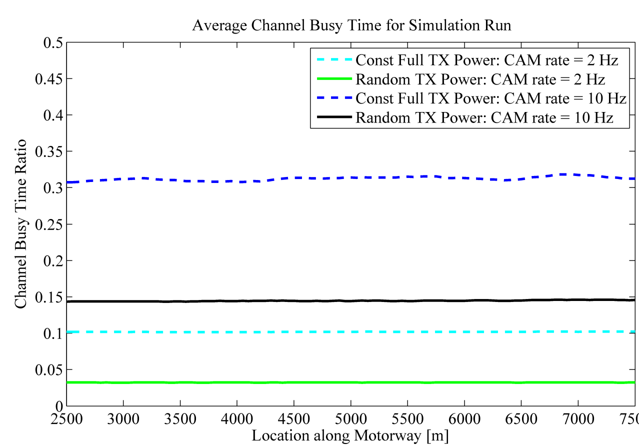

Fig. 10. Comparison of CBT ratios along the evaluation section for constant full and random TX power approach.

CAM TX RATE	CONST. FULL TX POWER	RANDOM TX POWER	IMPROVEMENT
2 Hz	2×10^{-3}	1×10^{-3}	factor 2
10 Hz	2×10^{-4}	1×10^{-5}	factor 20

TABLE III
THE 1 S SAFETY APPLICATION RELEVANT UPDATE DELAY EXCEEDANCE PROBABILITIES REGARDING THE IMMEDIATE VICINITY (AR $\leq$ 50 M).

CAM TX RATE	CONST. FULL TX POWER	RANDOM TX POWER	IMPROVEMENT
2 Hz	0.10	0.03	factor 3
10 Hz	0.32	0.14	factor 2

TABLE IV
THE AVERAGE CBT RATIOS ALONG THE MOTORWAY.

curves are a representation of fairness, too, as the traffic in our scenario is generated by using fixed configured Erlang distributions during the simulation.

Table III and Table IV summarize the main results and improvements with respect to the safety application relevant Update Delay exceedance probabilities in the immediate vicinity as well as the average CBT ratio along the motorway for both CAM TX rate scenarios.

V. DISCUSSION

Regarding the results above, there are some interesting aspects, which may discussed hereafter.

In this paper, we purposely evaluated our concept using a highly dense motorway scenario to illustrate the pertinence of the spatial distribution of the Awareness Quality. First, a dense traffic scenario brings the communication capabilities to their limits and justifies the need for smart and adapting communication policies. Second, a dense traffic scenario also reduces the average inter-distance between cars in immediate vicinities, and as such, increases the need for reactive awareness at low Update Delay. The stringent communication characteristics yet force us to find a trade-off and to favour a low update delay at short distances, while we relax it at larger distances. In sparse scenarios, the principle would remain, as we could adapt the small update delays to reach vehicles at larger awareness ranges, but let this evaluation to future work.

By having a closer look on the awareness range of 250 m and 500 m in Fig. 8 and Fig. 9, we can observe a cross-over point between random TX power and constant full TX power. Before that point, the Update Delay of the random TX power approach is higher than that of the constant TX power approach, while after that point, the Update Delay is lower for the random TX power. This should not lead to the conclusion that the random TX power approach provides worse Update Delay than constant full TX power for any point in the respective awareness ranges. As we used a probability distribution over the interval $[4\ dBm; 33\ dBm]$ for all awareness ranges, the curves only illustrate the desired spatial distribution of the Awareness Quality, where vehicles benefit from a high Awareness Quality at close range (up to 50 m) and a reduced Awareness Quality, potentially worse than with constant TX power, after. It is yet a design choice, as transmitting high quality awareness at large distances is not pertinent to applications (i.e. large distance also means longer reactivity time) and consumes precious network resources.

To be able to do a fair performance comparison for desired awareness ranges (e.g. 250 m or 500 m), the boundaries (P_{min} and P_{max}) should also be adapted. By varying distributions type, mean/variance, and boundaries, our approach provides a full control on the spatial pertinence of a particular high or low Awareness Quality. This aspect is also be pertinent to a multi CAM-based application optimization, as the fine tuning of the parameters of a common distribution could still be able to satisfy the various spatial Awareness Quality requirements of each application. We yet let this investigation to future work.

VI. RELATED WORK

Using random signal levels for channel access was first proposed by Lee [13]. In his work he applies this scheme to the slotted ALOHA access mechanism and increased significantly the throughput performance, compared to the conventional slotted ALOHA system, by making use of the capture effect. Most of the subsequent publications are focusing on the same problem, i.e. further increase throughput for time-slotted shared radio channel systems by exploiting the capture effect. Cidon et al. [14] were concentrating on Poisson distributed arrival processes and additionally discussing design issues, such as number of levels and selection schemes. La Maire et al. [15] determined an optimal choice of power levels and probability distributions to optimize the throughput. In [16], Wang et al. controlled the TX power in DS-CDMA packet mobile radios to increase the link capacity, too. Behzad et al. [17] introduced the Fair Randomized Power Control (FRPC) algorithm to increase throughput while providing fairness for different mobile users in the system. Improving the energy consumption in wireless sensor networks until reaching a consensus, was the objective of Pereira et al. [18]. They proposed a heuristic scheme of randomized transmission power to balance the energy consumed by the network among the nodes and to reduce the convergence time.

To the best of our knowledge, the random TX power approach was so far neither adopted to VANETs, nor investigated in detail with respect to appropriate metrics considering CAM based safety-related application requirements.

In VANETs, Decentralized Congestion Control (DCC) is the most common approach to improve communication performance by keeping the congestion below a certain threshold. An important step was proposed by Torrent-Moreno et al. [19] with their Fair Power Adjustment for Vehicular environments (FPAV) algorithm and its enhanced version called Distributed FPAV (D-FPAV) [2], which adapts the TX power to achieve max-min fairness between nodes in vicinity. Others started to adapt also the transmission rate [20], [21], or a combination of both [9], [22]. A context based approach was introduced by Sepulcre et al. [3]. Tielert et al. [4] introduced a rate adaptation oriented congestion control protocol named PULSAR, yet at constant TX powers. Similarly to [2], [19], [20], PULSAR uses 2-hop piggybacking in addition, to make all nodes located within the carrier sensing range of a congested area, converge to common harmonized TX parameters (power or rate).

Accordingly, all described DCC approaches either keep a constant TX power between all nodes, or make all nodes in the TX vicinity take common TX power or rate. Unfortunately, they do not consider the typical data traffic pattern in VANETs and its consequences on recurring collisions and interferences.

VII. Conclusion

In this paper, we showed that we can improve the Awareness Quality and reduce the channel congestion by adding a randomization figure to the selection of the TX powers for VANET safety-related applications. In a dense motorway scenario, our simulation results showed that our concept manages to improve the safety required awareness by a factor between 2 to 20, and at the same time reduce the channel congestion by a factor between 2 to 3.

This is an illustration that improving the performance of the WLAN medium access requires a better spatio-temporal usage of the wireless resources. Our concept indeed provides an increased Awareness Quality at close range (required by safety-related application), and a reduced Awareness Quality at long distance, where it is less critical. It also avoids transmitting periodic broadcast where collision and fading would hinder their reception success, and as such contribute to a reduction of the channel load.

In future work, we plan to investigate many details behind the concept presented in this paper, such as:

- *Probability distribution*: What is the optimal probability distribution for selecting the TX power?
- *Low dense VANETs*: What is the effect of our approach in low dense VANET scenarios?
- *Multi-applications*: How to join several applications with different communication requirements in a joint probability distribution?
- *Capture effect*: What would be the impact of the capture effect on our concept?
- *Hardware constraints*: What would be the impact of multiple quick power step changes on the chip and the power amplifier?

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