Analytical Transmit Power Adjustment in Cooperative Vehicle Safety Systems

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***Abstract*— Vehicular ad hoc networks (Vanets) play a critical role in enabling essential emergency safety applications (e.g., Forward Collision Warning) and subsequently help the driver deal with emergency situations, These emergency applications have strict different QoS requirements mainly on latency time [1]. In this work, we propose a Power Control Scheme, called PCS that adjusts the transmission power level to guarantee short delays for safety messages over 802.11p/DSRC, especially for occasional emergency messages. PCS aims to minimize contention within two-hop neighborhood of a vehicle under high-offered load conditions. Numerical results show the effectiveness of PCS scheme when coupled with either the traditional random access mechanism [2] or the priority-aware deterministic access protocol based on 802.11p/DSRC [3].**

Keywords- Vanets; emergency applications; power control; DSRC, strict delay.

I. INTRODUCTION

According to the World Health Organization report on road traffic injury prevention, 1.2 million people die and 50 million are injured in motor vehicle collisions each year worldwide[1]. One of the important purposes of enabling vehicles with wireless capabilities is to improve the safety of passengers on road, with what is referred to as traffic safety applications [1]. In traffic safety applications, the goal is to avoid impending collisions by disseminating early notifications of hazardous situations, e.g., when an airbag deploys in case of an accident or when an ABS brake system is activated in case of slippery road conditions. To enable wireless communications over vehicles, the Federal Communications Commission (FCC) in the US has allocated a 75 MHz spectrum to Dedicated Short Range Communications (DSRC) at the 5.9 GHz frequency band. These frequencies will be used by specialized radio equipment according to IEEE 802.11p standard.

IEEE 802.11p MAC layer is derived from IEEE 802.11 MAC and its physical layer parameters are based on IEEE 802.11a standard with minor changes. The 75 MHz spectrum is made up of seven 10 MHz wide channels. One of the channels is the control channel (CCH), which is the default channel for common safety communications, while the first and the last channels on the spectrum are reserved for special uses. The rest of the channels, so-called service channels (SCH), are available for both safety and non-safety applications.

Two different types of safety messages can be transmitted over CCH; probe messages and emergency messages. Vehicles periodically broadcast probe messages to their neighbors and based on these messages each vehicle maintains an updated neighbor list in their look-up tables.

When supporting safety applications over DSRC/802.11p we have to take into account strict requirements on low collisions and delays, especially for emergency messages such as Forward Collision Warning (FCW) or Electronic Emergency Break Light (EEBL) which require strict delay bounds [1]; otherwise many envisioned future safety systems would be useless to help the driver deal with emergency situations, avoid accidents and save lives.

Delivery delay should be kept below a threshold. In this paper, we analytically study the effect of the transmission power level on the delay experienced for different vehicle densities and when different data rates and packet sizes are allowed. We then introduce a Power Control Scheme to minimize delivery delays in high density scenarios.

Our contributions, in this paper, can be summarized as follows: (1) we introduce a Power Control Scheme, called PCS to keep delay under a pre-defined threshold, (2) we derive analytically the MAC layer delay taking into account the contention period and power adjustment; (3) we analyze the effect of such adjustment on safety messages exchange reliability under high-offered load conditions; and (4) we integrate PCS scheme to both the random access mechanism based on Carrier Sense Multiple Access with collision Avoidance (CSMA/CA) using DCF [2] and to the recent work named priority-aware deterministic access protocol for 802.11p/DSRC [3], introduced to allow vehicles to access the shared medium in collision-free periods.

We show that PCS can easily be applied to two different MAC protocols [2, 3] and that it is able to improve their

[1] World report on road traffic injury prevention: summary / edited by Margie Peden et al.., World Health Organization 2004.

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latency time and reliability in higher network density conditions.

II. RELATED WORKS

There has been a vast literature [3-10] on the description and evaluation of DSRC and VANET technologies. A thorough survey can be found in [5]. Existing works that use DSRC/802.11p stress the importance of meeting the strict delay and low packet collision requirements of safety applications, especially in high offered-load conditions. Works that try to find adequate solutions to these issues can roughly be divided into four categories: broadcast enhancement schemes [6], MAC layer solutions for back-off algorithm improvement [6], communication rate and/or power adjustment strategies [9-10], and deterministic access for DSRC/802.11p in collision-free periods [3].

Torrent-Moreno et al. [10] proposed a centralized power control algorithm that provides a solution to adjust the channel load in VANET environments problem by maximizing the minimum transmission range for all nodes in a synchronized approach. They analyzed the piggybacked beacon information received from neighbors to control the channel load.

Fattah et al. [2] show that DCF cannot achieve a high throughput nor a low delay as the number of devices increases. Therefore, some other mechanisms to enhance/complement DCF are needed to tackle these issues and to provide short delays and high reliability. In line with this idea, the authors in [3] proposed a deterministic access to the shared medium in collision-free periods within a two-hop neighborhood of vehicle. They showed that their scheme is able to attain low delivery delays and high reception rates by ensuring that vehicles have a dedicated access to the medium at specific time slots. However, adjusting the power level could also provide less contention among vehicles and thus enhance reception rates. An interesting study is presented [9] in which the authors maintain the tracking accuracy of vehicles within an acceptable range by dynamically adjusting the frequency of probe messages and their transmission power. This work can be considered as an extension to the scheme proposed in [3] by looking into the transmit power adjustment factor. By contrast to [9], where authors try to reduce the tracking error of probe messages, in this work we look into dynamically adjusting the transmission power of emergency messages to keep the reception delay within an acceptable range which is rather determined by the requirements of the emergency applications at hand[1].

III. PROBLEM FORMULATION

In this section, we first propose a power control scheme and second, we analytically provide the problem formulation.

A. *Power Control Scheme: PCS*

In this subsection, we present our power control algorithm for VANETs. PCS determines how far the emergency message should be broadcasted by adjusting the power level for DSRC/802.11p.

Based on the shared channel status observed and presence of an event to send on the road, PCS performs an adjustment on power level. It is worth mentioning that in this study we take into account eight high-priority cooperative vehicular safety applications as chosen by the National Highway Traffic Safety Administration [1]. These applications require strict pre-determined delay constraints. For example, the maximum latency of Traffic signal violation, Forward collision, Lane Change Warning, Stop Sign Assist, Left Turn Assist applications are equal to 100ms and their transmission ranges are about 250m, 150m, 150m, 300m and 300m, respectively. Latencies are caused by propagation time (distance), transmission errors and their recovery, queuing, and the processing capabilities of the transmission device in the vehicle. Adjusting the transmission power level determines the transmission range, but also plays into determining how many vehicles will be contending for the transmission channel in a given time, and how many transmission errors there will be.

Depending on the propagation model used as reference, the relationship between transmission power, transmission range, or distance is straight forward. This relationship is depicted in (1) for the two-ray ground propagation model [12] where the received power at transmission range *d* is denoted by P_L(d)., h_t , h_r are the heights of the transmitter and receiver antennas respectively, and P_t, G_t, G_r are the transmission power, transmitter gain and reception gain respectively.:

$$P_L(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} \quad (1)$$

Hence, the transmission power can be expressed as follows:

$$P_t = \frac{P_L(d) \times d^4}{G_t G_r h_t^2 h_r^2} \quad (2)$$

In the rest of the paper, we will consider this propagation model commonly used in the literature, in the analytical formulations. However, the presented scheme is general and can be applied with other propagation models.

Alg. 1 Power Control Scheme: PCS algorithm

Step0: Calculate the probability that vehicle i experiences consecutive collided transmissions

If emergency t**hen** compute P_j^i (Eq.5);

Step1: Contention period

-Compute contention period, CP_i (Eq.4);

Step2: use delay constraint given by the application [1] to adjust power level

-use the delay value obtained from (Eq. 3) in (Eq.10) to obtain the power level, P_t

B. Computing delay in 802.11p to adjust power level

In this paper, we derive our analysis based on the IEEE 802.11p standard in order to adjust the power level according to the maximum allowed latency when an event happens on the road.

As it is commonly the case in most other pertinent studies [10], the total MAC layer delay in this work is considered to comprised of three dominant terms; a) the average back-off time, b) the transmission time and c) the contention period. The back-off time is the number of time slots every transmitting node randomly waits before it transmits, multiplied by the time slot duration. The transmission time is the time needed for a successful transmission of the message on the channel. The contention period is the period of time in which neighboring vehicles contend to get access to the channel. Contention time is also referred to as the interference period in many studies. Hence, the MAC layer delay experienced by vehicle i, denoted by T_i, can be written as:

$$T_i = \overline{T_{backoff}} + \frac{L}{r} + CP_i \tag{3}$$

Where L is the size of the message, r is the data rate at which a vehicle transmits its messages and CP_i is the contention period experienced by vehicle i which is also the average number of consecutive congested timeslots multiplied by the length of each timeslot. CP_i can be written as follows:

$$CP_i = (\frac{L}{r}) \times \sum_{j=1}^{\infty} jP_j^i \tag{4}$$

where P^i_j is the probability that vehicle i experiences j consecutive collided transmissions and can be written as:

$$P_j^i = (P_j^i \mid e) * P_e^i \tag{5}$$

$$P_e^i \; function\, of \, \lambda_i$$

where P_e^i is the probability that an emergency occurs for vehicle i and $(P_j^i \mid e)$ is the conditional probability of vehicle i experiencing j consecutive collided timeslots provided that an emergency has occurred. $(P_j^i \mid e)$ can be obtained as follows:

$$P_j^i \mid e = P_{ts}^j = [1-(1-\Pr_t^i \mid e)^{N_{ct}}]^j \tag{6}$$

where P_{ts} is the probability of having a collision in a given timeslot and Pr_t is the probability of any vehicle in the range transmitting in a given timeslot. Obviously, P_{ts} can be easily calculated in terms of Pr_t and the number of all the vehicles in the range contending for the channel, N_{ct}, as given by (6). On the other hand, $\Pr_t^i$ itself can be written in terms of the arrival rates of safety occurrences, λ_i' which is function of λ_i and a constant value ω_i . λ_i is the arrival rates of emergency messages, ω_i is the arrival rate of routine occurrences and C_j is the average channel occupancy, as

$$\Pr_t^i = 1 - \frac{\sum_{i \in N_{ct}} \lambda_i' \times C_i}{\sum_{i \in N} \lambda_i' \times C_i} \tag{6}$$

We express the transmission range as follows:

$$d_t = \frac{C_{\max} - C_j}{C_{\max} - C_{\min}} \times d^{app} + d^{app} \tag{7}$$

where C_j is the average channel occupancy and it is a real number between 0 and 1, d^{app} is the transmission range for each emergency message as pre-defined by the National Highway Traffic Safety Administration. $C_{\max}$ and $C_{\min}$ represent the desired linear operating range of channel occupancy and are selected based on experimental or analytical data [9].

For DSRC, the granularity of power transmission is 0.5dbm to convert to transmission range [9]. Therefore, Eq.6 becomes as follows:

$$P_t = (\frac{C_{\max} - C_j}{C_{\max} - C_{\min}} \times d^{app}) \times \psi \tag{8}$$

Where ψ is the conversion parameter for DSRC and is equals to 0.5 dbm.

Therefore, we can express C_j as :

$$C_j = C_{\max} - [(C_{\max} - C_{\min}) \times \frac{P_t}{\psi d^{app}}] \tag{9}$$

Since in this paper we are aiming to keep the delay below a pre-defined threshold requested by the emergency application of interest, according to (9), we adjust the power level accordingly.

$$T_i \le Delay_{TH}^{app} \tag{10}$$

Then to compute power level according to maximum latency, we use the following equation.

$$\overline{T_{backoff}} + \frac{L}{r} + (\frac{L}{r}) \times \sum_{j=1}^{\infty} j[1-(1-(1-\frac{\sum_{i \in N_{ct}} \lambda_i' \times C_{\max} - \lambda_i'[(C_{\max} - C_{\min}) \times \frac{P_t}{\psi d^{app}}]}{\sum_{i \in N} \lambda_i' \times C_{\max} - \lambda_i'[(C_{\max} - C_{\min}) \times \frac{P_t}{\psi d^{app}}]}))^{N_{ct}}]^j * P_e \le Delay_{TH}^{app} \tag{11}$$

In equation (11), all the parameters are known (See Table. I for more details of each parameter used in Eq.11), the only unknown parameter is the power level, P_t. Particularly, both parameters $Delay_{TH}^{app}$ and d^{app} are pre-defined accordingly to each application defined in [1].

Therefore, strict QoS requirements on emergency messages could be achieved if we adjust the power level as described in Equation (11).

TABLE. I. NOTATIONS PARAMETERS

L	The packet size	1000bytes
R	The data rate	10Mbps
λ_i	The arrival rates of emergency messages	Values referred to in Table. II
λ_i'	The arrival rates of safety occurrences	F(λ_i , ω_i)
$C_{\max}$ and $C_{\min}$	The desired linear operating range of channel occupancy	They are selected based on experimental or analytical data[9]
d^{app}	The transmission range	Values referred to in Table. II
$Delay_{TH}^{app}$	Threshold delay	Values referred to in Table. II
N_{ct}	The number of interfering vehicles	Updated each interval of time of 1s
ψ	The granularity of power transmission	0.5dbm
$\overline{T}_{backoff}$	The average back-off time: $1/\varepsilon$	After c collisions, a random number of slot times, ε , between 0 and 2^c - 1 is chosen

IV. Simulations results

In this section, we conduct a simulation study using ns-2 to evaluate and compare the performance of PCSwith 802.11p using DCF function [2] and then with 802.11p using vehicular deterministic Access (VDA) [3]. We evaluate two metrics: 1) the delay and 2) the packet reception rate.

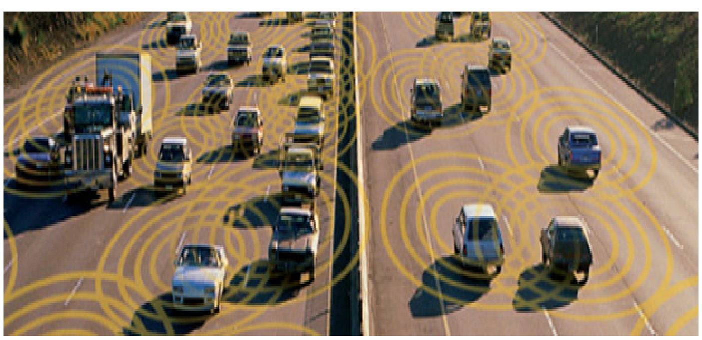
Fig.1 Simulation Scenario (4 lanes/ direction)

A. Simulation Configurations

We use a topology composed of 8 vehicles with 10 vehicles in each lane in an 8 lane highway (4 lanes/ direction). The radio transmission range r takes one of the following values: 50m, 150m, 200m, 250m and 300m and the transmission interference R of each vehicle is 550m. Also, we fix the packet size to 1000Bytes. In the simulations PCS takes into account eight high-priority cooperative vehicular safety applications as chosen in [1] and they are presented in Table II. I2V represents infrastructure-to-vehicle, while V2V represents vehicle-to-vehicle.

We evaluate the delay and the delivery reliability metrics while varying the traffic density. The purpose of varying traffic density between 10 and 100 veh/km/lane is to vary channel load [6] from a low communication channel load to a high channel communication load with (all other parameters being kept the same, e.g., message size, data rate) 10 veh/km/lane being a low load and 100 veh/km/lane being a high load. A value of 100 veh/km/lane corresponds to vehicles at a distance that is on average 10m, including their own length.

TABLE. II. EIGHT HIGHT-PRIORITY APPLICATIONS

Application (app)	Com. type	Com. rate (λ_i)	Threshold delay ($Delay_{TH}^{app}$)	Range (d^{app})
Traffic Signal Violation (TSV)	I2V	10Hz	100 ms	250m
Curve Speed Warning (CSW)	I2V	1Hz	1000 ms	200m
Emergency Brake Lights (EBL)	V2V	10Hz	100 ms	200m
Pre-crash Sensing (PS)	V2V	50 Hz	20 ms	50 m
Forward Collision (FC)	V2V	10 Hz	100 ms	150 m
Left Turn Assist (LTA)	I2V or V2V	10 Hz	100 ms	300 m
Lane Change Warning (LCW)	V2V	10Hz	100 ms	150 m
Stop Sign Assist (SAA)	I2V or V2V	10 Hz	100 ms	300 m

B. Results analysis

Due to lack of space, in the following, we choose to present only the performance of PCS scheme in terms of delay and reliability especially for LTA, SAA, and PS applications referred to in Table. II (using DCF and VDA MAC protocols). We opt to evaluate mainly these applications because they have strict QoS parameters on the delay (i.e., 100 ms, 20ms resp.).

1) Left turn assist (LTA) and Stop sign assist (SAA) applications study

Fig.2 shows the delay performance when varying the network density in the highway. In light network density conditions (10-20) where collisions are very rare, DCF access method provides almost similar delays than the schemes based on deterministic access (VDA and PCS_VDA). However, one should note that in low, medium and high density conditions, delays are very low both in VDA and in PCS_VDA schemes.

In medium network density conditions (e.g., 40-60), we notice that the delay, with both random access DCF and PCS_DCF) based on CSMA/CA is dramatically increased when the network density increases especially without the PCS improvement. Besides, with DCF method, the delay exceeds the threshold delay pre-defined in [1] and reaches 109 ms. However, when using PCS algorithm the delay is kept under the threshold delay, because PCS scheme coupled with DCF is able to adjust the power level according to the delay constraint so that the pre-defined delay parameter (100ms) is not violated over all network density conditions.

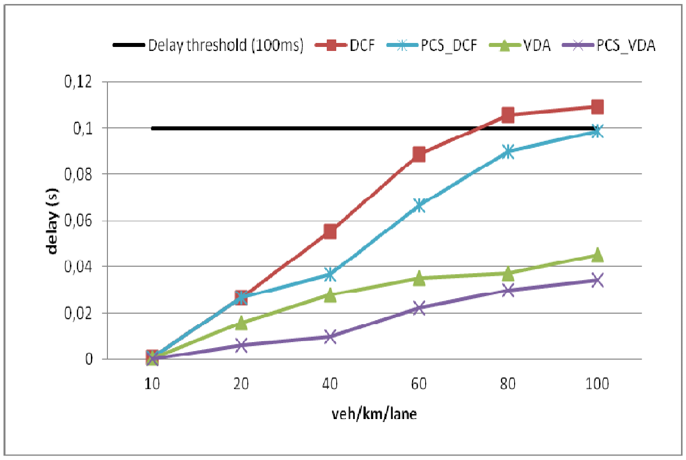

Fig.2 Delay performance of LTA/SAA (100ms)

We conclude that with MAC protocols either based on random or deterministic access, it is interesting to take into account the power level to reduce efficiently the delay and thereby meet the requirement of the target safety applications.

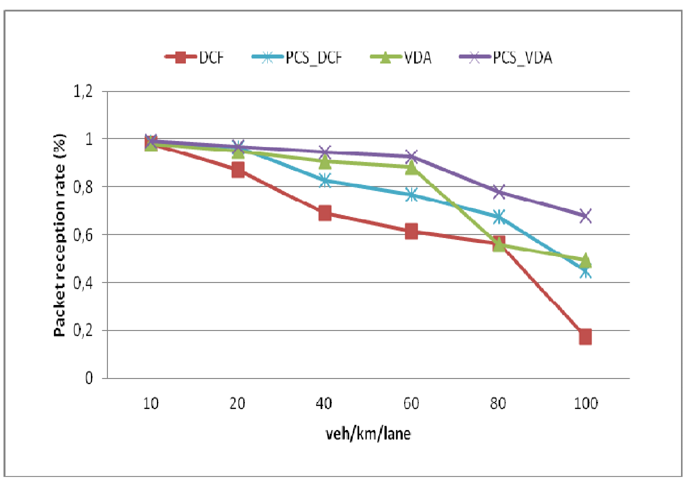

Fig.3 Packet reception rate performance of Left Turn Assist (LTA)/Stop Sign Assist (SAA)

In Fig.3, we remark that the schemes based on DCF method suffer from inevitable collisions when the network density increases. Therefore, it has a significant drop in reception probability. However, the reliability improvement made on DCF by PCS_DCF is about 17%. The schemes based on contention free period access enhance scheduling and guarantee a bounded delay and subsequently this impacts reliability of wireless communications of vehicles. PCS_VDA outperforms DCF, PCS_DCF and VDA in high density conditions (60-100) resp. by around 43%, 20% and 19% in terms of reception probability.

2) Pre-crash sensing (PS) application study

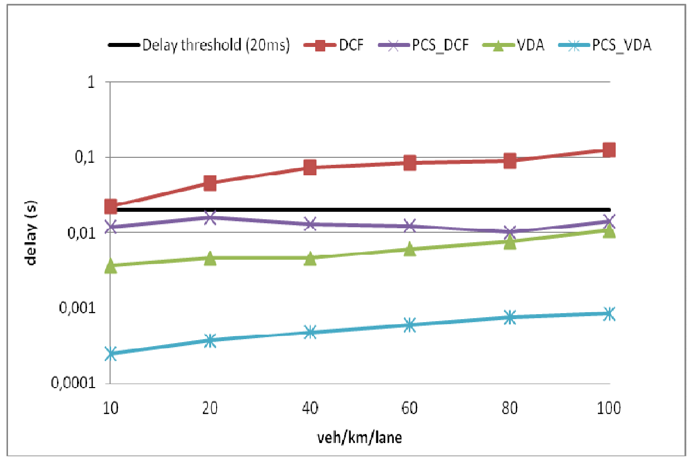

Fig.4 Delay performance of Pre-crash Sensing application (PS :20ms)

Fig.4 shows that using an efficient scheduling of time slots to serve emergency applications guarantees bounded delays which is well demonstrated using both VDA and PCS_VDA. However, adjusting the power level with PCS also impacts positively the delay performance of the traditional MAC access, DCF, as it is shown in the figure under PCS_DCF scheme. For PCS_DCF, the delay is higher than that of both VDA and PCS_VDA schemes but PCS_DCF is able to prevent the delay to exceed the hard delay constraint which equals 20ms.

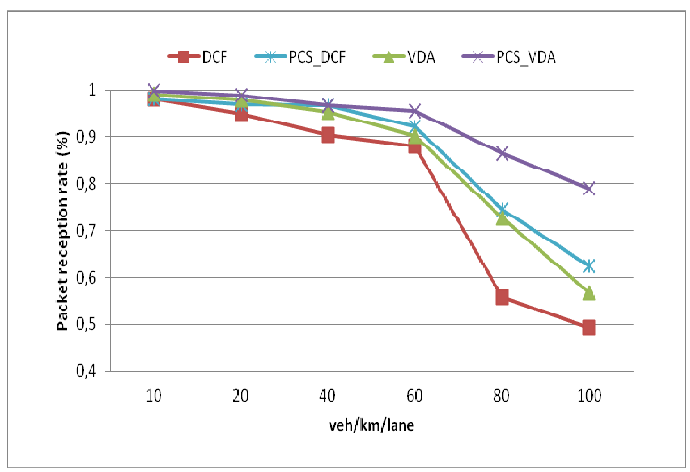

Fig.5 Packet reception rate of Pre-crash sensing application (PS :20ms)

The packet reception rate in shown in Fig.5, drops dramatically starting from a network density of 60 especially when using only DCF. For example, for network density=100, the packet reception rate with DCF drops to 0.4929. However, the results show that PCS provides higher reliability to both for DCF and VDA schemes. With VDA, PCS is able to maintain the packet reception rates for a density of 100, to a value close to 0.8. Overall, we remark that PCS_VDA outperforms all the others schemes DCF, PCA_DCF and VDA in high density conditions (60-100) resp. by around 26%, 12% and 16%.

An interesting remark here is that PCS_VDA shows a higher performance in terms of reliability for LTA/SAA application, compared to the PS application. This can be explained by the fact that PS has a higher data exchange rate compared to other emergency applications as shown in Table. II, which may affect network communications reliability for vehicles involved in emergency situations such as a collision. Therefore, a scheme such as PCS becomes very helpful to avoid higher delay transmissions and thus help the corresponding safety applications save lives in case of accidents.

V. CONCLUSIONS

In this paper, we show how we minimize contention between safety-oriented occasional emergency traffic while adjusting transmission power to guarantee shorter delays. Our proposed scheme called PCS uses the delay constraint as required by the emergency applications defined by the National Highway Traffic Safety Administration, to adjust the transmit power in order to meet those requirements. Using simulations, we show that PCS is general and can be useful when integrated to different MAC protocols.

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