Wireless Vehicular Adaptive Radio Resource Management Policies in Congested Channels

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Abstract—**The strict QoS traffic safety requirements and the potential widespread adoption of wireless vehicular communication systems require the design and optimization of radio resource management policies that efficiently use the communications channel. To this end, this work proposes an adaptive radio resource management mechanism designed considering the operating conditions and the traffic safety requirements. The proposed scheme is analysed under various traffic densities, and compensation mechanisms to overcome the channel congestion effects are proposed and evaluated.**

I. INTRODUCTION

Wireless vehicular communications represent a promising technology for the provision of Internet connectivity on the move, and the development of novel applications for traffic safety and efficiency. However, the development of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications systems imposes strong challenges given their decentralized nature, the strict Quality of Service (QoS) requirements of traffic safety applications, the node's mobility and the potential channel congestion in highly dense traffic conditions. To support traffic safety applications, vehicles will periodically broadcast, among others, their position and speed to nearby vehicles using the IEEE 802.11p standard. The 802.11p system, also referred as Wireless Access in Vehicular Environments (WAVE) [1], adapts the IEEE 802.11a standard at the physical and access layer to the vehicular environment. WAVE is based on seven ten-megahertz channels consisting of one control channel and six service channels in the 5.9GHz band. While the service channels are used for public safety and private services, the control channel is used as the reference channel to initiate and establish any communications link. The control channel is then used to periodically broadcast announcements of available application services, warning messages and safety status messages. Considering the strict traffic safety latency requirements, WAVE disables the use of RTS/CTS (Request To Send / Clear To Send) signalling and of acknowledgment reports in the control channel. Despite reducing transmission delays, disabling these features also increases the packet collision probability due to the hidden-terminal problem. As a result, the central role of the WAVE control channel requires the development of novel and adequate radio resource management schemes to efficiently use the control channel. This need will be further emphasized as V2V and V2I communication systems are widely adopted and channel congestion increases.

To optimize the vehicular network performance under various traffic densities, studies like [2] and [3] have proposed to dynamically adapt the transmission parameters to the operating conditions. In particular, the work in [2] proposes a power-rate control algorithm for high speed ad-hoc networks based on the number of interfered neighbours and the size of the transmitted packet. The work reported in [3] also proposes a power control algorithm for vehicular ad-hoc networks that dynamically changes the transmission power under low to high traffic densities to control the number of vehicles under each vehicle's transmission range. However, the design and dimensioning of efficient radio resource management policies should not only be based on system optimization aspects but also on traffic safety requirements. To this end, this work proposes and evaluates an opportunistic-driven adaptive radio resource management scheme that adapts the transmission parameters (transmission power and packet rate) based on the vehicle's position and its proximity to an area where a traffic collision could occur. The proposed scheme is evaluated under various traffic densities and various compensation schemes are proposed to overcome the negative effects derived from channel congestion under heavily dense traffic conditions.

II. ADAPTIVE RADIO RESOURCE MANAGEMENT

This work considers the critical traffic safety scenario illustrated in Fig. 1. To avoid a potential accident the two vehicles approaching the intersection should periodically broadcast traffic safety alerts on the WAVE control channel. To avoid a collision, the messages should be received with sufficient time for the driver's to react and decelerate. To this end, we define the critical distance *CD* as the minimum distance to the intersection at which a vehicle needs to receive a broadcast message from the other vehicle to avoid their potential collision at the intersection. Considering a uniform deceleration model, the critical distance can be computed as:

$$CD = v \cdot RT + \frac{1}{2}\frac{v^2}{a_{\max}} \tag{1}$$

where v represents the vehicle's speed, RT the driver's reaction time and a_{max} the vehicle's emergency deceleration.

To efficiently use the WAVE control channel, the authors proposed an OPportunistic-driven adaptive RAdio resource Management (OPRAM) mechanism that adapts the operating parameters (transmission power and packet data rate) based on the vehicle's position and its proximity to an area where a potential collision could occur. The proposal's aim is to guarantee the required traffic safety performance (i.e. receiving a broadcast alert with sufficient time for the driver to react) while efficiently using the WAVE control channel. To this end, it is important to limit the transmission power to the minimum necessary given that high transmission powers results in a higher channel collision probability due to their increased coverage range. As a result, the OPRAM proposal generally operates with a low transmission power sufficient to communicate with the vehicles moving along the same street in LOS (Line of Sight) conditions. However, OPRAM increases its transmission power when the vehicle is approaching the distance *CD* in order to guarantee a high probability to successfully receive a broadcast safety alert before *CD* (see Fig. 1); the region before *CD* where the transmission power is increased is called Algorithm Region (*AR*) and has been set equal to 1second in this work. OPRAM defines a target probability of not receiving a warning alert before *CD* equal to $p=0.01$. The proposed scheme considers that each vehicle transmits N_T broadcast messages in *AR* and that the probability that a single packet is successfully received p_e is independent and constant in *AR*. Consequently, the number of packets correctly received N_R in *AR* can be described through a Binomial distribution constructed by N_T Bernoully experiments (each of them with a probability of success p_e). In this case, the probability that vehicle *A* receives no broadcast safety alert from *B* before *CD* is:

$$P(N_R = 0) = (1 - p_e)^{N_T} = p \qquad (2)$$

Once p and N_T have been defined, p_e can be obtained through equation (2). To maintain p_e constant in *AR*, OPRAM varies the transmission power in *AR* with the distance. Increasing N_T offers OPRAM the possibility to reduce the target mean probability p_e and consequently the transmission power. Once p_e has been calculated, Fig. 2 is used to obtain the required average received power level *Pr* to successfully receive each transmitted packet within *AR* with the probability p_e. Fig. 2 has been obtained emulating the reception of a large set of samples with an average received power of *Pr* but with a varying instantaneous received power level given to the shadowing and fast fading contributions. The correct or incorrect reception of each emulated sample is then estimated based on the received signal level and the link level interfaces described in the following section. The probability of successfully receiving a packet p_e given an average received power level *Pr* is then estimated as the ratio of correctly received samples to the total number of samples generated.

Using Fig. 2 it is then possible to determine the required average *Pr* to guarantee the target p_e. Finally, the OPRAM transmission power can be obtained considering the pathloss contribution for the corresponding distance between transmitter and receiver. Fig. 3 illustrates an example of the OPRAM operation where it can be observed that an increase in N_T reduces the target p_e, and consequently the required OPRAM transmission power. Fig. 3 also shows that OPRAM

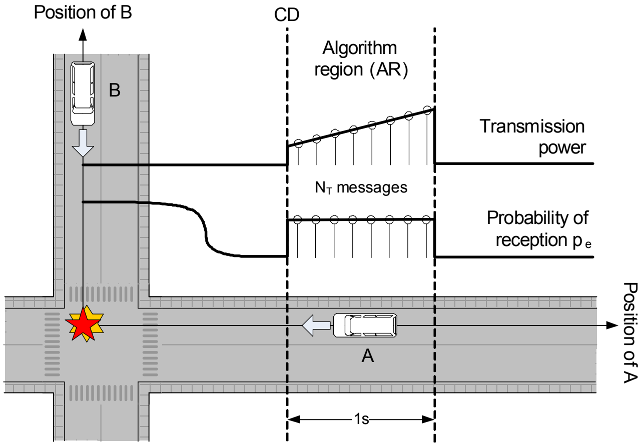

Fig. 1. Adaptive power control mechanism scheme.

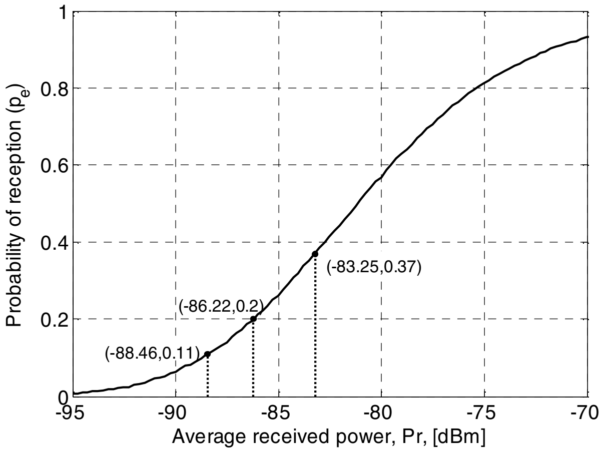

Fig. 2. Average probability p_e as a function of Pr.

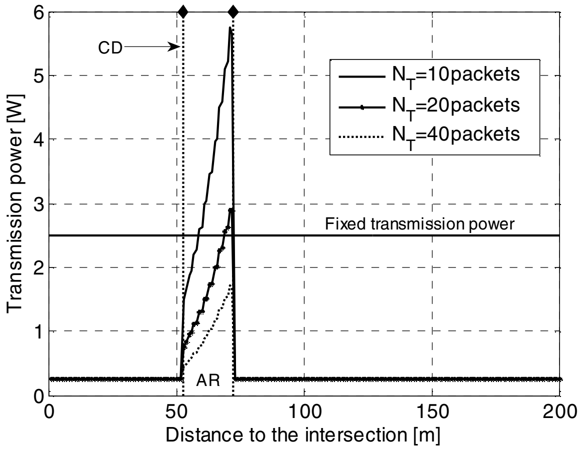

Fig. 3. OPRAM operation.

maintains a constant 250mW power level and 10packets/s data rate outside the *AR* region. These values have been selected since they guarantee each vehicle's connectivity with those located along the same street in a 150m range, as required by the WAVE guidelines for cooperative collision warning applications [4].

III. EVALUATION SCENARIO

To conduct this investigation, a wireless vehicular simulator developed in ns2 [5] has been implemented. It considers the critical intersection scenario illustrated in Fig. 1. Vehicles periodically broadcast safety messages on the WAVE control channel at 6Mbps, corresponding to the WAVE ½ QPSK transmission mode. In terms of traffic density, two scenarios have been simulated. In the first one, only the two vehicles approaching the intersection are emulated. In this case, transmission errors result solely from propagation effects. In the second scenario, other nearby vehicles also transmitting broadcast safety alerts are emulated. In this case, transmission errors are due to the propagation effects and channel congestion. Table I summarizes the main simulation parameters, where the null traffic density denotes the scenario where only the two vehicles approaching the intersection are emulated. The operational parameters have been selected following the WAVE recommendations and [6].

A detailed urban micro-cell propagation model developed in the WINNER project [7] has been considered to model the radio transmission effects defined in terms of pathloss, shadowing and multipath fading. Despite not considering V2V communication scenarios, the operating conditions of the WINNER urban micro-cell model are, to the author's best knowledge, those that currently best fit the V2V communications scenario[1] given the unavailability of a complete V2V communication propagation model for system level investigations. The model also differentiates between LOS and NLOS (Non Line of Sight) conditions, with the following pathloss expressions:

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Speed [km/h]	70
Traffic density [vehicles/km/lane]	0, 100
Reaction time, RT, [s]	1.5
Algorithm region, AR, duration [s]	1.0
Emergency deceleration [m/s^2]	8
Packet size [bytes]	100
Number of packets transmitted in AR, N_T	10, 20, 40
Background noise, N_o, [dBm]	-90

$$PL_{LOS} = \begin{cases} 22.7\log_{10}(d[m]) + 41 + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d < R_{bp} \\ 40\log_{10}(d[m]) + 41 - 17.3\log_{10}(R_{bp}) + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d \geq R_{bp} \end{cases} \quad (3)$$

$$R_{bp} = 4\frac{(h_A - 1)(h_B - 1)}{\lambda} \quad (4)$$

with d the distance between transmitter and receiver, and h_A and h_B their respective antenna heights.

$$PL_{NLOS} = PL_{LOS}(d_A[m]) + 20 - 12.5n_j + 10n_j\log_{10}(d_B[m]) \quad (5)$$

$$n_j = \max(2.8 - 0.0024d_A[m], 1.84) \quad (6)$$

with d_A and d_B the distances of vehicles *A* and *B* to the intersection.

The shadowing is modelled through a log-normal distribution with a zero mean and a standard deviation equal to 3dB and 4dB for LOS and NLOS conditions respectively. Finally, the fast fading effect resulting from the reception of multiple replicas of the transmitted signal at the receiver has also been implemented through Ricean (with the *K* parameter depending on the distance) and Rayleigh distributions for LOS and NLOS conditions.

To reduce the complexity of system level simulations, the physical layer effects resulting from the probabilistic nature of the radio environment have been included by means of the WAVE control channel Look-Up Tables (LUTs) shown in Fig. 4 [8]. These LUTs, extracted from link level simulations, map the Packet Error Rate (PER) to the experienced channel quality conditions expressed in terms of the effective Signal to Interference and Noise Ratio (SINR).

IV. OPRAM PERFORMANCE

Fig. 5 compares the OPRAM traffic safety performance to that achieved with a 2.5W fixed transmission power scheme. Based on previous investigations, the authors found that a 2.5W power level was necessary in constant power transmission policies to guarantee, for the simulated conditions, that a vehicle approaching the intersection

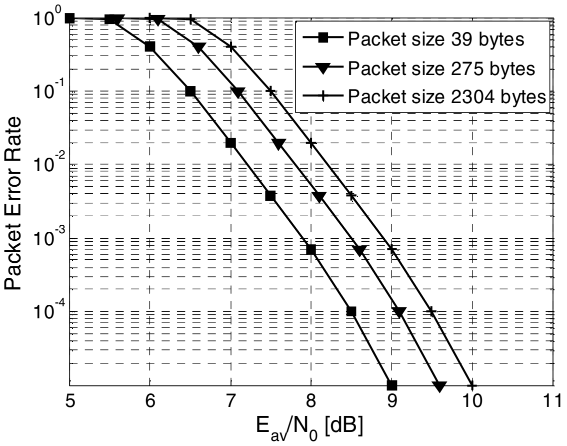

Fig. 4. Packet Error Rate for the WAVE Control Channel.

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[1] The WINNER model considers a frequency range between 2GHz and 6GHz, and minimum transmission and reception heights of 5m and 1.5m.

received a broadcast safety alert with sufficient time to react in 99% of the simulated iterations. The performance is compared by means of the cumulative distribution function (CDF) of the distance to the intersection at which a vehicle correctly receives the first broadcast safety message from the potentially colliding vehicle. The obtained results demonstrate that OPRAM achieves the target traffic safety performance while using more efficiently the WAVE control channel than a constant power policy. Fig. 3 showed that OPRAM transmission powers could further be reduced by increasing the number of packets N_T transmitted during *AR*. As shown in Fig. 6, such power reduction is achieved without sacrificing the traffic safety performance given that still only 1% of the vehicles did not receive a broadcast safety alert before *CD*. It is also important to note the inefficient use of the WAVE control channel by constant power policies, given that despite continuously transmitting at 2.5W, such policies achieve the same distribution results in Fig. 6 as the adaptive OPRAM proposal.

V. POLICIES TO OVERCOME CHANNEL CONGESTION

The previous section demonstrated the OPRAM benefits resulting in a significant transmission power reduction while guaranteeing the traffic safety QoS requirements and ensuring an efficient use of the WAVE control channel. The previous analysis was conducted considering a congestion free channel where only the vehicles approaching the intersection where transmitting broadcast safety messages. However, in a more realistic urban V2V scenario, nearby vehicles will also periodically transmit broadcast safety messages on the WAVE control channel. These transmissions will increase channel congestion and result in packet data losses that could significantly alter the traffic safety performance. Moreover, certain OPRAM configurations can result in transmission power increases during *AR*. Such power increases result in higher transmission ranges and consequently on a higher channel collision probability resulting from the hidden terminal problem. Given the importance of ensuring the proper operation of the OPRAM proposal in *AR*, it would then be necessary to develop adequate policies that overcome the negative effects derived from channel congestions in the WAVE control channel.

Fig. 7 depicts the probability p_e to correctly receive a packet considering a congestion free channel and the case in which nearby vehicles (traffic density) also transmit in the WAVE control channel. The results shown in Fig. 7 clearly affect the OPRAM proposal by significantly reducing (around 25%) the target p_e. This reduction in the achieved p_e significantly influences the OPRAM traffic safety performance. Fig. 8 shows that the channel congestion increases the probability of not receiving a broadcast safety alert before *CD* from the 1% target to over 4%. To compensate the negative channel congestion effects on the OPRAM proposal, this work proposes two approaches.

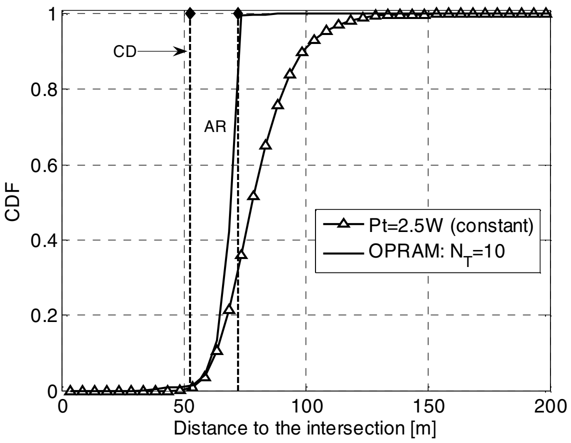

Fig. 5. CDF of the distance at which the first message is received for a constant transmission power and the OPRAM proposal.

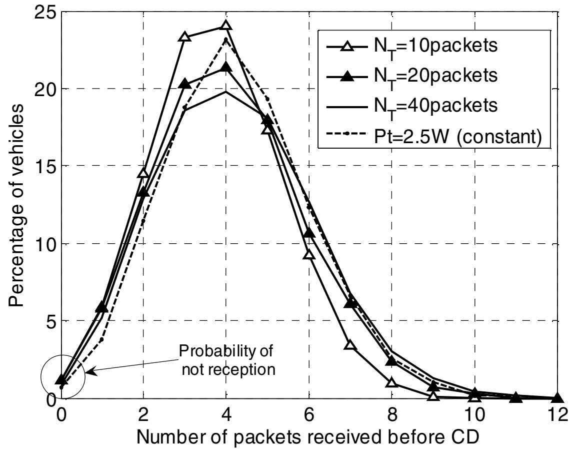

Fig. 6. Percentage of vehicles that receive a number of messages before CD.

The first channel congestion compensation policy considers the original OPRAM transmission power settings necessary to achieve a 1% probability of not receiving a packet before *CD* in a congestion free channel, but increases the number of packets N_T transmitted in *AR*. To this end, we use Equation (1) with the reduced target p_e resulting from the experienced channel congestion (as shown in Fig. 7, the channel congestion reduces p_e by over 25%). Considering Equation (1) and the target probability $p=0.01$, the first compensation policy requires the transmission of $N_T=14$ broadcast safety messages during *AR* instead of the original 10 in a non-congested WAVE control channel.

The second channel congestion compensation policy does not modify the number of transmitted messages during *AR* but increases the transmission powers during *AR* to compensate for the reduced p_e resulting from the channel congestion. The increased transmission powers during *AR* are then estimated to compensate for the 25% reduction in p_e obtained under high traffic densities[2]. Such power levels are then estimated

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[2] Different traffic densities would require to re-evaluate the power increase during *AR* necessary to compensate the channel congestion effects.

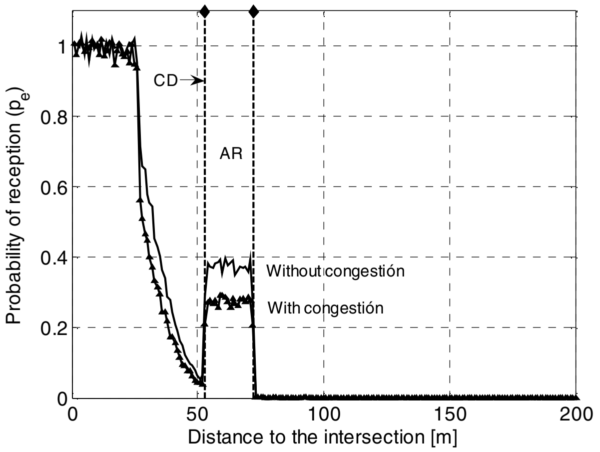

Fig. 7. Probability of successful packet reception from the potentially colliding vehicle for N_T=10.

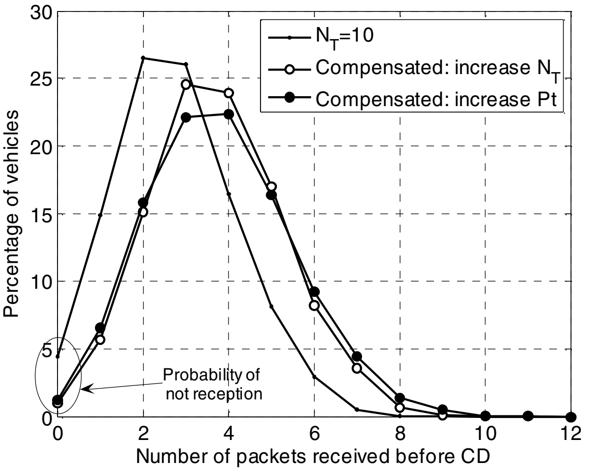

Fig. 8. Percentage of vehicles that receive a given number of messages before CD for N_T=10.

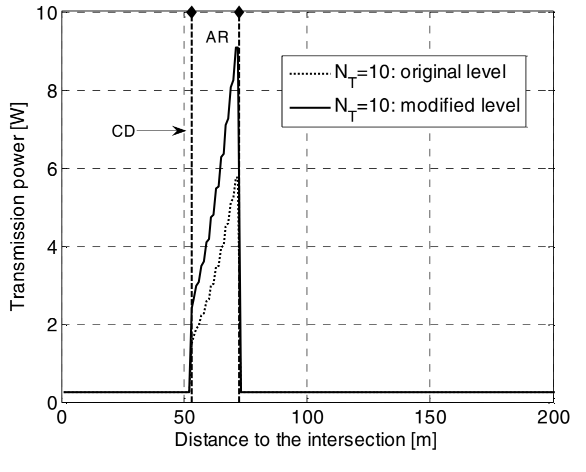

Fig. 9. OPRAM operation for N_T=10.

following the original OPRAM proposal, but considering a target p_e equal to 0.493 instead of 0.37 when transmitting $N_T=10$ during *AR*. In Fig. 9, the OPRAM original transmission power levels are compared to those necessary to compensate for the channel congestion effects.

The results presented in Fig. 8 clearly indicate that the two compensation policies proposed are capable to overcome the negative effects caused by channel congestion and achieve the original traffic safety target performance of receiving at least one broadcast safety alert before reaching *CD* with a 99% probability.

VI. CONCLUSIONS

This paper has proposed an adaptive radio resource management policy for V2V communications that guarantees traffic safety performance requirements while ensuring an efficient use of the control channel. The proposal has been evaluated under various traffic densities to emulate varying channel congestion probabilities. Channel congestion has been shown to significantly deteriorate the proposal's performance, but different policies have been defined to compensate for the negative effects derived from channel congestion.

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