Opportunistic-Driven Adaptive Radio Resource Management Technique for Efficient Wireless Vehicular Communications

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***Abstract*—Vehicle-to-vehicle and vehicle-to-infrastructure wireless systems are currently under development to improve the traffic safety and efficiency while providing Internet connectivity on the move. A widespread adoption of these wireless vehicular communication technologies will require an efficient use of the radio channel resources. To this end, this work proposes and analyses an opportunistic-driven adaptive radio resource management scheme that achieves the target traffic safety performance and efficiently uses the transmission and channel resources.**

Keywords-component—Adaptive radio resource management, vehicular communications, traffic safety.

I. INTRODUCTION

The development of the future Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications systems imposes strong radio channel management challenges due to their decentralized nature and the strict Quality of Service (QoS) requirements of traffic safety applications. To avoid road traffic collisions, vehicles will be required to periodically broadcast their position and speed to nearby vehicles using the IEEE 802.11p standard under development. The IEEE 802.11p system, usually referred as Wireless Access in Vehicular Environments (WAVE) [1], adapts the IEEE 802.11a standard to the vehicular environment. It 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 all communication links. As a consequence, the control channel is used to periodically broadcast announcements of available application services, warning messages and safety status messages. Messages are transmitted in the control channel using the CSMA/CA access protocol, and the RTS/CTS (Request To Send / Clear To Send) signalling used to avoid the hidden-terminal problem is disabled for broadcast messages. However, disabling the RTS/CTS transmissions, together with the reference use of the WAVE control channel in all V2V and V2I communications, requires the development of advanced radio resource management techniques that guarantee a reliable and efficient use of the radio channel.

Previous studies have demonstrated the need to adapt the transmission parameters based on the operating conditions to efficiently use the radio resources [2]. In particular, the transmission power and packet data rates have been shown to heavily influence the wireless vehicular system performance. To date, the vehicular radio resource management research has generally focused on the system optimization of V2V data transmissions and system interference. For example, the work reported in [3] analyses the combination of transmission power and packet data rate that optimizes the packet reception in highway scenarios. In [4], the authors propose a power control algorithm for vehicular ad hoc networks that dynamically changes the transmission power, based on the density of vehicles, to reduce channel collisions giving the number of vehicles within each vehicle's transmission range. Although these proposals improve the system's efficiency, it is important to consider the traffic safety performance requirements when developing advanced radio resource management schemes. In this context, this work proposes an opportunistic-driven adaptive radio resource management scheme that adapts the transmission parameters (transmission power and packet data rate) based on the vehicle's position and its proximity to an area where a traffic collision could occur. By dynamically varying the communication settings, the proposed scheme not only guarantees the traffic safety application requirements but also efficiently uses the transmission resources and the radio channel.

II. EVALUATION SCENARIO

Before describing the proposed opportunistic-driven adaptive radio resource management algorithm, it is necessary to present the simulated traffic scenario. This work considers the urban intersection scenario depicted in Fig. 1, where there is a potential risk of collision between vehicles *A* and *B*. To avoid such collision, both vehicles periodically transmit broadcast safety messages on the WAVE control channel to detect each other's presence. Messages are transmitted at

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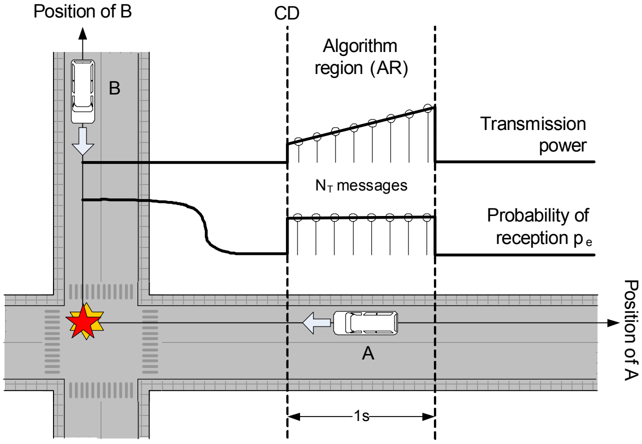

Figure 1. Intersection scenario and OPRAM proposal

6Mpbs following the 1/2 QPSK transmission mode defined for the WAVE control channel. The studied scenario has been emulated through a wireless vehicular simulator developed in ns2. Table I summarizes the main simulation and configuration parameters established following the WAVE guidelines and [5].

A detailed urban micro-cell propagation model developed in the WINNER project [6] 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 knowledge of the authors, those that currently best fit the V2V communications scenario given the unavailability of a complete V2V communication propagation model for system level investigations. In particular, the WINNER model considers a frequency range between 2GHz and 6GHz, and transmission and reception heights of 5m and 1.5m respectively. The model also differentiates between LOS (Line of Sight) and NLOS conditions, although in the scenario depicted in Fig. 1 there will only be NLOS transmissions between vehicles *A* and *B*. For NLOS conditions, the WINNER pathloss is expressed as follows:

$$PL_{NLOS} = PL_{LOS}(d_A[m]) + 20 - 12.5n_j + 10n_j \log_{10}(d_B[m]) \tag{1}$$

with

$$PL_{LOS} = \begin{cases} 22.7\log_{10}(d_A[m]) + 41 + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d_A < R_{bp} \\ 40\log_{10}(d_A[m]) + 41 - 17.3\log_{10}(R_{bp}) + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d_A \geq R_{bp} \end{cases} \tag{2}$$

$$R_{bp} = 4\frac{(h_A - 1)(h_B - 1)}{\lambda} \tag{3}$$

$$n_j = \max(2.8 - 0.0024 d_A[m], 1.84) \tag{4}$$

with d_A and d_B representing the distances of vehicles *A* and *B* to the intersection, and h_A and h_B their respective antenna heights.

TABLE I. SIMULATION PARAMETERS

Parameter	**Value**
Speed [km/h]	70
Reaction time, RT, [s]	0.75, 1.5
Emergency deceleration [m/s^2]	8
Packet size [bytes]	100
Background noise, N_o, [dBm]	-90

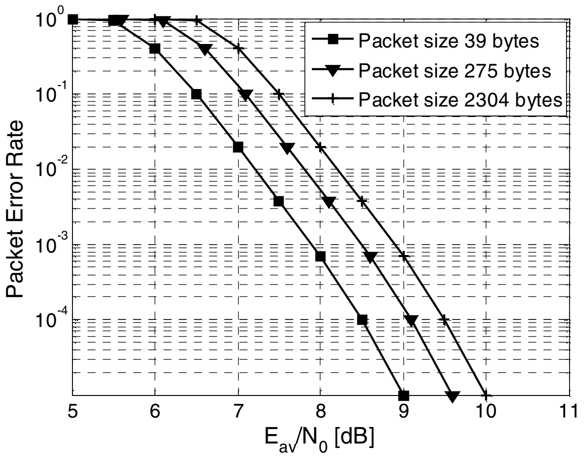

Figure 2. Packet Error Rate for the WAVE Control Channel

The shadowing is modelled through a log normal distribution with a zero mean and a standard deviation equal to 4dB for NLOS conditions. Finally, the fast fading effect resulting from the reception of multiple replicas of the transmitted signal at the receiver has also been implemented through a Rayleigh distribution.

To reduce the complexity of system level simulations, the effects of the physical layer resulting from the probabilistic nature of the radio environment have been included by means of the Look-Up Tables (LUTs) shown in Fig. 2 [7]. 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), E_{av}/N_0.

III. OPPORTUNISTIC-DRIVEN ADAPTIVE RADIO RESOURCE MANAGEMENT ALGORITHM

Based on the scenario reported in Fig. 1, we define the critical distance *CD* as the minimum distance to the intersection at which vehicle *A* needs to receive a broadcast safety alert from vehicle *B* to avoid their potential collision at the intersection. Considering a uniform deceleration model, the critical distance can be computed as:

$$CD = v \cdot RT + \frac{1}{2}\frac{v^2}{a_{\max}} \tag{5}$$

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, it would be sufficient to correctly receive just one broadcast safety alert with the minimum signal level before reaching the distance *CD*. Through limiting the number of messages received and their signal level (and hence the transmitting power), it would be possible to increase the WAVE control channel's efficiency by reducing the channel congestion. In this context, this work proposes an OPportunistic-driven adaptive RAdio resource Management (OPRAM) mechanism that adapts the transmission 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. Considering the scenario reported in Fig. 1, the OPRAM proposal operates with a low transmission power sufficient to communicate with the vehicles moving along the same street in LOS conditions, but increases its transmission power when the vehicle is approaching the distance *CD*. With such sudden increase, the aim of the OPRAM proposal is to guarantee the correct reception of a broadcast safety alert from vehicle *B* before reaching *CD* while minimising the transmission power, and hence, maximising the channel's efficiency. The region before *CD* where OPRAM increases its transmission power is called Algorithm Region (*AR*) and has been set to 1second for this work. To define the operation of the OPRAM proposal, we consider that each vehicle transmits N_T broadcast messages in *AR*. The objective of the proposed algorithm has been set to successfully receive at least one broadcast message before reaching *CD* in 99% of the cases; this is equivalent to define a probability of not receiving a warning alert before *CD* equal to $p=0.01$. Considering that OPRAM defines the probability that a single packet is successfully received p_e as independent and constant in *AR*, 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), i.e. $N_R \sim B(N_T, p_e)$. In this case, the probability that no broadcast message from *B* is received before *CD* is:

$$P(N_R = 0) = (1 - p_e)^{N_T} = p \,. \qquad (6)$$

Having defined p and N_T, p_e can be obtained through equation (6). Given that the aim is to maintain p_e constant in *AR*, the OPRAM proposal requires a varying transmission power as shown in Fig. 1. If N_T is increased, OPRAM can reduce the target mean probability p_e to successfully receive each transmitted packet within *AR* (see Table II). Once p_e has been calculated, Fig. 3 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. 3 has been obtained by separately evaluating a wide range of average received power levels, *Pr*. For each of these average *Pr* values, a large set of instantaneously received power level samples is generated by adding to the average *Pr* value the shadowing and fast fading contributions following their respective distributions. By computing E_{av}/N_0 and using Fig. 2, it can be decided whether each sample is correctly received or not. 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. Fig. 4 illustrates the described process for $Pr=-83.25dBm$, which corresponds to $p_e=0.37$; black and white circles represent, respectively, correctly and erroneously received samples.

Once the mean *Pr* value necessary to guarantee the target p_e has been determined, the transmission power is obtained considering the distance between transmitter and receiver and the WINNER pathloss expression. Fig. 5 illustrates an example of the OPRAM operation. Following the observations extracted from Table II, Fig. 5 shows that an increasing value of N_T results in a lower p_e parameter, and hence, in

TABLE II. PROBABILITY OF RECEPTION p_e FOR A VARYING N_T

N_T	p_e
10	0.37
20	0.2
40	0.11

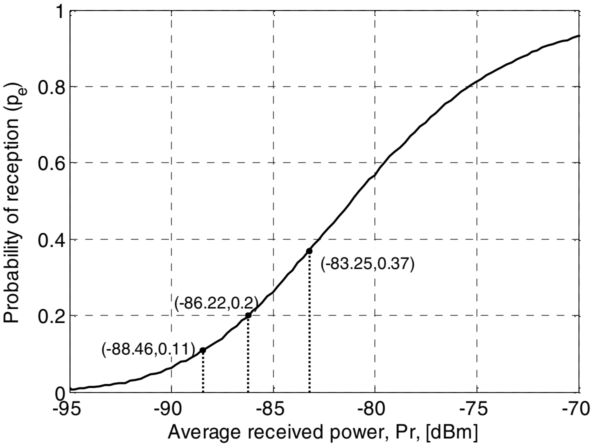

Figure 3. Average probability p_e as a function of P_r

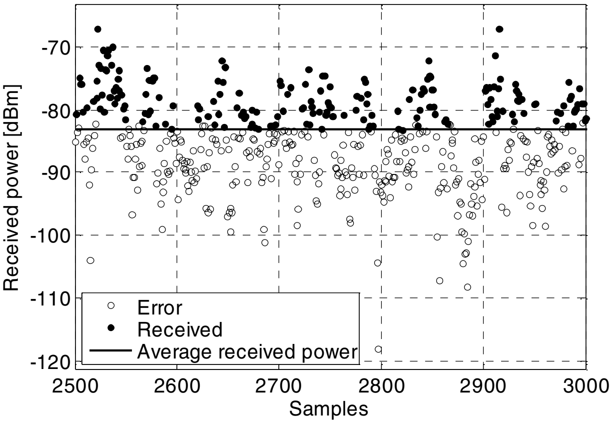

Figure 4. Instantaneously received samples for an average Pr equal to -83.25dBm

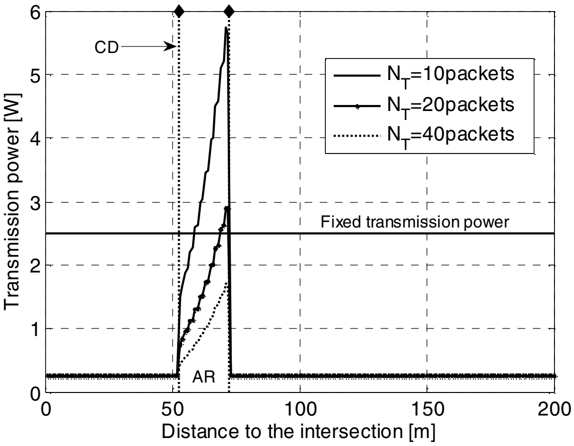

Figure 5. OPRAM operation for RT=1.5s

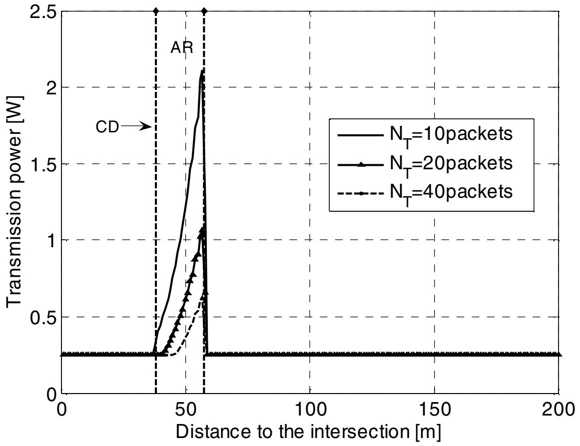

Figure 6. OPRAM operation for RT=0.75s

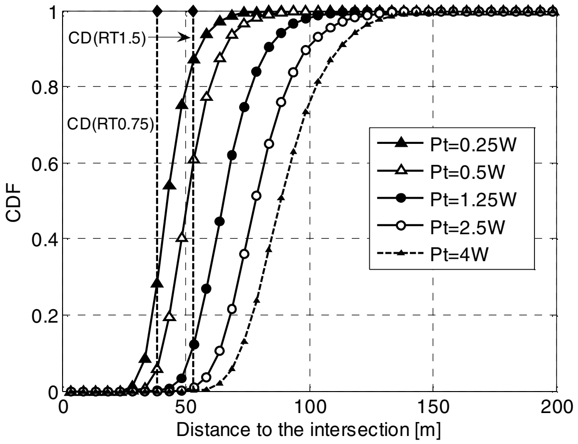

Figure 7. CDF of the distance at which the first message is received for constant transmission powers

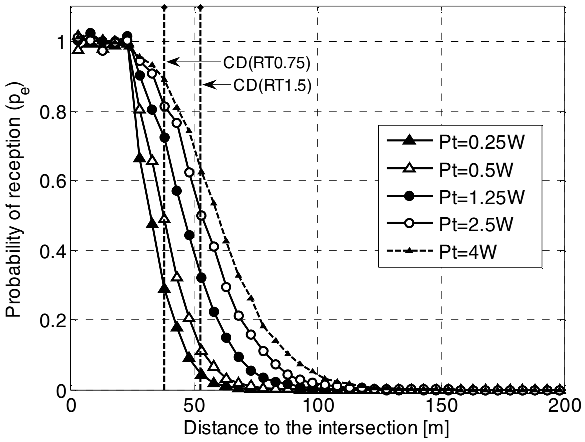

Figure 8. Probability of successful reception vs. distance to the intersection

significantly lower transmission power levels. As depicted in Fig. 5, the OPRAM proposal maintains a constant 250mW power level and a constant 10packets/s data rate outside the *AR* region. A 250mW transmission power is sufficient to guarantee a vehicle's connectivity with those located along the same street in a 150m range; this performance is required by the WAVE guidelines for cooperative collision warning applications [8]. By employing low transmission powers outside *AR*, OPRAM also reduces the coverage range and channel collisions, which results in a more efficient use of the communications channel. While Fig. 5 corresponded to a driver's *RT* of 1.5seconds, Fig. 6 illustrates the OPRAM operation for a driver's *RT* of 0.75seconds. Lower *RTs* result in a shorter *CD* and lower OPRAM transmission powers (theoretically even below 250mW) given the reduced distances between vehicles *A* and *B* when entering *AR*.

IV. PERFORMANCE

To analyse the benefits of the OPRAM proposal, this section first estimates, with regard to the traffic safety application under evaluation, the V2V communications performance using fixed transmitting powers. Fig. 7 shows, for different transmission powers, 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 figure also shows the critical distance for the two considered driver's *RTs*. The probability of accident, i.e. the probability of not receiving an alert before *CD*, can then be defined as the intersection of the cdf curve with *CD*. The results depicted in Fig. 7 show that the transmission power necessary to avoid an accident varies with the driver's reaction time. In particular, for large driver's *RTs*, the V2V communications system would have to employ large transmission powers to avoid a collision at the intersection. Fig. 8 represents the probability to correctly receive a broadcast message as a function of the distance to the intersection. As shown in Fig. 8, the probability to correctly receive a message rapidly decreases with the distance, even when using high transmission powers. This observation questions the need to constantly transmit at high power levels for the traffic safety application under study given that high transmission powers result in increased transmission ranges and higher channel collisions due to the hidden-terminal problem. The results illustrated in Fig. 8 also show that the higher probability of correctly receiving a broadcast safety

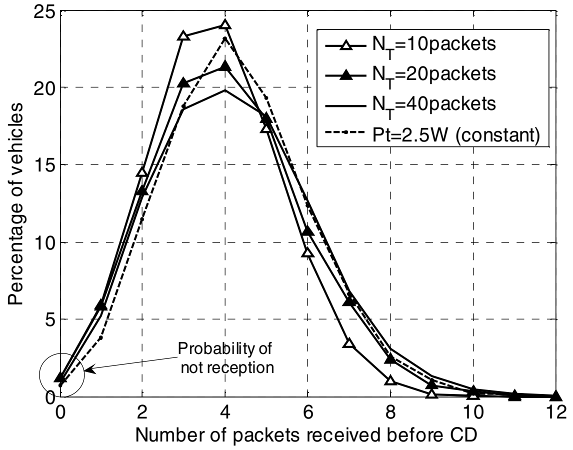

Figure 9. Percentage of vehicles that receive a given number of messages before CD for a driver's RT=1.5s

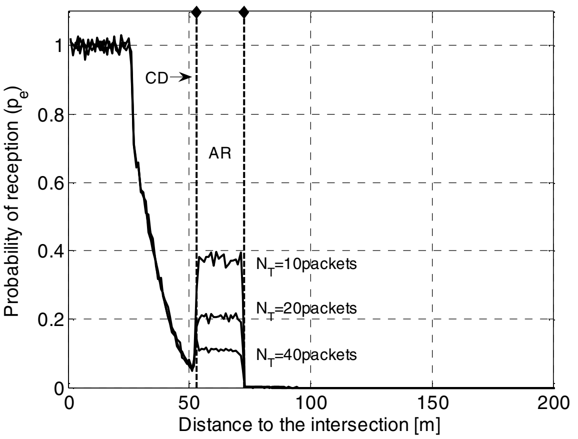

Figure 10. Probability of successful packet reception from the potentially colliding vehicle for RT=1.5s

alert is obtained after *CD*, i.e. when the alert is of limited use to prevent the collision at the intersection. The observations extracted from Fig. 8 highlight the inefficient use of the WAVE control channel with fixed transmitting power levels, and the need to develop adaptive proposals, such as OPRAM, that modify the transmission parameters based on the safety applications requirement and the aim to maximise the channel's efficiency.

Fig. 9 shows the percentage of vehicles that receive a given number of messages before *CD* considering the OPRAM proposal and a fixed transmitting power of 2.5W; as shown in Fig. 9, a 2.5W transmission power was needed to correctly receive a broadcast safety alert in 99% of the cases for a 1.5seconds driver's *RT*. The results shown in Fig. 9 demonstrate that the OPRAM proposal is able to provide the same traffic safety performance than using a constant high transmission power while significantly reducing the global transmitting power levels as shown in Fig. 7[1]. The reduction in transmission power is even more significant as the value of N_T within *AR* is increased (Fig. 7), while still guaranteeing the target traffic safety performance. The OPRAM proposal offers then an interesting option to trade-off transmission power and packet data rate while maintaining the traffic safety performance and efficiently using the WAVE control channel. Fig. 10 represents the probability of successful reception of a broadcast safety alert considering the OPRAM proposal. First of all, Fig. 10 shows that OPRAM achieves a constant p_e during *AR* that decreases with higher values of N_T. Also, it is important to note that OPRAM achieves the same traffic safety performance as constantly transmitting at high power levels despite experiencing a p_e equal to zero outside *AR*[2]. These observations highlight that OPRAM results in a more efficient use of the transmission and channel resources since it reduces the power consumption and radiation, and the channel congestion probability.

V. CONCLUSIONS

The strict traffic safety latency requirements and the decentralized nature of V2V communications systems impose strong radio resource management challenges to guarantee the viability of wireless vehicular communications systems. In this context, this work has proposed an opportunistic-driven adaptive radio resource management technique that guarantees the traffic safety performance while efficiently using the transmission and radio resources.

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[1] As previously mentioned, low transmission powers reduce the coverage range and therefore the channel congestion derived from the hidden-terminal problem.

[2] This probability corresponds to the probability of successfully receiving a broadcast safety alert between vehicles *A* and *B*, and not between vehicles moving along the same street for which p_e will not be equal to zero.