CHANNEL EFFICIENCY OF ADAPTIVE TRANSMISSION TECHNIQUES FOR WIRELESS VEHICULAR COMMUNICATIONS

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The adoption of wireless vehicular communication technologies would strongly depend on the technologies transmission reliability, required by QoS demanding traffic safety applications, and the system's scalability as the technology is gradually introduced. To this aim, this work proposes the use of opportunistic transmission policies that dynamically adapt the transmission parameters based on the operating conditions and potential traffic safety risks. The work shows that this proposal adequately meet the strong traffic safety QoS requirements while ensuring an efficient system level channel use, crucial to guarantee the future system's scalability.

Keywords: wireless vehicular communication systems, radio resource management, opportunistic and adaptive transmission

INTRODUCTION

Wireless vehicular communication systems have been identified as a promising Intelligent Transportation System (ITS) technology to improve traffic safety and efficiency while providing Internet access on the move. However, its future deployment would require to solve an important number of research challenges ranging from the integration with the vehicles electronics to the HMI (Human-Machine Interface) or the radio communications management. Contrary to current mobile and wireless systems, future wireless vehicular communication systems need to guarantee an ubiquitous robust transmission reliability while ensuring the system's scalability. In fact, the potential benefits from wireless vehicular technologies will strongly depend on its market introduction. However, in traffic dense scenarios, a wide adoption of the technology could result in high channel congestion and system instability. Therefore, guaranteeing the future system's scalability as wireless communication technologies are gradually implemented would require the implementation of communication protocols that not only guarantee the application QoS (Quality of Service) levels, for example low latency and high transmission reliability, but also an efficient communications channel use that would reduce congestion and favour the system's scalability.

Adaptive transmission policies based on the specific operating conditions have been shown to improve the system performance (1)(2). In particular, it has been proposed to adapt the transmission power level to mitigate interferences or maintain the network connected. However, most of the adaptive transmission policies being proposed focus on the system level operation and do not adequately consider the instantaneous specific QoS requirements for traffic applications. Such requirements can be especially challenging for traffic safety applications that rely on maximum transmission reliability. In this context, the authors proposed in (3) an OPportunistic-driven adaptive RAdio resource Management (OPRAM) mechanism aimed at guaranteeing the strict traffic safety QoS requirements while efficiently using the available channel resources. While (3) analysed OPRAM's traffic safety QoS performance benefits, this work is aimed at demonstrating OPRAM's efficient use of the radio channel at the system level under large scale realistic traffic scenarios.

WIRELESS ACCESS IN VEHICULAR ENVIRONMENTS

To overcome the vehicular limitations of current wireless communication systems, the IEEE is developing an amendment to the IEEE 802.11 standard specific for the vehicular environment: the IEEE 802.11p standard or WAVE (Wireless Access in Vehicular Environments) (4). WAVE, based on seven ten-megahertz channels consisting of one control channel and six service channels in the 5.9GHz band, adapts the IEEE 802.11a standard to the vehicular environment. The service channels are used for public safety and private services, while the control channel is used as the reference channel to initially detect surrounding vehicles and establish all communication links. As a consequence, the traditional IEEE 802.11 channel scanning process is disabled and the control channel is used to periodically broadcast announcements of available application services, warning messages and safety status messages. The WAVE upper layers are being defined in the IEEE 1609 Family of Standards for Wireless Access in Vehicular Environments currently under development (5). This family of standards will specify interfaces, security and networking services, and multi-channel operations.

WAVE is based on the DCF (Distributed Coordination Function) of IEEE 802.11a and consequently makes use of the CSMA/CA medium access mechanism to grant the vehicles access to the channel. The ad hoc mode is the only operational mode allowed in the WAVE control channel, which requires distributed channel management policies. In addition, the control channel's reference status to initiate any V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) communications or to even detect the presence of a nearby vehicle could result in a high channel load. Such potential channel congestion together with the strict traffic safety needs requires the definition of advanced radio resource and channel management policies that efficiently uses the WAVE control channel. It is important to note that ensuring the efficient use of the WAVE control channel will improve the system's scalability as V2V and V2I communication technologies gradually penetrate the market.

OPPORTUNISTIC-DRIVEN TRANSMISSION TECHNIQUES

To define a wireless vehicular communications policy capable to achieve the strict traffic safety QoS requirements while efficiently using the communications channel, the authors proposed OPRAM (3). OPRAM is an opportunistic communications policy that adapts the vehicles transmission parameters based on its position and proximity to an area where a potential collision could occur. This adaptation is decentralised and can be based on the information provided by digital maps, surrounding vehicles or any other source. In particular, for traffic safety applications, the OPRAM proposal adapts the transmission power and packet rate only in a small region, named AR (Algorithm Region), before the critical distance (*CD*). This critical distance is the minimum distance to a potential collision area at which a warning message needs to be received in order to provide the driver with sufficient time to stop and avoid the accident. A target scenario for OPRAM's application is intersections (see Figure 1 (a)) where over 25% of road accidents occur in the US. By modifying the communications parameters in AR, OPRAM aims to guarantee the successful reception from a potentially colliding vehicle of at least one broadcast safety message before reaching *CD* in 99% of the cases. As illustrated in Figure 1 (a), OPRAM transmits N_T broadcast safety messages in AR at a transmission power equal to that needed to ensure that all N_T messages are correctly received with an equal probability p_e. As further explained in (3), p_e has been selected to ensure that at least one of the N_T transmitted messages in AR is successfully received by the vehicle approaching the intersection and that represents a potential collision risk. As shown in Figure 1 (a), guaranteeing the same packet reception probability p_e for the N_T broadcast safety messages requires their transmission at different power levels. Outside AR, OPRAM maintains a constant 0.25W transmission power level and a constant packet transmission rate of 10 packets/s. These communication conditions are sufficient to guarantee a vehicle's connectivity with the vehicles located along the same street in a 150m range under Line of Sight (LOS) propagation conditions, as established by the WAVE guidelines for cooperative collision warning applications (6).

From a system perspective, an important foreseen OPRAM benefit is channel congestion control. In fact, OPRAM allows maintaining the communications parameters to their minimum level to guarantee the required QoS levels. Such radio resource efficient use is also expected to result in an important channel congestion control which will be extremely useful to guarantee the system's scalability in particular in traffic dense vehicular scenarios. As illustrated in Figure 1 (b), only the vehicles approaching the intersections will increase their transmission power and resources following the OPRAM proposal. Outside AR, communications resources are kept to the minimum levels required by the WAVE guidelines.

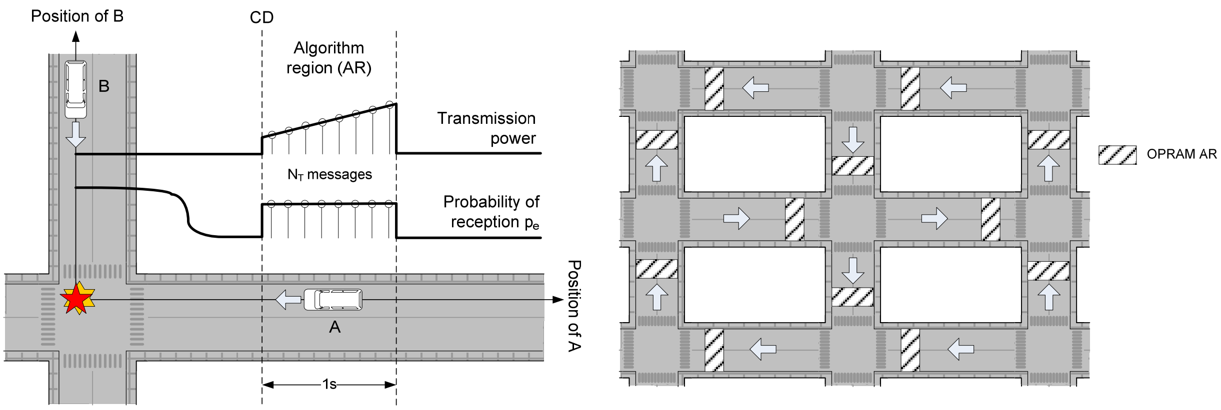

Figure 1. (a) OPRAM local configuration for traffic safety.
(b) OPRAM AR zones for traffic safety in a Manhattan-like scenario.

TRAFFIC URBAN SCENARIO

In order to demonstrate the feasibility and potential benefits derived from the use of adaptive opportunistic transmission policies, this work considers a Manhattan-like urban scenario consisting of a uniform grid of 15x15 blocks. Although a relatively large scale simulation test site is being considered, the performance is only monitored in the central 5x5 blocks in order to avoid boundary effects. This scenario has been selected mainly because of its challenging propagation constraints due to the presence of obstacles like buildings, which enforce using high transmission power levels. All simulated vehicles are WAVE-equipped and periodically transmit broadcast safety beacons on the WAVE control channel for traffic safety purposes.

All packets are transmitted at 6Mpbs following the 1/2 QPSK transmission mode defined for the WAVE control channel (4).

The studied scenario has been analysed through a wireless vehicular simulator developed in the open source networking platform ns2 (7). In order to ensure realistic evaluation scenarios, accurate radio propagation models are considered following the observations in (8) and (9). For that reason, a detailed urban micro-cell propagation model developed in the WINNER project (10) that considers pathloss, correlated shadowing (shadowing correlation is introduced through the Gudmundson's model (11)) and multipath fading has been implemented. Despite not being developed for V2V communications, the operating conditions of the WINNER urban micro-cell model are to the authors' knowledge those that currently best fit the V2V communications scenario[1]. Moreover, despite considerable progress in V2V channel modelling, to the authors' knowledge there is currently no complete V2V channel model that considers pathloss shadowing and multipath fading. This works models the radio transmission effects through the inclusion of the PER (Packet Error Rate) performance for the WAVE control channel transmission mode, following the results obtained in (12).

To evaluate the system level performance and benefits of adaptive and opportunistic wireless vehicular communication policies, two mobility models have been implemented. In the first one, vehicles are uniformly distributed along the streets and move at a constant and equal speed of 70km/h; the emulated traffic density is equal to 27 vehicles per kilometre road. This simplistic scenario is targeted to analyse opportunistic transmission policies under the same configuration for all vehicles; this case will result in uniform critical distances and consequently transmission power levels. To consider a more realistic scenario where the vehicle's movement is influenced by the surrounding traffic, a second mobility model based on the microscopic road traffic simulator SUMO (Simulation of Urban Mobility) (13) has been considered. In this case, a vehicular traffic density of 7 vehicles per kilometre road is simulated.

OPRAM TRAFFIC SAFETY PERFORMANCE

To demonstrate OPRAM's traffic safety and channel management's efficiency, its performance is compared against that achieved using fixed transmission power levels; in particular, transmission powers of 0.25W and 2W are considered. As previously explained, 0.25W is a WAVE-defined minimum transmission power threshold. On the other hand, 2W is the power needed to guarantee that two vehicles approaching an intersection with a risk of collision received in 99% of the cases a broadcast safety message before reaching *CD* for a vehicle's speed of v=70km/h and a driver's reaction time of RT=0.75 seconds[2].

In this work, OPRAM is applied with N_T=10 packets transmitted in AR, which is equal to 1 second. OPRAM's operation and transmission power levels are illustrated in Figure 2 (a) following the OPRAM's configuration described in (3) and two additional mechanisms to compensate negative channel congestion and channel correlation effects on OPRAM performance. On one hand, channel congestion increases packet losses due to packet collisions, decreasing the packet reception probability p_e in AR and, consequently, the resulting system QoS level. In order to guarantee the target p_e and the desired QoS level despite such packet collisions, the OPRAM transmission power level in AR needs to be

[1] The WINNER model is defined for the 5GHz band and considers transmitter antenna heights as low as 5m.
[2] Different fixed power levels are necessary if any of these two conditions are changed.

increased under congested channel situations (see (14) for further details). On the other hand, an additional compensation mechanism is needed to overcome the negative effects of radio channel correlation. Such compensation policy is necessary since OPRAM's original proposal considers the probability of reception of the N_T packets transmitted in AR to be independent of each other. However, realistic radiocommunications are generally characterised by significant channel correlation levels.

Figure 2 (b) shows the cumulative distribution function (CDF) of the distance to the intersection at which the first message from a potentially colliding vehicle is received for *v*=70km/h and *RT*=0.75s using OPRAM or fixed transmission power levels and considering the uniform mobility model. As it can be observed, OPRAM and a 2W fixed transmission power are capable to guarantee that 99% of the vehicles receive a broadcast safety message alerting of a potential road danger before reaching *CD*. On the other hand, a transmission power of 0.25W importantly decreases the traffic safety performance.

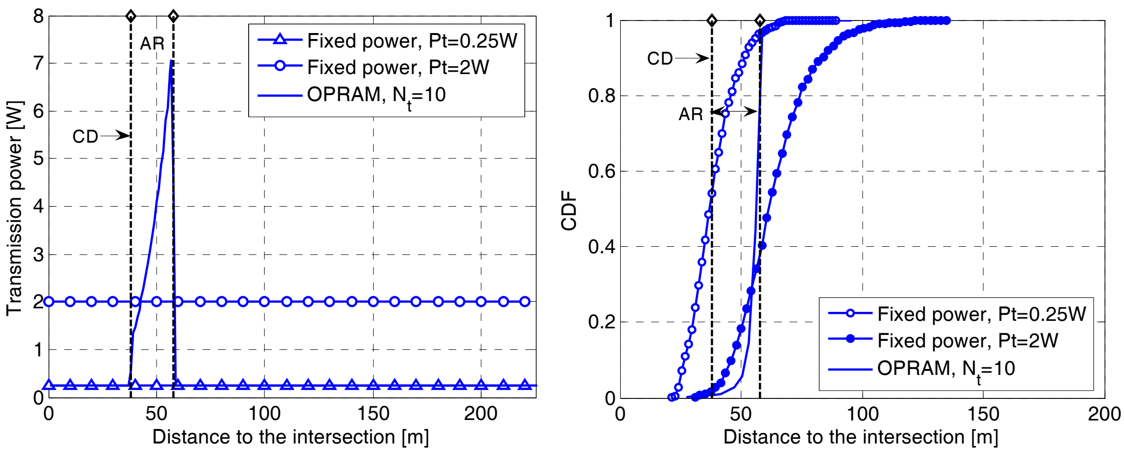

Figure 2. (a) Transmission power levels as a function of the distance to the intersection for uniform speed v=70km/h and RT=0.75s. (b) CDF of the distance to the intersection at which the first message from a potentially colliding vehicle is received for v=70km/h and RT=0.75s.

It is important to note that OPRAM is capable to achieve the same traffic safety QoS performance than a 2W fixed transmission power, while transmitting at the minimum transmission power outside AR. OPRAM is then expected to significantly reduce the channel's occupancy and congestion, thereby improving the technology's scalability perspectives.

Although this work aims to demonstrate the potential system level benefits of the OPRAM proposal over fixed transmission power policies, the OPRAM technique offers itself an interesting option to trade-off transmission power and packet data rate by modifying its configuration parameters (e.g. N_T or *AR*). In fact, increasing the number of packets transmitted in AR decreases considerably the transmission power levels required to achieve the target traffic safety QoS level, but increases packet collisions. Future work will investigate the best OPRAM configuration with minimum channel's occupancy and congestion.

OPRAM SYSTEM LEVEL CHANNEL USE

This section is focused on demonstrating OPRAM's efficient channel use. To this aim, OPRAM's system level performance is evaluated under the two mobility models previously described. First of all, it is important to note that despite OPRAM's increase in transmission power above 2W inside AR, such increase only affects a small percentage of packets as depicted in Figure 3. In fact, the use of OPRAM results in that only 9% of the transmitted packets used a transmission power above the 0.25W minimum threshold established in the WAVE guidelines.

OPRAM's operation results in a significant average transmission power reduction compared to a fixed 2W transmission power level. This results in a lower transmission range and a lower number of vehicles receiving (with or without error) a given packet. At this stage, it is worthwhile highlighting that in wireless vehicular communication systems where a potential high number of vehicles will be transmitting over the same channel, what is important is not to receive a high number of packets but to receive the packets that are relevant to each vehicle while minimising the channel's interference that each vehicle can cause. Such interference can be reduced by preventing vehicles to transmit messages to distant vehicles that will not be influenced by the information being conveyed.

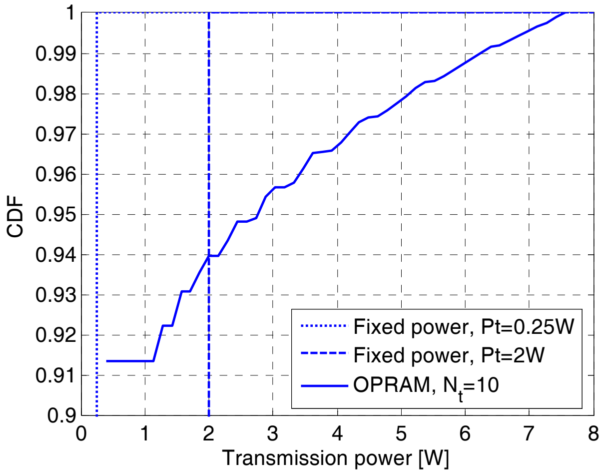

Figure 3. CDF of the transmission power level.

Uniform Mobility Model

Figure 4 shows the average number of packets detected per second and per kilometre in the scenario under evaluation. As it can be observed, the OPRAM transmission power increase inside AR augments by only 8% the number of packets being detected with respect to a 0.25W fixed transmission policy. On the other hand, using the 2W fixed transmission power results in an increase close to 80%. Such significant increase is observed without any traffic safety performance improvements with respect to OPRAM, which highlights that OPRAM results in a more efficient channel use by avoiding the unnecessary reception of packets that do not provide relevant information for the application at hand (in this case, intersection collision avoidance). As a result, OPRAM's operation reduces channel occupancy and congestion, and improves the system's scalability.

Contrary to the results observed for a 2W fixed transmission power, Figure 5 (a) shows that OPRAM only slightly increases the number of packets from very distant vehicles, resulting in the efficient channel management previously described. OPRAM's major difference with respect to the minimum transmission power threshold is obtained under NLOS (Non LOS) conditions. The difference is due to the temporary OPRAM transmission power increases necessary to satisfy the traffic safety QoS requirements.

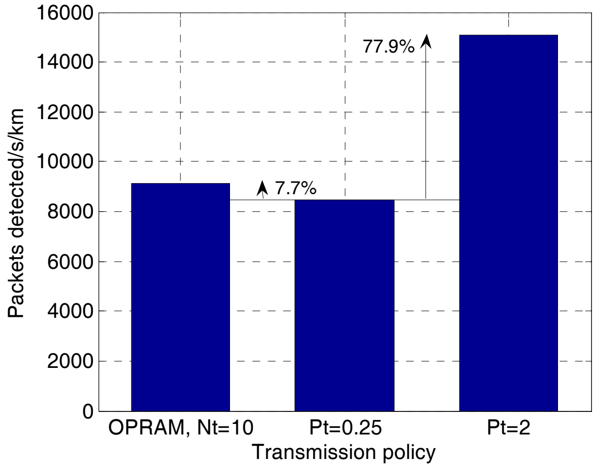

Figure 4. Average number of packets detected per second and per kilometre.

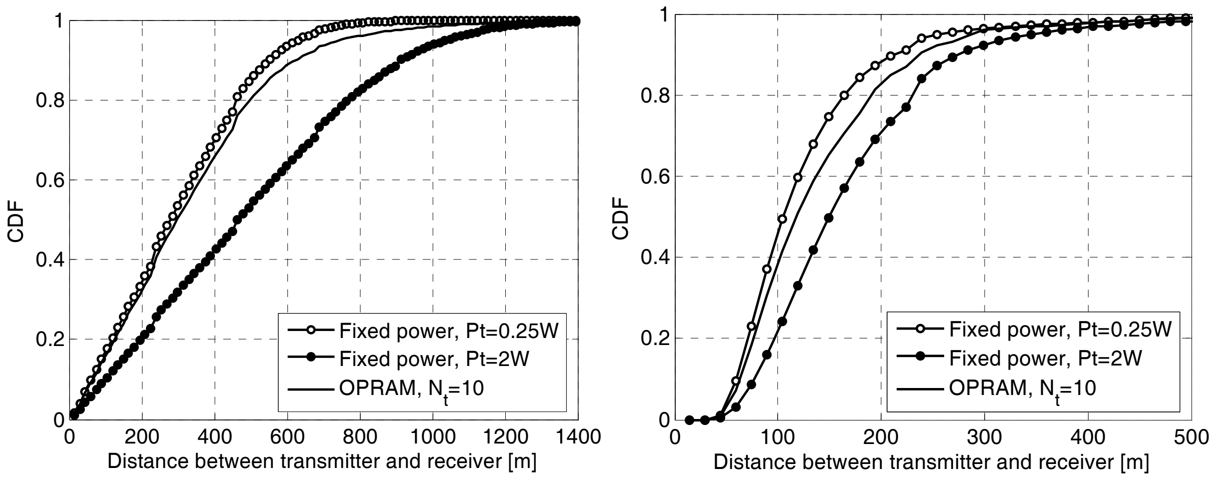

Figure 5. CDF of the distance between transmitter and receiver for all detected packets.
(a) LOS conditions. (b) NLOS conditions.

The inefficient channel management observed with fixed transmission power policies with respect to OPRAM is further emphasized when analysing the amount of packets dropped due to packet collisions (mostly due to the well known hidden terminal problem) or channel errors. Figure 6 shows the status distribution of detected packets, which can be classified as follows:

- RCV: correctly received packets.
- ERR: packets received with error due to only radio channel error.
- COL: packets received with error due to only packet collision.
- ECO: packets received with error due to both radio channel error and collision.
- TRX: packets received with error because the vehicle was transmitting its own packet when it received the packet.

As it could be expected, the results illustrated in Figure 6 (a) show that increasing the transmission power results in a larger number of packets being received, but also in an absolute higher number of packets received with error due to either radio transmission effects or channel collisions. Observing Figure 6 (a) and Figure 2 (b) clearly highlights that while OPRAM's slight increase in the number of detected packets (includes RCV/ERR/COL/ECO/TRX) compared to using the fixed minimum transmission power threshold results in a significant traffic safety QoS improvement, further increasing the number of detected packets (e.g. through higher transmission power levels) does not result in additional application QoS improvements. Instead, an unnecessary constant high transmission power level increases the channel's occupancy with information not relevant to all vehicles receiving it, thereby increasing the channel congestion and reducing the potential system's scalability.

The OPRAM system level benefits are further emphasized in Figure 6 (b), where the detected packets are analysed in relative terms. This figure clearly shows that using constant high transmission power levels increases the probability of packet collisions and hence channel congestion. On the other hand, OPRAM, which only increases transmission power levels when necessary to satisfy the target QoS levels, results in a packet collision probability similar to that achieved with the minimum transmission power threshold. These results clearly indicate that the opportunistic communications parameters adaptation improves the system's efficiency while guaranteeing the target QoS levels, in addition to reducing energy consumption and minimising exposure to electromagnetic fields.

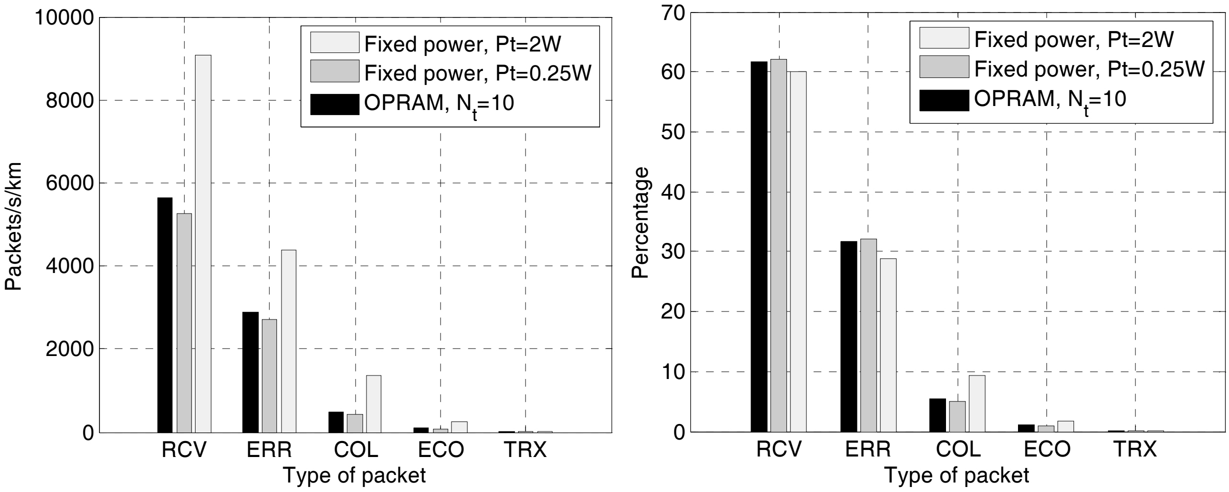

Figure 6. System level packet's reception distribution. (a) Absolute number of packets per second and per kilometre. (b) Percentage of packets with respect to the total number of packets detected.

An illustration of the geographical distribution of packet collisions is depicted in Figure 7. This figure confirms OPRAM's low packet collision probability and shows that such probability increases at the intersections, where a higher number of vehicles experience LOS propagation conditions.

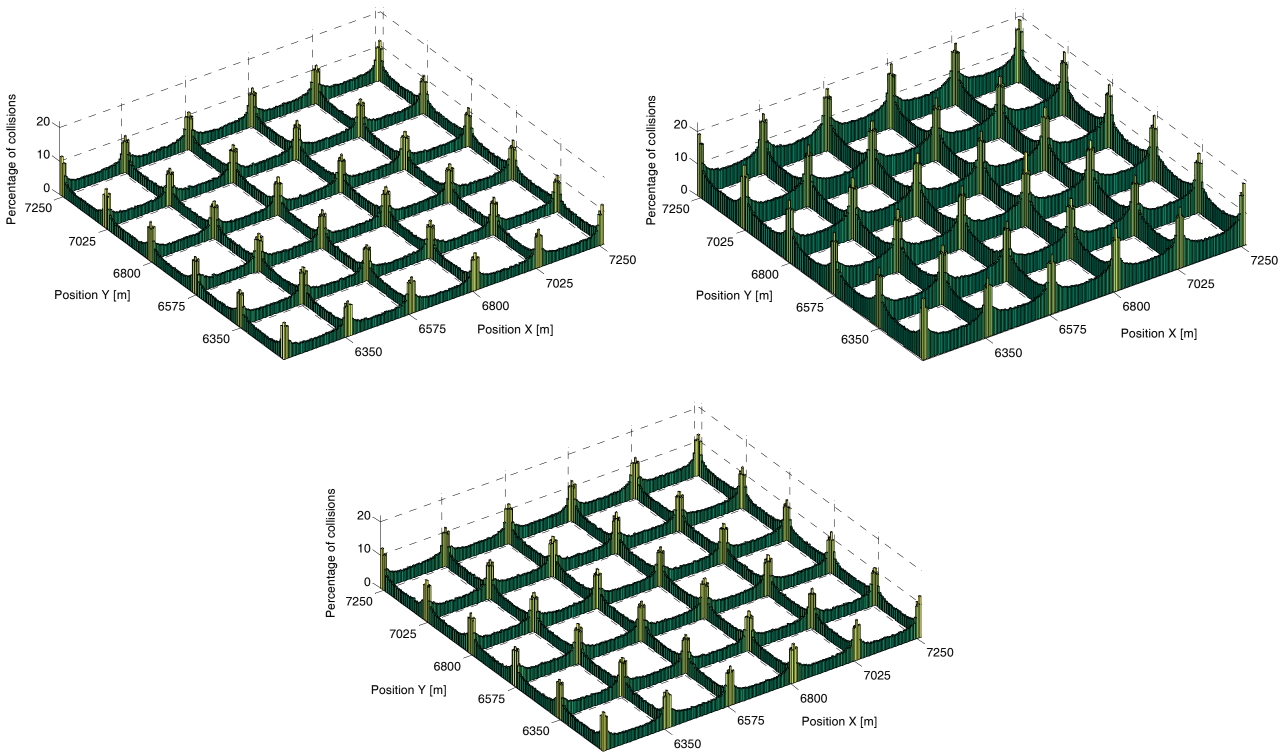

Figure 7. Geographical distribution of packet collisions.
(a) Fixed power, Pt=0.25W. (b) Fixed power, Pt=2W. (c) OPRAM, N_T=10.

Realistic Mobility Model

To analyse whether the conclusions previously extracted can be influenced by the employed traffic mobility model, this section reviews the previous study using mobility traces extracted from SUMO. As previously mentioned, a uniform mobility model results in identical critical distances and OPRAM transmission power levels inside AR. On the other hand, realistic traffic simulators are able to capture a vehicle's movement dependence on its surrounding traffic. In this case, the vehicle's speed will vary and consequently the critical distance and the application of OPRAM. In particular, reduced traffic speeds derived from instantaneous traffic congestion can result in a reduction of *CD* and OPRAM transmission power levels. This is the case because all vehicles equipped with digital maps are continuously monitoring their speed and distance to the next intersection. Based on their speed and the calculated critical distance[3], OPRAM dynamically estimates the required transmission power levels so that the N_T packets transmitted inside AR guarantee the established QoS performance. Figure 8 shows that the OPRAM transmission power levels are further reduced under realistic traffic conditions.

[3] In this work it is computed following a uniform deceleration model.

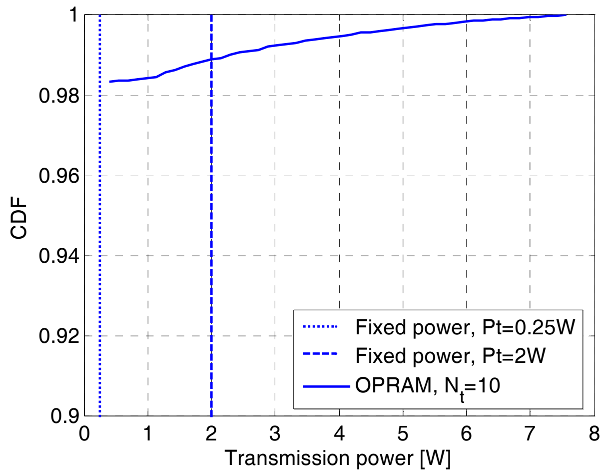

Figure 8. CDF of the transmission power level with the realistic mobility model.

Figure 9 shows that despite OPRAM's lower transmission levels under realistic traffic patterns, OPRAM is still capable to guarantee that 99% of vehicle approaching an intersection with a risk of collision received at least one broadcast safety message from the potentially colliding vehicle before reaching the critical distance.

Despite a decrease in the number of OPRAM detected packets due to its transmission power reduction, Figure 10 (a) shows that under realistic traffic conditions OPRAM only needs to slightly increase the number of detected packets compared to the minimum transmission threshold policy, in order to achieve the traffic safety QoS target[4]. As it was the case under simplistic mobility patterns, further increasing the transmission power only results in a higher channel occupancy and channel congestion probability (see Figure 10 (b)) due to the reception of irrelevant information from distant vehicles that only contributes to overloading the communications channel.

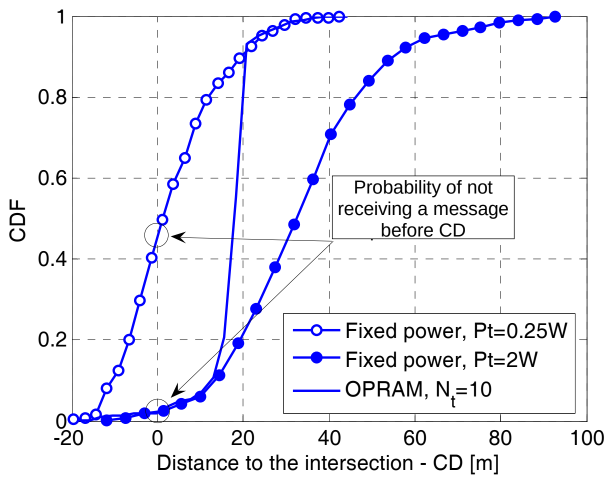

Figure 9. CDF of the distance to the intersection minus CD at which the first message from a potentially colliding vehicle is received for RT=0.75s.

[4] It is important to note that the absolute received packet figures are also influenced by different traffic densities under simplistic and realistic traffic mobility models.

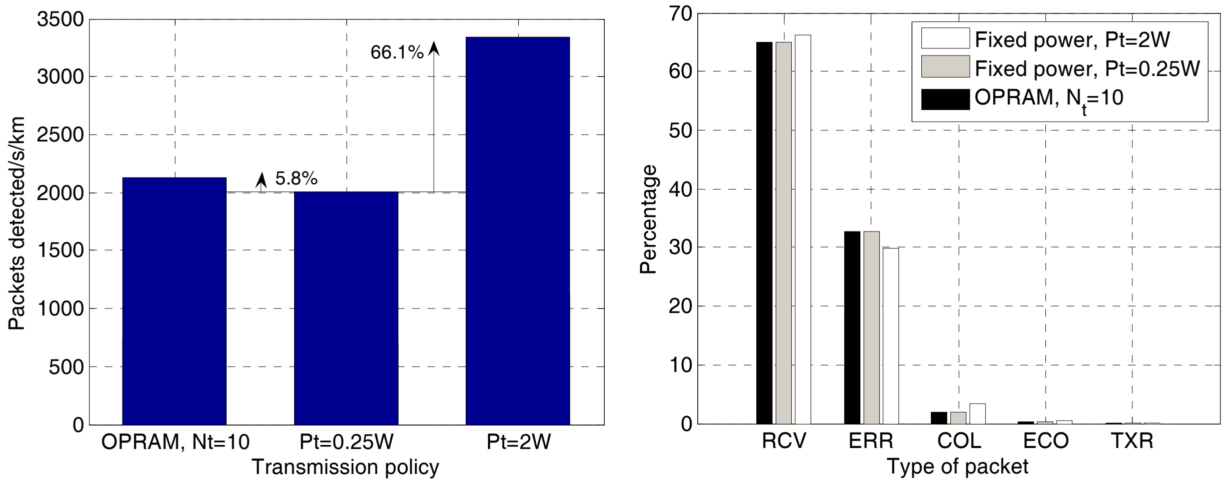

Figure 10. (a) Average number of packets detected per second and per kilometre. (b) System level packet's reception distribution: percentage of packets with respect to the total number of packets detected.

CONCLUSIONS

This work has compared the system level performance of fixed and opportunistic transmission techniques for wireless vehicular communication systems. While both transmission policies could satisfy the required traffic safety QoS levels, the obtained results demonstrate that the use of opportunistic transmission techniques, such as the authors' OPRAM proposal, efficiently uses the radio resources by dynamically adjusting the communications parameters to guarantee that only the vehicular relevant information is detected. As a result, adaptive transmission techniques have been shown to not only significantly reduce transmission powers and exposure to electromagnetic fields without sacrificing QoS levels, but also to increase the channel's efficient use and consequently the wireless vehicular system's scalability perspectives.

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REFERENCES

(1) M. Sepulcre and J. Gozalvez, "Dimensioning WAVE-based inter-vehicle communication systems for vehicular safety applications", *Proceedings of the 4th International Symposium on Wireless Communications Systems ISWCS*, September 2006, Valencia (Spain), pp 312-316.

(2) G. Caizzone, P. Giacomazzi, L. Musumeci and G. Verticale, "A power control algorithm with high channel availability for vehicular ad hoc networks", *Proceedings of the*

IEEE International Conference on Communications ICC, May 2005, Seoul (Korea), pp 3171-3176.

(3) J. Gozalvez and M. Sepulcre, “Opportunistic-Driven Adaptive Radio Resource Management Technique for Efficient Wireless Vehicular Communications”, *Proceedings of the 1st IEEE International Symposium on Wireless Vehicular Communications WiVeC*, September 2007, Baltimore (USA), pp 2116-2120.

(4) IEEE P802.11p/D0.21, “Draft Part 11: WLAN MAC and PHY Specifications: Wireless Access in Vehicular Environments (WAVE)”, IEEE Standards Association, June 2005.

(5) IEEE 1609, “Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE)”, IEEE Standards Association, 2006.

(6) Vehicle Safety Communications Consortium, “Vehicle safety communications project task 3 - Final Report: Identify intelligent vehicle safety applications enabled by DSRC”, *DOT HS 809 859*, March 2005.

(7) The Network Simulator - ns-2. Website: http://www.isi.edu/nsnam/ns/

(8) M. Sepulcre and J. Gozalvez, “On the importance of radio channel modeling for the dimensioning of wireless vehicular communication systems”, *Proceedings of the 7th International Conference on ITS Telecommunications ITST*, June 2007, Sophia Antipolis (France), pp 207-211.

(9) M. Torrent-Moreno, F. Schmidt-Eisenlohr, H. Füßler, H. Hartenstein, “Effects of a Realistic Channel Model On Packet Forwarding in Vehicular Ad Hoc Networks”, *Proceedings of IEEE Wireless Communication and Networking Conference WCNC*, April 2006, Las Vegas (USA), pp 385-391.

(10) WINNER Wireless World Initiative New Radio, “D1.1.1. WINNER II interim channel models”, Public Deliverable. Website: https://www.ist-winner.org/index.html

(11) M. Gudmundson, “Correlation model for shadow fading in mobile radio systems”, Electronic Letters, 27(23), pp 2145-2146, November 1991.

(12) Y. Zang, L. Stibor, G. Orfanos, S. Guo and H.J. Reumerman, “An error model for inter-vehicle communications in high-way scenarios at 5.9GHz”, *Proceedings of the 2nd International workshop on Performance evaluation of wireless ad hoc, sensor, and ubiquitous networks*, October 2005, pp 49-56.

(13) SUMO - Simulation of Urban Mobility. Website: http://sumo.sourceforge.net/

(14) M. Sepulcre and J. Gozalvez, “Wireless Vehicular Adaptive Radio Resource Management Policies in Congested Channels”, *Proceedings of the 4th IEEE International Symposium on Wireless Communication Systems, ISWCS*, October 2007, Trondheim (Norway), pp 380-384.