On the Importance of Radio Channel Modeling for the Dimensioning of Wireless Vehicular Communication Systems

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Abstract— **Vehicle-to-vehicle and vehicle-to-infrastructure wireless communications are currently under development to improve traffic efficiency and safety. The time-critical nature of road safety applications imposes the need to accurately dimension the operation and performance of wireless vehicular communication systems. Given that radio propagation modeling has been shown to importantly affect the performance of traditional mobile and wireless communication systems, this work investigates its impact on the dimensioning of traffic safety wireless vehicular communications by separately analyzing the contributions of pathloss, shadowing and fast fading.**

Index Terms— **wireless vehicular communications, channel modeling, system simulations.**

I. Introduction

WIRELESS vehicular communications have been identified as a promising technology for deploying Intelligent Transportation Systems (ITS) aiming at improving traffic safety, efficiency and quality. To exploit the potential of this new technology, the IEEE is currently developing an amendment to the IEEE 802.11 standard (IEEE 802.11p), usually referred as Wireless Access in Vehicular Environments (WAVE) [1]. The WAVE proposal 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 communication links between an RSU (Road-Side Unit) and an OBU (On-Board Unit) or between OBUs. In particular, the control channel is used by OBUs and RSUs to periodically broadcast announcements of available application services, warning messages and safety status messages. OBUs reply to broadcast messages using the service channel listed on the announcement since no replies are allowed to be transmitted on the control channel. In this context, the use of wireless vehicle-to-vehicle communications will enable vehicles that are not within direct sight of each other to exchange safety messages that will help prevent any potential road traffic danger.

Traffic safety applications are characterised by very severe low latency requirements. As a result, any investigation on the use of wireless vehicular communications for safety applications requires the maximum possible accuracy to ensure that the achieved results closely match those that could be obtained under real operating conditions. Previous work has shown that radio channel modeling can have a significant impact on the study and dimensioning of traditional mobile and wireless communication systems. For example, the work reported in [2] highlighted the important effect of fast fading modeling at the system level when analyzing the performance and operation of adaptive radio link techniques. Similar conclusions where obtained in [3], where the impact of shadowing correlation modeling was analysed in system level investigations. The work reported in [4] has also shown the strong effect of the channel modeling accuracy on the performance of communication protocols in wireless ad-hoc networks. In this context, and considering the fact that channel modeling accuracy can be particularly relevant when assessing latency for time critical applications, this work studies the effect of channel modeling on the dimensioning of wireless vehicular communications devoted to improve road safety. To conduct this investigation, this paper differentiates the effect of pathloss, shadowing and fast fading modeling on the dimensioning of wireless vehicle-to-vehicle communications.

II. Radio Channel Modelling

Giving that the research and development of fully operational wireless vehicular systems are yet at their early stages, most of the published work on this topic has been conducted using simple propagation models merely including the pathloss and shadowing effects. The pathloss represents the local average received signal power relative to the transmit power as a function of the distance between the transmitter and the receiver. The shadow fading models the effect of surrounding obstacles on the mean signal attenuation at a

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given distance. While different pathloss models can be found in the literature, the shadowing has been shown to follow a log-normal distribution with a zero mean and a standard deviation σ that depends on the operating conditions.

Due to the widespread use of the ns2 simulator within the wireless vehicular research community, its radio channel model has been used as the reference model against which to compare the obtained results with accurate and realistic radio channel models. The ns2 simulator considers a log-distance path loss model with log-normal shadowing. Following the indications in [5] for urban scenarios, this model has been used with a pathloss exponent equal to 3.5 and a 4dB shadowing standard deviation.

The work reported in [6] proposed a more realistic model for urban micro-cell scenarios that differentiates between LOS (Line of Sight) and NLOS (Non-Line of Sight) conditions. The pathloss expression for LOS conditions is

$$PL_{LOS}(d[m]) = \begin{cases} 22.7\log_{10}(d[m]) + 41 + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d < R_{bp} \\ 40\log_{10}(d[m]) + 41 - 17.3\log_{10}(R_{bp}) + 20\log_{10}(f[GHz]/5) \\ \quad if \quad d \geq R_{bp} \end{cases} \quad (1)$$

where

$$R_{bp} = 4\frac{(h_A - 1)(h_B - 1)}{\lambda} \quad (2)$$

d[m] is the distance between transmitter and receiver, h_A and h_B are their respective antenna heights and f is the carrier frequency. For NLOS conditions, the pathloss can be expressed as

$$PL_{NLOS}(d_A[m], d_B[m]) = PL_{LOS}(d_A[m]) + 20 - 12.5n_j + 10n_j\log_{10}(d_B[m]) \quad (3)$$

where

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

and d_A and d_B are the transmitter and receiver distances to the closest intersection.

The work reported in [6] also indicates that the shadowing standard deviation should be set equal to 3dB and 4dB for LOS and NLOS conditions respectively. However, Gudmunson demonstrated that the shadowing is a spatially correlated process with an exponential autocorrelation function [7]. To account for the shadowing correlation properties, the Gudmunson model has also been implemented for this work.

Finally, the fast fading effect resulting from the reception of multiple replicas of the transmitted signal at the receiver has also been shown to have significant impact on the performance of mobile and wireless communication systems. As a result, a Ricean fast fading implementation following the observations reported in [6] has also been considered. Following the literature, for NLOS conditions the Ricean distribution becomes a Rayleigh distribution.

To illustrate the radio propagation effects, Fig. 1 plots the combined effect of pathloss, correlated shadowing and fast fading on the received signal power for a moving vehicle receiving packets under NLOS conditions.

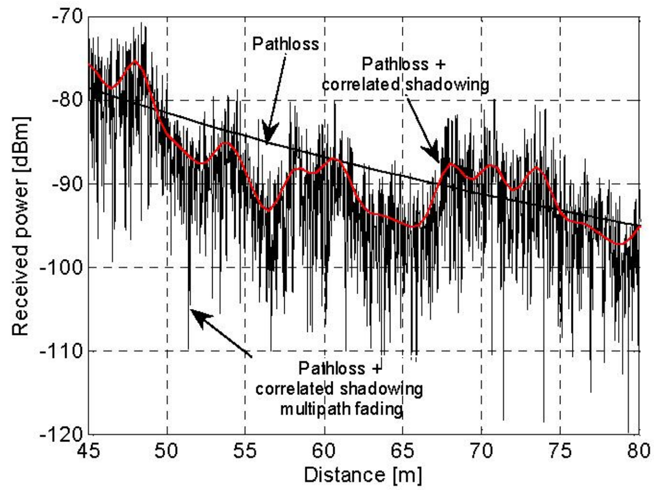

Fig. 1. Wireless propagation effects on the received power [dBm].

III. Evaluation Scenario

A. Wireless Access for Vehicular Environments

The WAVE system evolves the 802.11a standard introducing new PHY and MAC techniques improving its operation in vehicular environments. Like 802.11a, WAVE uses Orthogonal Frequency Division Multiplexing (OFDM) with data transmission rates of 3, 4.5, 6, 9, 12, 18, 24, and 27 Mbps in 10 MHz channels. The standard uses 52 subcarriers that are modulated using binary or quadrature phase shift keying (BPSK/QPSK), 16-quadrature amplitude modulation (QAM), or 64-QAM. Forward error correction coding (convolutional coding) is used with coding rates of 1/2, 2/3, or 3/4. WAVE broadcasts traffic-safety messages using its control channel. This channel transmits at a data rate of 6Mbps in a 10MHz channel, which corresponds to a QPSK transmission mode with coding rate of ½.

In terms of the MAC layer, WAVE also reuses the IEEE 802.11.a access method based on CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). To alleviate the hidden terminal problem, WAVE maintains the RTS/CTS (Request-To-Send/Clear-To-Send), although it is disabled on the control channel given its broadcast nature. Consequently, all wireless nodes using the control channel are subject to the hidden terminal problem, which increases the risk of channel congestion.

B. Simulation environment

To conduct this investigation, the ns2 simulator has been employed emulating the critical intersection scenario illustrated in Fig. 2. This scenario represents two vehicles moving towards an intersection with a risk of collision. To detect each other's presence, the vehicles periodically broadcast basic safety messages on the WAVE control channel. In terms of network load, two scenarios have been emulated. The first one, modeling only the two vehicles approaching the intersection with a risk of collision, represents a scenario where radio transmission errors are just due to propagation effects and not channel congestion. The second scenario also considers other surrounding vehicles in order to emulate real conditions where numerous vehicles broadcast their safety messages through the same channel, resulting in resulting in higher channel congestion. In this work, each scenario under evaluation has emulated more than 5000 iterations to ensure that results with good statistical properties have been obtained. Table I summarises the main simulation parameters, where traffic density zero denotes the absence of interferers in the scenario.

To reduce the complexity of system level simulations, the effects of the physical layer resulting from the probabilistic nature of the radio environment are generally modeled by means of simplified Look-Up Tables (LUTs). These LUTs, extracted from link level simulations, map the Packet Error Rate (PER) to the experienced channel quality conditions. In this work, the PER performance for the WAVE control channel transmission mode has been included at the system level, following the results from [8] and illustrated in Fig. 3. In this figure, the PER performance is shown as a function of the effective Signal to Interference and Noise Ratio (SINR), E_{av}/N_0, which represents the SINR reduced by a factor α to model the effect introduced by the cyclical prefix attached to each OFDM symbol.

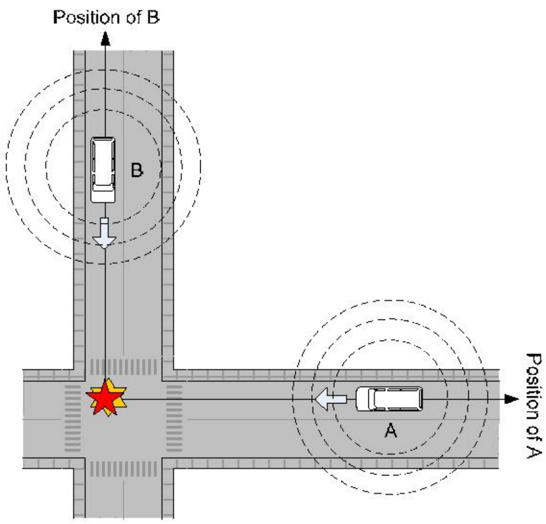

Fig. 2. Intersection scenario

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Speed [km/h]	70
Traffic density [veh/km/lane]	0, 100
Transmission power [W]	0.75, 1.5
Emergency deceleration [m/s^2]	8
Packet size [bytes]	100
Packet rate [pkts/sec]	10
Floor noise [dBm]	-90

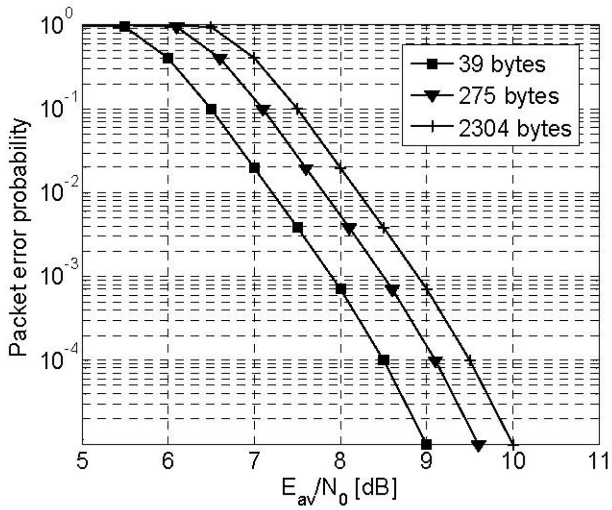

Fig. 3. Packet Error Rate for the WAVE 6Mbps transmission mode (QPSK and ½ coding rate)

IV. RESULTS

As it has been previously explained, the aim of this work is to analyse the impact of the different radio propagation effects on the performance and dimensioning of wireless vehicular communications devoted to traffic safety applications. In this context, this work uses as a reference the basic propagation model employed in the ns2 simulator, and sequentially analyses the effect of including more realistic pathloss, shadowing and fast fading models. This approach will enable identifying the most relevant propagation effects with regard of accurately dimensioning wireless vehicular systems designed for improving road safety.

For the scenario shown in Fig. 2, it is important that vehicles approaching an intersection where a risk of collision might occur, receive a broadcast WAVE safety message from the potentially colliding vehicle with sufficient time for the driver to react. Fig. 4 shows, for different radio propagation models, the cumulative distribution function (CDF) of the distance from the intersection at which a vehicle correctly receives the first broadcast WAVE safety message from the potentially colliding vehicle. The figure also shows the critical distances (CD), i.e. the distances from the intersection at which a vehicle needs to have correctly received a safety message to avoid an accident, considering driver's reaction times (RT) of 0.75 and 1.5 seconds and an emergency deceleration of 8m/s^2. The curves shown in Fig. 4 correspond

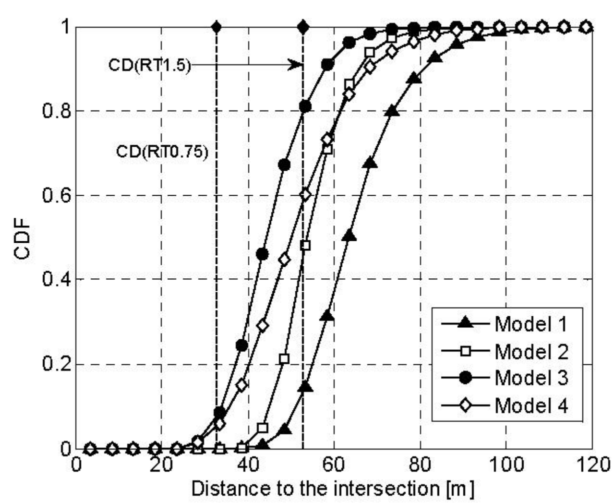

Fig. 4. CDF of the distance at which the first message is received (Pt=0.75W).

to the following radio propagation models:

- Model 1: ns2 radio model.
- Model 2: pathloss and shadowing from [6].
- Model 3: same as Model 2 but including the shadowing correlation as proposed by Gudmunson.
- Model 4: same as the Model 3 but including the fast fading.

A direct comparison of the first and second models shows, that in the considered scenario and operating conditions, there is a significant difference in the results obtained considering the log-distance pathloss model used in ns-2 and the model proposed in [6]. In fact, the realistic pathloss model produces higher power level loses at long distances, while both present a similar behaviour at close distances.

The comparison of the traffic safety wireless vehicle-to-vehicle communications dimensioning for the 2nd and 3rd radio propagation models in Fig. 4 shows that the shadowing correlation diminishes the channel variability and significantly affects the obtained results; in particular, the shadowing correlation reduces the number of broadcast safety messages correctly received before reaching the intersection (see Fig. 5), which increases the risk of collision (see Fig. 4). In fact, while the first broadcast safety message was always received before reaching the critical distance for short reaction time values (RT=0.75s) if shadowing correlation was not modeled, modeling shadowing correlation induces that in around 8% of emulated iterations (vehicles approaching a dangerous intersection), the first broadcast safety message was not received with sufficient time for the driver to react. These results clearly highlight the importance of modeling the present shadowing correlation, since not doing so can significantly overestimate the performance of wireless vehicle-to-vehicle communications in terms of its ability to prevent traffic collisions.

The results shown in Fig. 4 also illustrate the effect of fast fading modeling on the dimensioning of wireless vehicular communications. It is well known that fast fading results in an increased variability of the received signal level. Although such increase can result in important instantaneous signal level drops, it can also provoke important increases in the received signal levels. The obtained results prove that the increased radio variability induced by fast fading benefits the system's ability to detect road traffic dangers. For example, while the study conducted using the 3rd radio model and a 1.5seconds driver's reaction time indicated that around 81% of vehicles did not receive any broadcast safety message while approaching the intersection, the same study using the 4th radio model reduces this figure to about 60%. In this case the obtained results show that not including the fast fading results in a pessimistic dimensioning of wireless vehicle-to-vehicle communications.

The obtained results have shown that channel variability is a positive effect to guarantee the correction reception of broadcast safety messages with sufficient time for a driver to react in front of a road danger. This positive effect is obtained since the channel variability improves the probability of

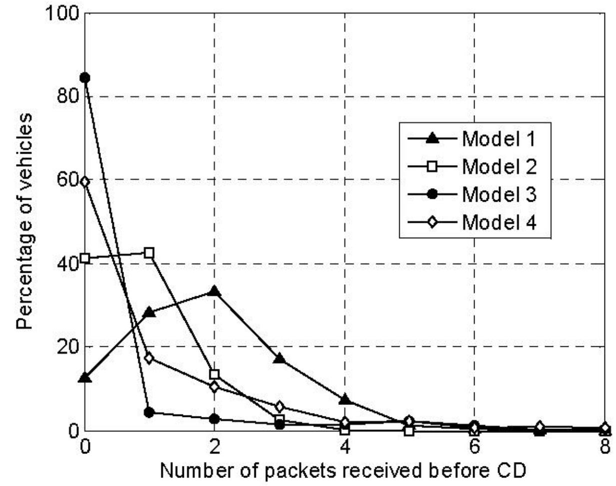

Fig. 5. Percentage of vehicles that receive a particular number of messages before the critical time corresponding to a RT=1.5s (Pt=0.75W).

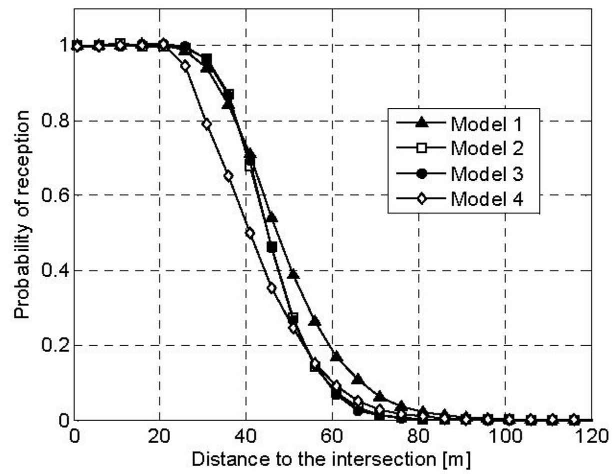

Fig. 6. Probability of successful reception (Pt=0.75W).

successfully receiving a broadcast safety message at medium and long distances from the intersection (see Fig. 6). The results illustrated in Fig. 4 show such positive effect despite the fact that the channel variability is also at the origin of a reduced probability of successful reception of a broadcast safety message for short distances to the intersection (see Fig. 6). From Fig. 6 it can be seen that modeling the shadowing correlation does not affect the results in terms of probability of successful reception at a given distance in average (Models 2 and 3). However, when analyzing specific situations such as guaranteeing the successful reception of a message before reaching the critical distance this effect is certainly non negligible.

The results shown in figures 4, 5 and 6 corresponded to a transmitting power of 0.75W. The direct comparison of figures 4 and 7 clearly show that the same conclusions in terms of the effect of the radio propagation modeling on the performance and dimensioning of wireless vehicle-to-vehicle communications can be reached for higher transmission powers (Fig. 7 corresponds to a 1.5W transmitting power).

The previous figures showed the system performance for

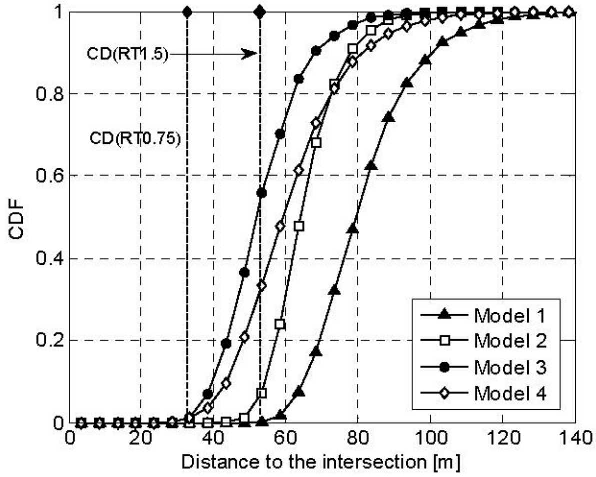

Fig. 7. CDF of the distance at which the first message is received (Pt=1.5W).

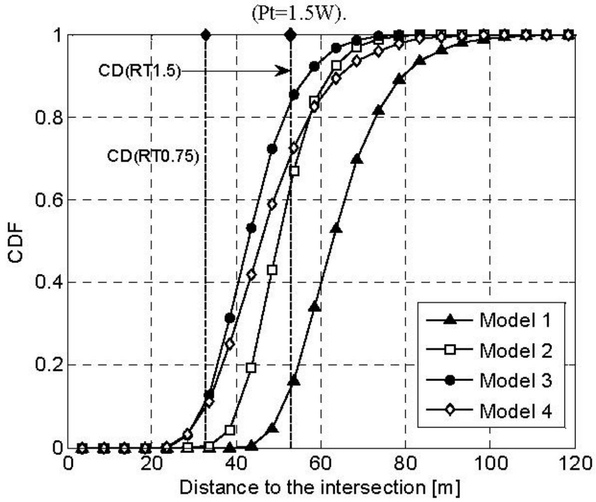

Fig. 8. CDF of the distance at which the first message is received under high channel load (Pt=0.75W).

scenarios where no surrounding vehicles were modeled. As a result, the obtained results were not affected by packet collisions and only by the channel effects. Despite the performance degradation generally observed with higher system loads, the conclusions regarding the channel modeling effect on the dimensioning of wireless vehicular communication systems are maintained, as shown in Fig. 8.

However, the influence on the system performance of surrounding vehicles transmitting on the same channel can considerably vary depending on the channel model employed. In fact, there is an important difference between the propagation models when the degradation of the probability of successful reception is analysed (Fig. 9). As it can be seen in Fig. 9 for a high traffic density, Model 1 presents a considerable difference when compared with the rest of the models. This is due to the fact that Models 2, 3 and 4 differentiate between LOS and NLOS propagation conditions, providing with a higher transmission range along the streets and hence with more potential interfering vehicles. The results obtained using Model 1 present the lowest increase of the probability of accident at the intersection when a high channel load is emulated (Fig. 4 and 8).

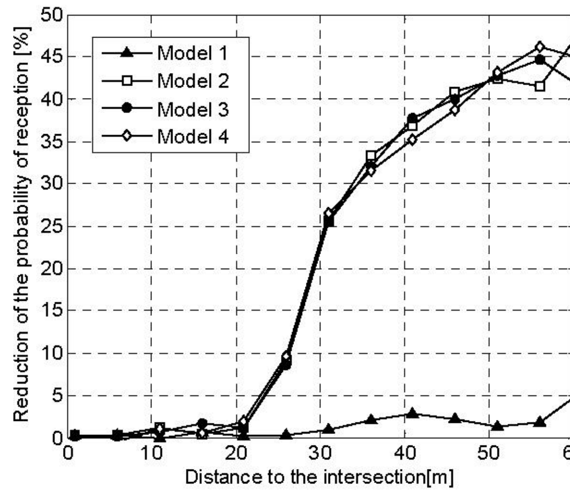

Fig. 9. Reduction of the probability of reception (Pt=0.75W).

V. Conclusions

This paper has studied the effect of the radio propagation modeling on the performance and dimensioning of wireless vehicular communications devoted to traffic safety. The obtained results have shown that conducting wireless vehicle-to-vehicle communication studies without properly modeling the radio channel conditions can significantly affect the obtained conclusions. This is particularly critical when considering road safety applications with low latency requirements. In this case, this work has shown that accurate radio propagation models properly reflecting the effects of pathloss, shadowing and fast fading need to be considered to conduct relevant investigations.

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