Assessing the Impact of a Realistic Radio Propagation Model on VANET Scenarios using Real Maps

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***Abstract*—Research in *Vehicular Ad hoc Networks* (VANETs) has found in simulation the most useful method to test new algorithms and techniques. This is mainly due to the high cost of deploying such systems in real scenarios. However, when determining the factors that should be taken into account in these simulations, some features such as using real topologies, radio signal absorption due to obstacles and channel access are rarely included, and therefore, results obtained are far from being realistic. In this paper, we present a new *Radio Propagation Model* (RPM), called *Real Attenuation and Visibility* (RAV), proposed to simulate more realistically both attenuation of wireless signals (signal power loss) and the radio visibility scheme (presence of obstacles interfering with the signal path). We evaluated this model and compared it against existing RPMs using real scenarios. Simulation results confirmed that our proposed RAV scheme can better reflect realistic scenarios.**

***Keywords*-vehicular ad hoc networks; physical layer; radio propagation model; inter-vehicle communication.**

I. Introduction

Vehicular ad hoc networks (VANETs) are wireless communication networks that do not require any sort of fixed infrastructures, offering a novel networking paradigm to support cooperative driving applications on the road. VANETs are characterized by: (a) constrained but highly variable network topology, (b) specific speed patterns, (c) time and space varying communication conditions (e.g., signal transmissions can be blocked by buildings), (d) road-constrained mobility patterns, and (e) no significant power constraints.

Deploying and testing VANETs involves high cost and manpower. Hence, relying on simulation is an useful methodology prior to actual implementation. Simulations of VANETs often involve large and heterogeneous scenarios. An important issue when creating a simulation environment in VANETs is to correctly model how vehicles move. Based on a study of mobility behavior of mobile users [1], existing models try to closely represent the movement patterns of users, providing a suitable environment for the simulation and evaluation of ad hoc communications performance.

IEEE 802.11p [2] is a draft amendment to the IEEE 802.11 standard to add *Wireless Access in the Vehicular Environment* (WAVE). It defines enhancements to 802.11 required to support *Intelligent Transportation Systems* (ITS) applications. This includes data exchange between moving vehicles and between vehicles and roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz).

In urban scenarios, and at the frequency of 5.9 GHz (i.e., the frequency band adopted by the 802.11p standard), radio signals are highly directional and will experience a very low depth of penetration. Hence, in most cases, buildings will absorb radio waves at this frequency, making communication only possible when vehicles are in line-of-sight. In order to accurately simulate how radio signals propagate in urban scenarios, we must consider the effect of the signal attenuation due to distance, along with the effect of obstacles blocking the signal propagation. Therefore, to better reflect wireless signal propagation, both attenuation and visibility schemes should be taken into account.

When taking into account visibility schemes, the topology of the map used to constrain vehicle movement is very important. Using complex layouts implies more computational time, but the results obtained are closer to real ones. Typical simulation topologies used are highway scenarios (the simplest layout, without junctions) and Manhattan-style street grids (with streets arranged orthogonally). Layouts obtained from real urban scenarios are rarely used, although they should be chosen to ensure that the results obtained are likely to be similar in realistic environments. In this paper, we present a novel model, called *Real Attenuation and Visibility* (RAV), which models radio signal propagation in a realistic way, taking into account both attenuation and visibility in real urban scenarios.

The rest of the paper is organized as follows: Section II presents several existing attenuation schemes and their limitations. In Section III we elaborate on some visibility schemes for VANETs. Section IV presents our proposed radio propagation model. Section V presents the simulation environment. Simulation results are described in Section VI. Finally, Section VII concludes this paper.

II. Limitations of Existing Attenuation Schemes

When simulating radio signal transmission, we use a mathematical formulation of the radio wave propagation as a function of parameters such as distance between vehicles and radio frequency. This formulation is called *Radio*

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TABLE I
SOME EXISTING RPMS FOR VANETS

Schemes	Remarks
Free Space	The received power is only dependent on the transmitted power, the antenna gains and on the distance between the sender and the receiver. Obstacles are not modeled.
Two-Ray Ground	Assumes that the received energy is the sum of the direct line of sight path and the reflected path from the ground. It takes no account for obstacles and sender and receiver have to be on the same plane.
Ricean and Rayleigh fading	Both models describe the time-correlation of the received signal power. Ricean model considers indirect paths between the sender and the receiver, while Rayleigh fading model considers when there is one dominant path and multiple indirect signals.
Nakagami	Signal reception power is determined using a probability distribution dependant on the distance. Configuration parameters are used to simulate different levels of fading. It can be interpreted as a generalization of the Rayleigh distribution.
Shadowing	A gaussian random variable is added to the path loss to account for environmental influences.
RPMO [3]	Radio Propagation Model with Obstacles models obstacles, but when there are no obstacles, RPMO behaves like Two-ray Ground, so distance attenuation is not taken into account.
Mahajan et al. [4]	This model behaves like Two-ray Ground, adding the influence of obstacles and the distance attenuation, but it has been designed considering the signal propagation under the 802.11b technology.

Propagation Model (RPM). An important effect experienced by wireless signal is its loss of power density as it propagates through a specific environment. To estimate the impact of signal attenuation on packet losses, we have two different possibilities: (i) to use a very detailed analytical model that relates signal strength and noise at the receiver with the *Bit Error Rate* (BER) and the *Packet Error Rate* (PER), and (ii) to directly relate the BER or PER to distance under specific channel conditions. The latter, though more restrictive, allows us to simplify calculations and thus significantly reduce simulation run-time. Hence, we call *Attenuation Schemes* to the mathematical functions which determine the strength of the received signal as a function of the distance between sender and receiver. These are directly related to the probability of a packet being successfully received.

The ns-2 simulator [5] offers some RPMs to estimate the wireless signal strength. These models assume a flat surface, where the simulation environment contains no objects that could block the signal. The RPMs included in ns-2 v2.33 are: (i) Free Space model, (ii) Two-ray Ground model, that accounts for multipath reflection from the ground, (iii) Ricean and Rayleigh fading models, that account for multipath propagation of the radio waves, (iv) Nakagami model, that is a mathematical general modeling of a radio channel with configurable fading, and (iv) Shadowing model, which models more complex environments.

In ns-2, the provided RPMs simulate a network with total absence of obstacles. Only the power level is taken into account, i.e., when the first bit of a new packet arrives, the power level at which the packet was received is compared to two different values: the carrier sense threshold and the receive threshold. Hence, determining whether a packet reaches its destination is a deterministic process. In fact, only the Nakagami model uses a probabilistic distribution.

Table I compares six of the most representative RPMs provided by the ns-2 simulator, and two others, [3] and [4]. When studying the results presented by Marinoni and Kari [3], we realize that the simulation scenario is constrained to an orthogonal grid, which could not represent a typical European city where the streets' layout is usually irregular. Moreover, the communications range is limited to 250m, which, as we will later demonstrate, is too limiting for 802.11p based communications. Mahajan et al. [4] implemented different traffic lights, lane and stop models, but they did not measure notification time and they only simulated 100 nodes. Differently from previous works, the approach we present in Section IV is based on the 802.11p standard, and it will be validated under different RPMs.

III. VISIBILITY SCHEMES

One relevant effect in radio propagation is the signal absorption due to some obstacles in the environment, i.e., buildings, geographic conditions such as mountains, etc. In our simulations, we focus on urban scenarios, thus taking into account the low depth of penetration of the wireless signal into buildings and other urban artifacts. Simulation results will largely depend on how this effect is modeled.

The simplest approach concerning visibility is not considering obstacles at all, as if vehicles were moving in an empty surface. This is the default model implemented within the ns-2 simulator. This model will cause the obtained results to be very optimistic, as we always consider that vehicles are in line-of-sight. A variation of this scheme is reducing the scenario to a simple highway where all the vehicles move in the same direction, like the one found in [6] and [7].

A more complex scheme, used in [8] and [3], assumes that all the vehicles are moving only in streets arranged as a Manhattan-style grid, so every vehicle movement can be either vertical or horizontal. This environment is more realistic than the previous one, but in real scenarios (like many European cities) it is very difficult to find perfect Manhattan layouts. In a Manhattan-style visibility scheme, two vehicles in different streets are in line-of-sight when the following condition is satisfied (see Figure 1):

$$(\Delta x < l_x) \vee (\Delta y < l_y) \vee \left(\frac{-\Delta y \times l_x}{\Delta x} + \Delta y < l_y \right), \quad (1)$$

where Δx is the absolute difference between the x coordinates of the two vehicles ($\Delta x = |x_1 - x_2|$), Δy is the absolute difference between the y coordinates of the two vehicles ($\Delta y = |y_1 - y_2|$), l_x is the half of the streets' width in the x coordinate, and l_y is the half of the streets' width in the y coordinate.

This approach is simple and it is easy to implement in a simulator. When used, results can give some information about

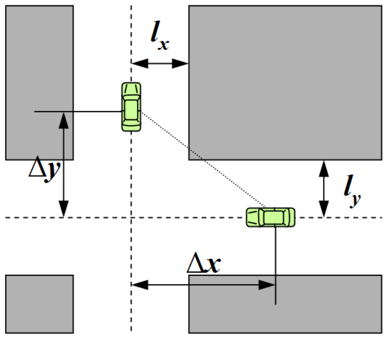

Fig. 1. Parameters to determine if two vehicles are in line-of-sight in a Manhattan layout.

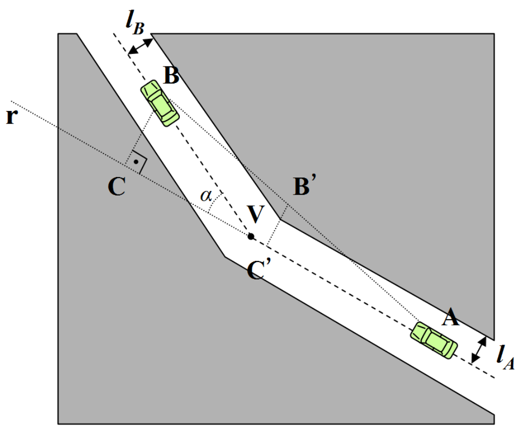

Fig. 2. Parameters to determine if two nodes are in line-of-sight in a realistic layout.

the general performance trends of the different algorithms studied. However, a more realistic layout should be used to ensure that the results resemble real ones.

A. Visibility Scheme for Real Maps

We now propose a more realistic visibility scheme which was designed to be used in real scenarios where streets are quite irregular. Figure 2 shows the mathematical basis of visibility models in real scenarios. Since two vehicles in the same street are considered in line-of-sight, we will rather focus on vehicles located in different streets.

The values we know *a priori* are the coordinates of vehicle A (x_A, y_A), the coordinates of vehicle B (x_B, y_B), the angle (α) formed by the streets where the two vehicles are moving, and the coordinates of the vertex V (x_V, y_V) the two streets have in common. As we can see, vehicles A and B are in line-of-sight if the following condition is satisfied:

$$d(B', C') < l_A \tag{2}$$

Function d represents the Euclidean distance between two points, and l_A is half the width of the street where vehicle A is located. We can find the value of $d(B', C')$ as follows:

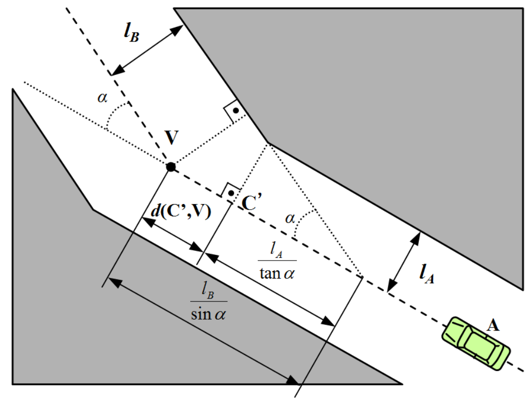

Fig. 3. Graphical explanation of the computation of $d(C', V)$.

$$\frac{d(B,C)}{d(A,C)} = \frac{d(B',C')}{d(A,C')} \Rightarrow d(B',C') = \frac{d(A,C') \cdot d(B,C)}{d(A,C)} \tag{3}$$

Point C' depends on l_A, l_B, α and the vertex coordinates (V) which the two streets have in common. Figure 3 graphically depicts the different points and distances used in computations. The value of $d(A, C')$ can be calculated as follows:

$$\begin{aligned} d(A,C') &= d(A,V) - d(C',V) \\ &= d(A,V) - \left(\frac{l_B}{\sin\alpha} - \frac{l_A}{\tan\alpha}\right) \end{aligned} \tag{4}$$

Distance between points B and C is equal to the minimum distance (d_{min}) between point B (x_B, y_B) and the line r (formed as an extension of the street where A is located) in the form $A_r \cdot x + B_r \cdot y + C_r = 0$. It can be calculated as follows:

$$d(B,C) = d_{min}(B,r) = \frac{|A_r \cdot x_B + B_r \cdot y_B + C_r|}{\sqrt{A_r^2 + B_r^2}} \tag{5}$$

Finally, $d(A, C)$ has the following value:

$$d(A,C) = d(A,V) + d(V,C) = d(A,V) + \frac{d(B,C)}{\tan\alpha} \tag{6}$$

IV. Our Proposed Radio Propagation Model

As shown in Sections II and III, we divide the generation of a wireless signal propagation model into two different features: attenuation schemes and visibility schemes. The combination of these schemes makes up our novel Radio propagation model, called *Real Attenuation and Visibility* (RAV).

Figure 4 presents the summary flowchart of the process to determine if a packet is successfully received using our proposed model. Next, we detail both the attenuation and the visibility schemes used in RAV.

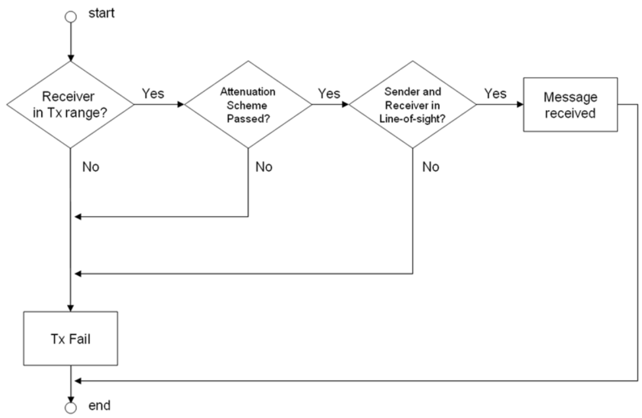

Fig. 4. RAV model flowchart.

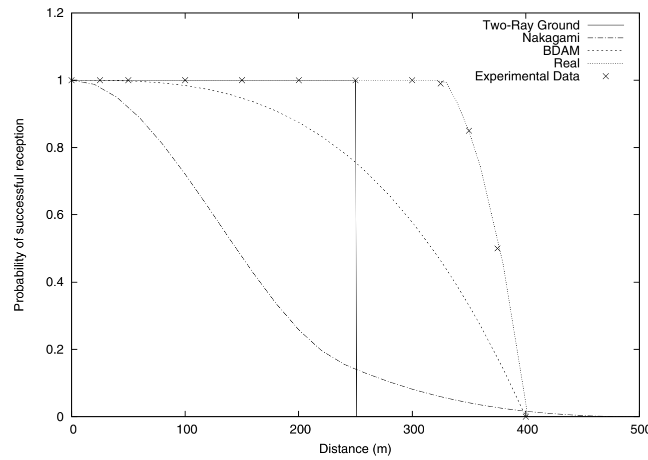

Fig. 5. Comparison of different attenuation schemes.

A. RAV Attenuation Scheme

Our model implements signal attenuation due to the distance between vehicles as close as possible to reality. In general, ns-2 offers deterministic RPMs, i. e., the function used determines the maximum distance a packet could reach. If the receiver is within this range, the packet will be successfully received; otherwise, it will be lost. In order to increase realism, we use a probabilistic approach to this problem to model packet losses due to collisions or other situations. So, we use a probability density function to determine the probability of a packet being successfully received at any given distance.

Our scheme is based on real data obtained from experiments in the 5.9 GHz frequency band using the IEEE 802.11a standard. The experiments consisted of several measurements of the *Packet Error Rate* (PER) in a wireless file transmission varying the distance between sender and receiver within a range of 500 meters. In these experiments, we obtained an empirical maximum transmission distance of 400 meters.

Using the collected data, we tested several monotonically decreasing functions for the curve fitting process, finding that an acceptable trade-off between accuracy and execution time could be achieved using a fourth order polynomial (see Equation 7):

$$PER(x) = ax^4 + bx^3 + cx^2 + dx + e, \qquad (7)$$

where PER is the Packet Error Rate and x is the Euclidean distance between vehicles. In particular, the values obtained through regression were:

(a, b, c, d, e) = (–6.14e–10, 3.98e–7, –7.87e–5, 4.80e–3, 0.96)

With respect to other attenuation schemes, such as Two-Ray Ground and Nakagami, our Real scheme, instead of being theoretical, is obtained directly from experimental data. Moreover, instead of using a deterministic approach, we use a probabilistic function to model packet losses. Figure 5 shows the empirical data obtained in our experiments and our proposed attenuation curve compared with (a) Two-Ray Ground, (b) Nakagami [9] and (c) BDAM [10].

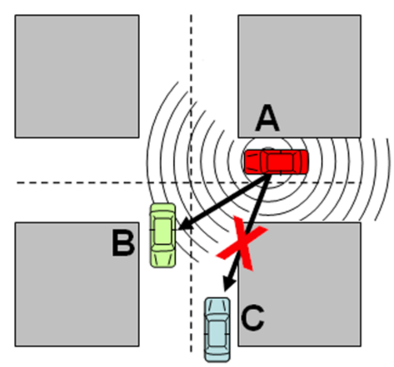

Fig. 6. BDAM visibility scheme: example scenario.

As we can see, the only deterministic scheme is Two-Ray Ground, which is represented with a maximum transmission range of 250 meters. The Nakagami scheme has a greater range, but the probability of successful transmission when distance is above 200 meters is very low. The BDAM attenuation scheme behaves similarly to the Real scheme, but for distances above 300 meters the probability of successful transmissions is much higher for the RAV attenuation scheme.

B. RAV Visibility Scheme

The main objective that a realistic visibility scheme should accomplish is to determine if there are obstacles between the sender and the receiver which may interfere with the radio signal. In most cases, when using the 5.9 GHz frequency band (used by the 802.11p standard), buildings absorb radio waves and so communication is not possible. A previous model called *Building and Distance Attenuation Model* (BDAM) [10] was designed to work only in Manhattan-style grid layouts, where simpler calculations were used to determine if two vehicles were in line-of-sight. Figure 6 depicts the BDAM model, where dark rectangles represent buildings.

Our proposal goes one step forward by adapting the algorithm to support more complex and realistic layouts. Given a real reference map containing the street layout, our proposal basically states whether two different vehicles are in line-of-sight. Our street layouts are considered as undirected graphs where junctions are vertices and streets are edges that connect some pairs of vertices. We use a notation to define streets in which (x_s^1, y_s^1) is the initial vertex of the street s, and (x_s^2, y_s^2) represents its end vertex.

Instead of using the detailed mathematical model presented in Section III-A, we use an approach to reduce simulation time. In our simulations, we calculate the angular difference between the streets where the vehicles are located. If it is below a threshold (th_a), we state that the vehicles can communicate.

Figure 7 shows an example of the visibility scheme used in RAV, where vehicle (A) is trying to disseminate a message. In that case, and assuming that any vehicle receiving a message will rebroadcast it the first time, the result will be vehicles (B, C, D, F, G, and I) receiving the message while the others (E, H, and J) will be never reached by this message.

The RAV visibility scheme works as follows to determine if two vehicles are in line-of-sight:

- Two vehicles in the same street are always in line-of-sight. Using Equation 5, we consider that a vehicle is in a street (s) when the minimum distance (d_{min}) between its position ($P(x, y)$) and the line (r) formed as a extension of the street is less than a threshold (th_s). In addition, $P(x, y)$ must be included in the axis-oriented rectangle extended by th_s involving the street. As an example, in Figure 7, vehicles D and F are in the same street.

$$\begin{aligned} &d_{min}(P(x,y), r) \leq th_s \wedge \\ &(x_s^1 - th_s) \leq x \leq (x_s^2 + th_s) \wedge \\ &(y_s^1 - th_s) \leq y \leq (y_s^2 + th_s) \end{aligned} \tag{8}$$

- When a vehicle is in a junction (j), we consider that this vehicle may potentially communicate with all the vehicles present in the streets which start from junction j, i.e., the vehicle is considered to be at the same time in all the neighbor streets. A threshold distance (th_j) is used to determine if a vehicle is close enough to a junction. As shown in Figure 7, vehicles A, C and F are close to a junction and, therefore, they are simultaneously in all the adjacent streets.
- Two vehicles in adjacent streets (labeled i and j) are in line-of-sight if the angular difference (α) between their streets is below a threshold th_a:

$$\begin{aligned} \alpha'(i,j) =& |atan2(|y_i^2 - y_i^1|, |x_i^2 - x_i^1|) \\ & - atan2(|y_j^2 - y_j^1|, |x_j^2 - x_j^1|)| \\ \alpha(i,j) =& min(\alpha'(i,j), 360 - \alpha'(i,j)) < th_a \end{aligned} \tag{9}$$

This property can be extended if there is a series of linked streets between vehicles, and for every street in the chain, the angular difference with all its predecessors is less than th_a (see Equation 10). In Figure 7, we have chosen $th_a = 20°$ ($\approx$ 0.349 radians).

$$\forall i, j : i < j \Rightarrow \alpha(i,j) < th_a \tag{10}$$

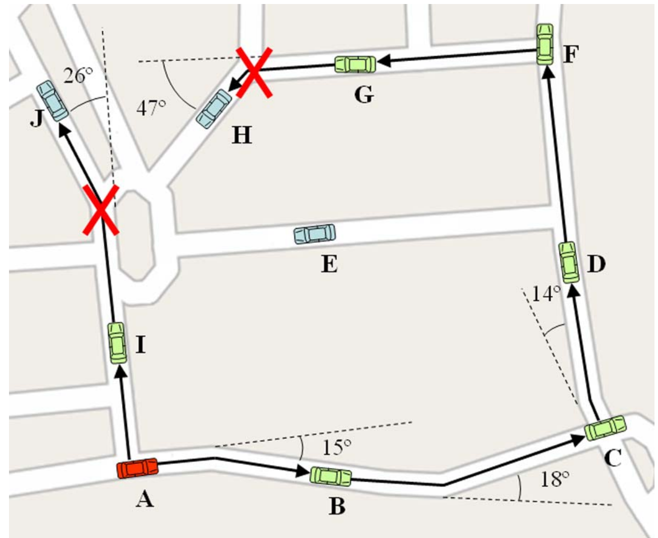

Fig. 7. RAV visibility scheme: example scenario.

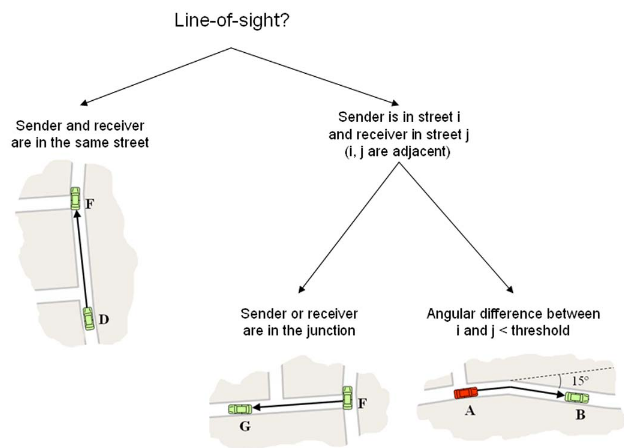

Fig. 8. RAV: line-of-sight algorithm conditions.

Notice that the RAV visibility scheme only determines if there are obstacles between sender and receiver. The final communication also depends on the distance between them and the attenuation scheme used (for example, the RAV attenuation scheme). Figure 8 schematically shows the three different conditions to consider that two vehicles are in line-of-sight in our RAV visibility scheme.

V. Simulation Environment

In this section we present our simulation environment. Simulations were done using the ns-2 simulator, modified to include IEEE 802.11p to follow the upcoming WAVE standard closely. In terms of the physical layer, the data rate used for packet broadcasting is of 6 Mbit/s, as this is the maximum rate for broadcasting in 802.11p. The MAC layer was also extended to include four different priorities for channel access. Therefore, application messages are categorized into different *Access Categories* (ACs), where AC0 has the lowest and AC3 the highest priority.

The purpose of the 802.11p standard is to provide the minimum set of specifications required to ensure interoperability between wireless devices attempting to communicate in potentially rapid changing communication environments. For our simulations, we chose the IEEE 802.11p technology because it is expected to be widely adopted by industries. For 802.11p-based VANETs, the received signal strength will largely depend on the presence of obstacles and the distance from the sender.

Each simulation run lasted for 450 seconds. In order to achieve a stable state, we only collect data after the first 60 seconds. We evaluated the performance of a simple Warning Message Dissemination mechanism where each vehicle periodically (every second) broadcasts information about itself or about an abnormal situation (slippery roads because of ice, traffic jam, etc.).

In order to mitigate the broadcast storm problem [11], our simulations use the *Street Broadcast Reduction* (SBR) scheme [12], with a rebroadcast minimum distance of 200 meters. SBR outperforms the flooding, the distance-based, and the location-based schemes, and it can overcome corners and road intersections by allowing data propagation on different roads.

With regard to data traffic, vehicles operate in two modes: (a) warning, and (b) normal. Warning mode vehicles inform other vehicles about their status by sending warning messages periodically (every T_w seconds). These messages have the highest priority at the MAC layer. Normal mode vehicles enable the diffusion of these warning packets and, periodically (every T_b seconds), they also send *beacons* with information such as their positions, speed, etc. These periodic messages have lower priority than warning messages, and are not propagated by other vehicles. With respect to warning messages, each vehicle is only allowed to propagate them once for each sequence number, i.e., older messages are dropped.

Finally, concerning to our scenario, we have selected the downtown area of the Valencia city in Spain, where 300 vehicles move in a 4 km^2 area. Figure 9 shows the simulated topology for the map layout, obtained from OpenStreetMap [13] and converted using SUMO [14]. Table II shows the most representative parameter values used in our simulations.

TABLE II
PARAMETER VALUES FOR THE SIMULATIONS

Parameter	Value
number of vehicles	300
maximum speed	$23\ m/sec. \approx\ 83\ km/h$
simulated area	$2000m \times 2000m$
distance between streets (Manhattan)	$100m$
street width (Manhattan)	$20m$
number of warning mode vehicles	3
warning packet size	$256B$
normal packet size	$512B$
packets sent by vehicles	$1\ per\ second$
warning message priority	$AC3$
normal message priority	$AC1$
MAC/PHY	802.11p
maximum transmission range	$400m$
SBR distance threshold (D) [12]	$200m$
RAV th_s	$20m$
RAV th_j	$20m$
RAV th_a	$20°$

Fig. 9. Simulated scenario of Valencia city, Spain.

VI. SIMULATION RESULTS

In this section, we evaluate the impact of the RAV model presented in section IV on the performance of a Warning Message Dissemination application, typically used in VANETs.

We are interested in the following performance metrics: (a) percentage of blind vehicles, (b) warning notification time, and (c) number of packets received per vehicle. The percentage of blind vehicles is the percentage of vehicles that do not receive the warning messages sent by warning mode vehicles. These vehicles can remain blind because of their positions, due to collisions, or signal propagation limitations. The warning notification time is the time required by normal vehicles to receive a warning message sent by a warning mode vehicle. The number of packets received per vehicle (including beacons and warning messages) gives an estimation of channel contention.

We test both attenuation and visibility schemes independently, i.e., we perform simulations by varying the attenuation scheme using the same visibility scheme, and

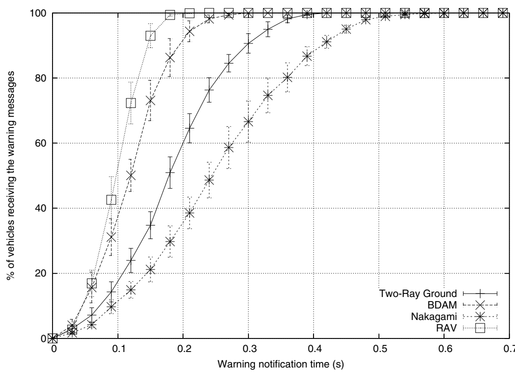

Fig. 10. Warning notification time when varying the attenuation scheme without obstacles and using a Manhattan layout.

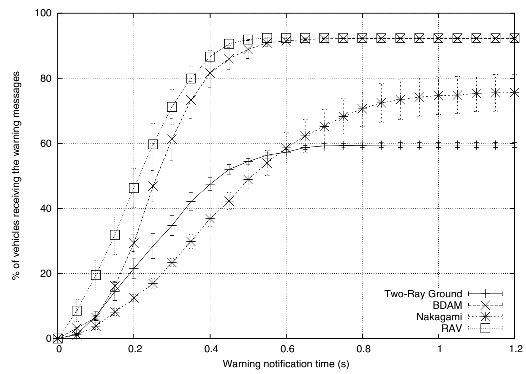

Fig. 11. Warning notification time when varying the attenuation scheme with obstacles and using a real map layout.

vice versa. Our intention is to evaluate the cross-effect the different schemes will have over the network performance, and to measure the differences appearing when we increase the level of realism of the simulations.

Since the performance results are highly related to the scenarios, and due to the random nature of the mobility model used, we repeated the simulations to obtain reasonable confidence intervals. All results represent an average over several executions with different random scenarios, presenting all of them a maximum error of 10% with a degree of confidence of 90%.

A. Evaluating the impact of the Attenuation Scheme

Figures 10 and 11 show the results obtained when using different attenuation schemes in a Manhattan and a real map layout, respectively.

Figure 10 represents a synthetic Manhattan scenario without buildings, so the default ns-2 visibility scheme is used. As shown, in all the simulations 100% of the vehicles received the warning messages since signal propagates without being interfered by buildings. When using Two-Ray Ground, the system required 0.55 seconds to reach all vehicles; however, when using our Real attenuation scheme (obtained from experimental data), the warning notification time is reduced to 0.2 seconds.

Results in Figure 11 are obtained using a real map from Figure 9 as the simulation topology. The RAV visibility scheme is most suitable for this environment. Hence, all simulations were run with this scheme. Differences are more noticeable in this situation. With Two-Ray Ground, only 60% of the vehicles are aware of the dangerous situation, and it increases to around 75% when using the Nakagami fading model. If we use RAV and BDAM instead, warning messages reach 92% of the vehicles, but RAV warning notification time is lower (80% of the vehicles are informed in only 0.35 seconds).

B. Evaluating the impact of the Visibility Scheme

In this section, we use our proposed attenuation scheme (Real) in all the simulations, and then we vary the visibility scheme. We have chosen our realistic attenuation scheme as it is the closest to reality. A synthetic Manhattan layout is used with the Manhattan visibility scheme because the equations shown in Section III are only valid in a orthogonal grid; we use real map layouts with the rest of the schemes.

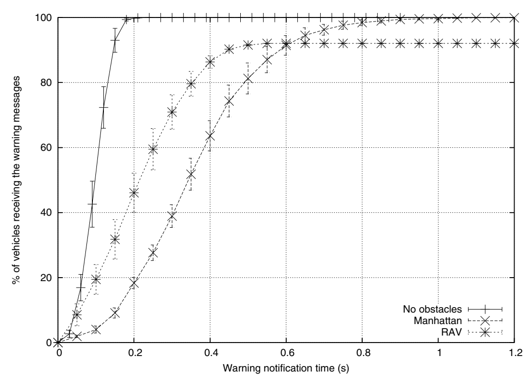

Fig. 12. Warning notification time when using the realistic attenuation scheme and varying the visibility/layout schemes.

Results are shown in Figure 12. If we do not account for obstacles (ns-2 current visibility model), warning messages rapidly reach 100% of the vehicles because signal propagation suffers from few constraints. As expected, there are more blind vehicles using a realistic topology than using a Manhattan layout, but the warning notification time is lower (80% of vehicles are informed in only 0.35 seconds), and so the propagation process needs less time to be completed (0.55 seconds). The higher percentage of blind vehicles in a real scenario is due to the complex topology used, which makes it harder to reach specific areas of the map, while in the Manhattan layout streets are straight and signal reaches longer distances making it easier to discover new vehicles. However, in our real map, there are many more junctions, which increases the probability of a vehicle being near a junction and, therefore, simultaneously in all the adjacent streets (which, in contrast to Manhattan layouts, can be greater than four). This effect can cause warning notification time to be reduced.

TABLE III
PERFORMANCE UNDER DIFFERENT ATTENUATION SCHEMES (ACCOUNTING FOR OBSTACLES)

Performance	Schemes			
	Two-Ray	**Nakagami**	**BDAM**	**RAV**
Warning notification time (s)	0.83	0.61	0.30	0.25
% of blind vehicles detected	34.36	17.93	8.04	7.91
Number of packets received	220.47	159.87	398.6	653.87

TABLE IV
PERFORMANCE UNDER DIFFERENT VISIBILITY SCHEMES (REAL ATTENUATION)

Performance	Schemes		
	No obs.	**Manhattan**	**RAV**
Warning notification time (s)	0.11	0.39	0.25
% of blind vehicles detected	0	0.07	7.91
Number of packets received	7871.8	1664.07	653.87

C. Overall Summary

Table III presents a summary of the average performance results obtained when simulating different attenuation schemes in a realistic environment, i.e., with the presence of obstacles and using a real map. The data presented for warning notification time is the time required to inform at least 60% of the vehicles in the simulated scenario. As shown, when using more realistic attenuation schemes, the warning notification time is reduced, the percentage of blind vehicles is also drastically reduced, and the number of packets received per vehicle increases.

Table IV shows a summary of the average performance results obtained when simulating different visibility schemes, and using the Real attenuation scheme. As shown, when accounting for the effect of buildings in signal propagation, the system requires more time to warn the rest of the vehicles, although warning notification time is lower in RAV. Nevertheless, when simulating real map layouts, the percentage of blind vehicles slightly increases, and the number of packets received per vehicle is drastically reduced.

VII. CONCLUSIONS

The increasing popularity and attention in VANETs has prompted researchers to develop accurate and realistic simulation tools. In this paper we introduced RAV, a novel Radio Propagation Model that allows researchers to increase the level of realism of their VANET simulations. RAV uses both a realistic attenuation scheme (using real experimental data), and a realistic visibility scheme (accounting for the effect of buildings in radio signal propagation and their presence in real map layouts).

Previous attenuation schemes were too restrictive in terms of maximum transmission range. Our experiments show that the radio signals generated by of-the-shelf IEEE 802.11a wireless cards, which use same band as 802.11p ones, have a reachability of about 400 meters, instead of 250 meters (ns-2 default transmission range). Our realistic attenuation scheme achieves better simulation results in terms of warning notification time and percentage of blind vehicles. As for visibility schemes, most research works do not consider the effect of buildings in their radio signal propagation model, or their models use very simplistic layouts. RAV allows researchers to simulate real map layouts, allowing them to obtain more accurate results.

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