

Realistic Radio Propagation Models (RPMs) for VANET Simulations

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Abstract—Deploying and testing *Vehicular Ad hoc Networks* (VANETs) involves high cost and intensive labor. Hence simulation is a useful alternative prior to actual implementation. Most works found in the literature employ very simplistic *Radio Propagation Models* (RPMs), ignoring the dramatic effects presented by buildings on radio signals.

In this paper, we present three different RPMs that increase the level of realism, thereby allowing us to obtain more accurate and meaningful results. These models are: (a) the *Distance Attenuation Model* (DAM), (b) the *Building Model* (BM), and (c) the *Building and Distance Attenuation Model* (BDAM).

We evaluated these different models and compared them with the *Two-ray Ground* model implemented in ns-2. We then carried out further study to evaluate the impact of varying some important parameters such as vehicle density and building size on VANET warning message dissemination. Simulation results confirmed that our proposed BDM significantly affects the percentage of blind vehicles present and the number of received warning messages, and that our models can better reflect realistic scenarios.

I. INTRODUCTION

Vehicular Ad hoc Networks (VANETs) support cooperative driving among communicating cars on the road. Deploying and testing VANETs involves high cost and manpower. Hence, simulation is an useful step prior to actual implementation.

Simulations of VANETs often involve large and heterogenous scenarios. One of the important issues 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. These models provide a suitable environment for the simulation and evaluation of ad hoc communication performance.

We observe that the most widely used simulators, such as ns-2, Glomosim, QualNet and OPNET have not accurately simulated the radio propagation model. They do not take into account the physical obstacles present in urban environments (mostly buildings). For example, the commonly used *Two-ray ground* radio propagation model ignores effects such as *Radio Frequency* (RF) attenuation due to buildings and other obstacles. In ns-2 [2], it is assumed that signals have a perfect 250m radius range, which is overly optimistic for urban environments. Consequently, simulation results so obtained are unlikely to accurately reflect system performance in the real world.

IEEE 802.11p is a draft amendment to the IEEE 802.11 standard to add *Wireless Access in the Vehicular Environment* (WAVE) [3]. It defines enhancements to 802.11 required to support *Intelligent Transportation Systems* (ITS) applications. This includes data exchange between high speed vehicles and between vehicles and roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz).

To the best of our knowledge, the impact of buildings or other obstacles (specifically on 802.11p-based VANETs) has not yet been studied. It is evident that urban obstacles, such as buildings, will act as barriers for radio signals. In this paper, we propose three different *Radio Propagation Models* (RPMs) specifically designed for IEEE 802.11p-based VANETs. Furthermore, we study the impact of these models on communication performance.

This paper is organized as follows: Section II presents the limitations of the RPMs provided by the ns-2 simulator. Section III presents our proposed radio propagation models. Section IV presents the simulation environment. Simulation results are described in Section V. Finally, Section VI concludes this paper.

II. LIMITATIONS OF NS-2 RPMs

ns-2 offers some RPMs to estimate the wireless signal strength. They assume a flat surface, where the simulation environment contains no objects that could block the signal. The ns-2 RPMs are: (i) *Free Space* model, (ii) *Two-ray Ground* model that accounts for multipath reflection from the ground, (iii) *Ricean* and the *Rayleigh* fading models that account for multipath propagation of the radio waves, 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, i.e., the carrier sense threshold and the receive threshold.

Table I compares five of the most representative RPMs provided by the ns-2 simulator, and two others proposed in [4] and [5]. Compared to [5], our approach is based on 802.11p and our results evaluate the performance of an information dissemination approach under different RPMs. In [5], they implemented different traffic lights, lane and stop models, but they did not measure notification time and they only

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 height.
Ricean and Rayleigh fading	Both models describe the time-correlation of the received signal power. First model considers indirect paths between the sender and the receiver, while the second model considers when there is one dominant path and multiple indirect signals.
Shadowing	A gaussian random variable is added to the path loss to account for environmental influences.
RPMO [4]	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. [5]	This model behaves like Two-ray Ground, adding the influence of obstacles and the distance attenuation, but it is designed for the 802.11b environment

simulated 100 nodes. We understand that excessive details when modeling the physical layer may extend the simulation run-times with little or no impact on the results, while too few details invariably lead to inaccurate results. To achieve a trade-off between accuracy and run-time, propagation models must simplify and reduce the calculations involved.

III. OUR PROPOSED RADIO PROPAGATION MODELS

In this section, we present three new *Radio Propagation Models* (RPMs) that allow better modeling of losses due to attenuation and obstacles.

They are:

- 1) The *Distance Attenuation Model* (DAM) considers the signal attenuation due to the distance between the vehicles. To estimate the impact of signal attenuation on packet losses, we have two different possibilities: (i) use a very detailed analytical model that relates signal strength and noise at the receiver with *Bit Error Rate* (BER) and *Packet Error Rate* (PER), and (ii) 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.

We had integrated the results presented in [6] into ns-2. We had also tested several monotonically decreasing functions for the curve fitting process and found that an optimum trade-off between accuracy and execution time could be achieved using a third order polynomial (see Equation 1):

$$PER(x) = ax^3 + bx^2 + cx + d \quad (1)$$

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

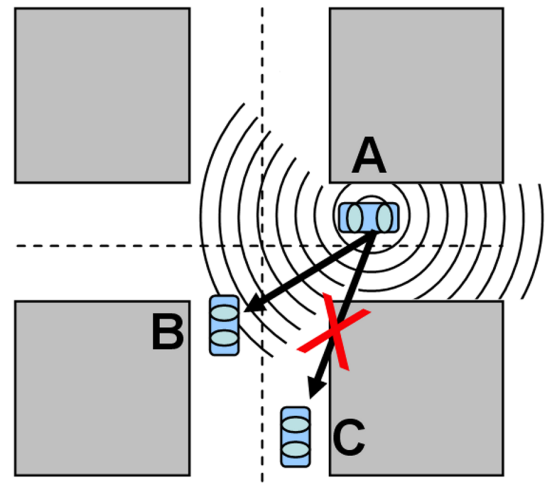


Fig. 1. The Building Model: example scenario.

- (a, b, c, d) = (-4.367e-09, 8.686e-06, -5.523e-3, 1)
- 2) The *Building Model* (BM) takes into consideration that, at a frequency of 5.9 GHz (i.e., the frequency band of the 802.11p standard), the signal is 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 the vehicles are in line-of-sight. Figure 1 shows an example of this model. Dark rectangles represent buildings. In the Two-ray Ground and DAM models, vehicle C may receive the message from A. Nevertheless, with our Building Model, only communication between vehicles A and B is possible. Vehicle C does not receive the message from A due to the presence of a building.
- 3) The *Building and Distance Attenuation Model* (BDAM) combines both DAM and BM models. Now, communication will only be possible when the received signal is strong enough and vehicles are within line-of-sight. BDAM can be considered the most realistic model.

IV. SIMULATION ENVIRONMENT

In this section, we present our simulation environment. Simulations were done using the ns-2 simulator. Our simulated system tries to follow the upcoming WAVE standard as closely as possible. Achieving this requires the modification of ns-2 simulator to include IEEE 802.11p. In terms of the physical layer, the data rate used for packet broadcasting is 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 Classes* (ACs), where AC0 has the lowest and AC3 the highest priority.

The purpose of 802.11p standard is to provide the minimum set of specifications required to ensure interoperability between wireless devices attempting to communicate in

TABLE II
PARAMETER VALUES FOR THE REFERENCE SCENARIO

Parameter	Value
number of vehicles	100
maximum speed	23 m/sec. \approx 83 km/h
simulated area	2000m \times 2000m
building size	20m
distance between streets	50m
number of warning mode vehicles	3
downtown size	500m \times 500m
downtown speed (min.-max.)	3 – 14 m/sec. \approx 11 – 50 km/h
downtown probability	0.7
warning packet size	256B
normal packet size	512B
packets sent by vehicles	1 per second
warning message priority	AC3
normal message priority	AC1

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.

Our simulation methodologies include first defining a reference scenario (see Table II), then evaluating the impact of the proposed RPMs by varying the number of vehicles and the building size. This allows us to generate and evaluate a large number of different scenarios. 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.).

Since the Random Waypoint Model is considered unrealistic [7], in our simulation, vehicles move according to a mobility model called *Downtown Model* (DM). This is a model that we had developed in a previous work [8]. In this model, streets are arranged in a Manhattan-style grid, with a uniform building size across the simulation area. All streets are two-way, with lanes in both directions.

In addition, our model adds traffic density in a manner similar to a real town, where traffic is not uniformly distributed. Hence, there will be zones with a higher vehicular density. These zones are usually in downtown, and vehicles must move more slowly than those in the outskirts. Finally, there are two types of vehicles: (i) vehicles that are in warning mode sending warning messages, and (ii) vehicles representing the rest of vehicles that relay these messages over the whole map area. Table II shows the parameter values used in our reference scenario.

V. SIMULATION RESULTS

In this section, we evaluate the impact of the RPMs presented in section III on the performance of a VANET message dissemination protocol.

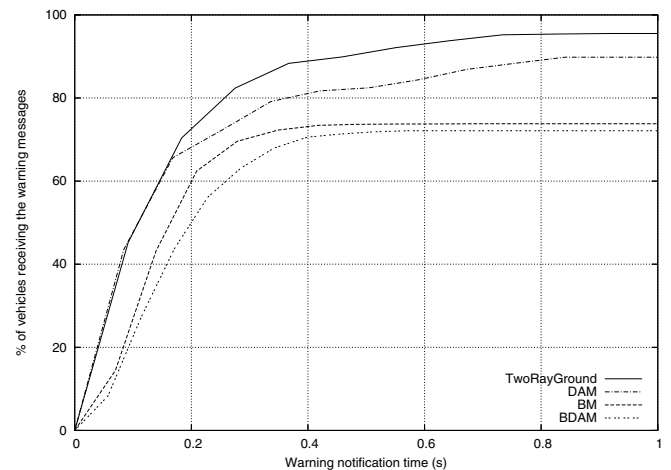


Fig. 2. Cumulative histogram for the time evolution of disseminated warning messages for the different RPMs (reference scenario).

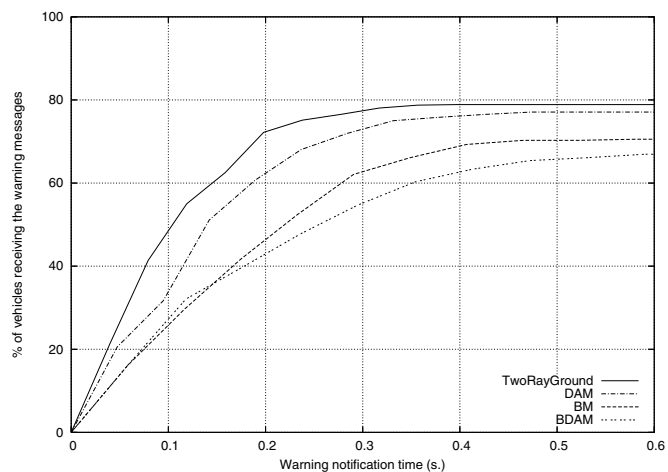
We are interested in the following performance metrics: (a) percentage of blind vehicles, (b) warning notification time, and (c) number of packets received per vehicle. The percentage of blind vehicles is the percentage of vehicles that do not receive the warning messages sent by the accident vehicles. These vehicles can remain blind because of their positions, or 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.

To perform evaluation, we first determine a set of basic results using a reference scenario (see table II). Then, by using a wide variety of scenarios, and by varying the selected parameters one at a time, we performed a detailed analysis to illustrate the impact of the realistic RPMs introduced.

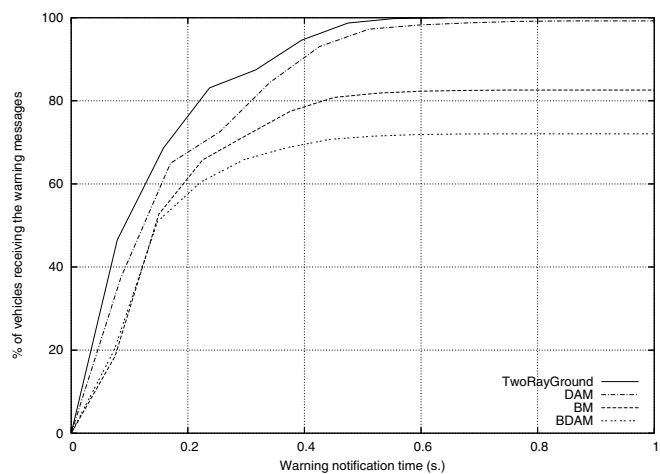
The results shown in this section represent an average over various executions with different randomly generated mobility scenarios and with three warning mode vehicles placed randomly. Since the performance results are highly related to the scenarios, and due to the random nature of the mobility model used, we repeated the simulations to obtain reasonable confidence intervals. All results present a maximum error of 10% with a degree of confidence of 90%.

A. Reference scenario

Figure 2 depicts the warning notification time for different RPMs in the reference scenario. As shown, information does not reach all vehicles, but within 0.26 seconds about 60% of the vehicles receive the warning message in the worst case (BDAM). The propagation process needs more time to complete for Two-ray Ground and DAM models, since these models are less restrictive and the number of possible hops is greater. Although, in the BM and BDAM models, the propagation ends sooner, fewer vehicles are informed since warning messages are blocked by buildings. The BDAM model reveals the presence of blind vehicles more accurately than other RPMs. The number of packets received per vehicle is 77.34, 47.51, 20.78 and 16.00 in



(a)



(b)

Fig. 3. Cumulative histogram for the time evolution of disseminated warning messages when varying the number of vehicles (a) 25 and (b) 200.

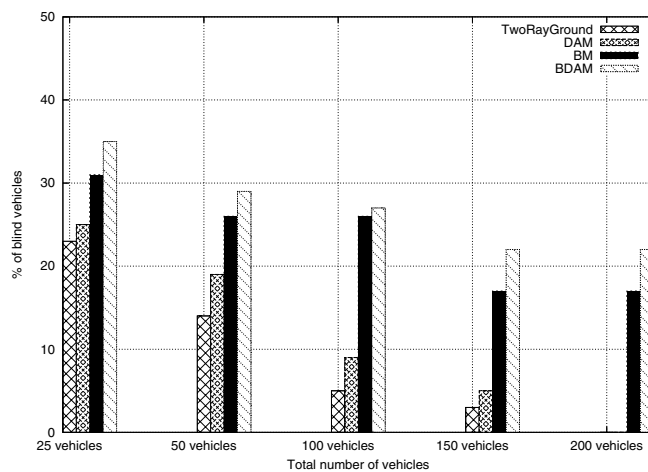
Two-ray Ground, DAM, BM and BDAM models respectively. The number of packets received decreases considerably since signal propagation encounters more restrictions.

We observed that BM and BDAM performance is similar in this scenario and hence, dissemination is more affected by the effect of buildings rather than solely on the signal attenuation due to distance.

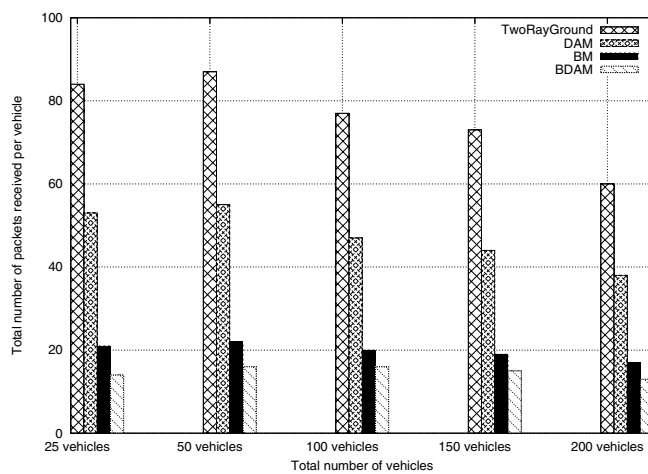
B. Varying the number of vehicles

Figures 3 and 4 show the simulation results when varying the number of vehicles while maintaining the rest of parameters unaltered. We performed simulations for 25, 50, 100 (reference scenario), 150 and 200 vehicles.

As shown, the warning notification time and the percentage of blind vehicles highly depends on the vehicle density (see Figures 3 and 4). With a small number of vehicles, i.e. the vehicle density is low, the behavior of the RPMs is similar since vehicles are mainly concentrated in the downtown. The warning message propagation is faster for the Two-ray



(a)



(b)

Fig. 4. (a) Percentage of blind vehicles vs. number of vehicles and (b) Total number of packets received at each vehicle vs. number of vehicles.

Ground and DAM models. Nevertheless, with a large number of vehicles, i.e. when the vehicle density is higher, there are no blind vehicles for both Two-ray Ground and DAM models. For the BM and BDAM models, warning information does not reach all vehicles since these two RPMs are more restrictive. Obviously, the propagation process needs more time to complete when there are more vehicles, but the difference is almost negligible.

RPMs can also affect the number of packets received per vehicle (see Figure 4b). In BM and BDAM models, the number of packets received decreases considerably since signal propagation encounters more restrictions. We observe that in both BM and BDAM models, the number of warning message packets received does not depend on vehicle density.

C. Varying the building size

In this section, we present the simulation results when varying the building size while maintaining other parameters. We used building sizes of 10m, 20m (reference scenario), 30m

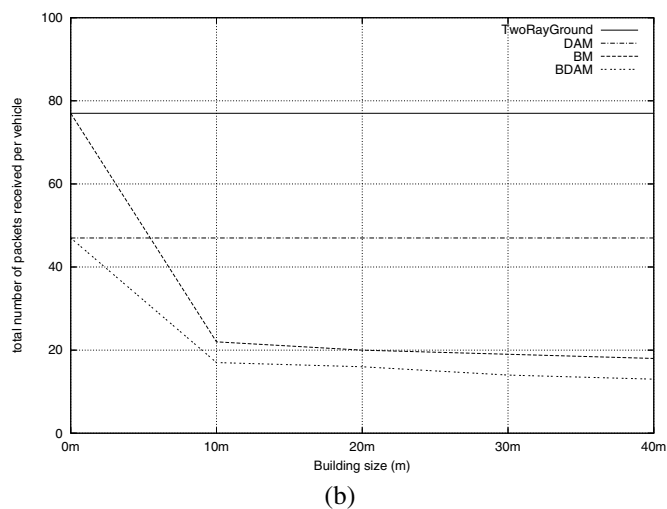
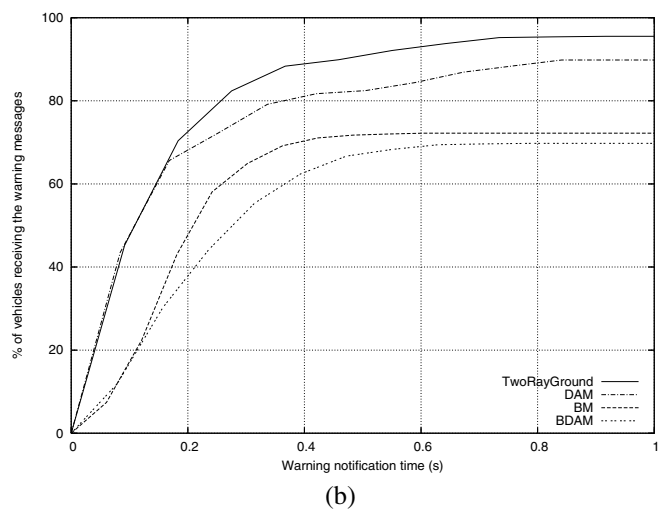
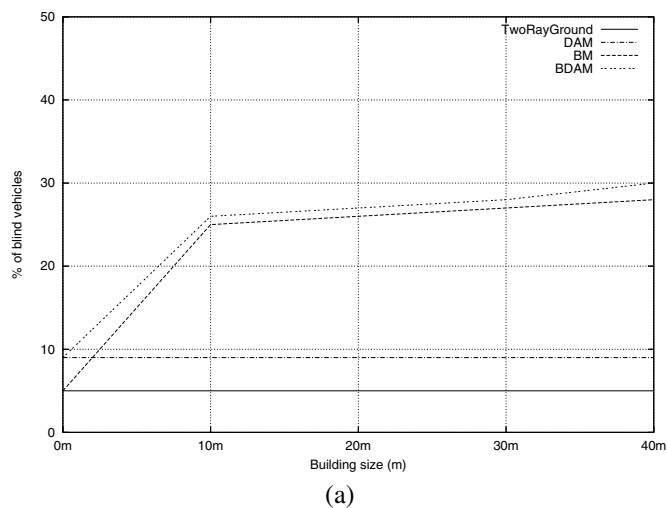
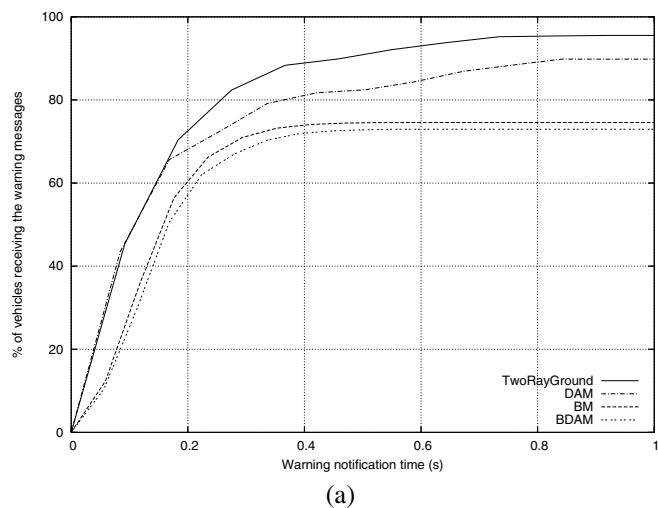


Fig. 5. Cumulative histogram for the time evolution of disseminated warning messages when varying the building size (a) 10m and (b) 40m.

Fig. 6. (a) Percentage of blind vehicles and (b) number of packets received in BM and BDAM models when varying the building size.

and 40m. Note that in our proposed urban scenario, the effect of increasing the building size is exactly the same that reducing the road width (see Figure 1).

As expected, Figures 5 and 6 show that building size does not affect the Two-ray Ground and DAM models. This is so since these RPMs do not take into account the presence of buildings. The warning notification time is slightly lower for the BM and BDAM models when the building size is smaller, meaning that wider streets make communication easier and faster.

The percentage of blind vehicles increases and the number of packets received (see Figures 6a and 6b) decreases initially when the building comes into existence for both BM and BDAM models.

The percentage of blind vehicles increases when the building size increases (from 10m to 40m: +12.27% for BM and +10.59% for BDAM). Note that the number of packets received decreases when the building size increases (from

10m to 40m: -18.03% for BM and -23.36% for BDAM). This is because buildings block the dissemination of warning messages.

D. Overall summary

In table III, we present a summary of the average performance results obtained when simulating with different RPMs. The data presented for warning notification time, is the time necessary to inform at least the 60% of vehicles in the simulated scenario. As shown, when the model is more restrictive, more time is needed to reach the same percentage of vehicles, and the percentage of blind vehicles increases. Nevertheless, the average number of packets received per vehicle decreases considerably.

The results show that using more realistic models tends to reduce protocol performance, allowing us to better understand the impact of buildings and obstacles along the road on car-to-car communications.

TABLE III
PERFORMANCE UNDER DIFFERENT RPMs

Performance	Schemes			
	Two-ray	DAM	BM	BDAM
Warning notification time (s)	0.15	0.17	0.23	0.29
% of blind vehicles detected	9.59	12.03	23.82	27.43
Number of packets received	76.58	47.84	20.23	15.17

VI. CONCLUSIONS

In this paper, we assessed the impact of having realistic radio propagation models on the performance of warning message dissemination in VANETs. We observed that the number of warning messages received does not depend on vehicle density. However, when vehicle density increases, both the percentage of blind nodes and the warning notification time decrease for all RPMs. In Two-ray and DAM models, warning messages can even reach all vehicles due to the "ideal" assumptions in these models. The variation of building sizes has no impact on these two models, since they do not take account for obstacles. The warning notification time is reduced in both BM and BDAM models when the building size is smaller and streets are wider. On the contrary, the percentage of blind vehicles increases and the number of packets received decreases when building size increases.

Results obtained from our simulations allow us to conclude that realistic RPMs significantly affect the percentage of blind vehicles present and the number of received warning messages. When using the BDAM model, the number of packets received decreases considerably; this means that the broadcast storm problem is not a serious issue. Although the BDAM model yields poorer performance results than others models, it is in fact a more realistic RPM for use in future VANET simulations.

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REFERENCES

- [1] C.-K. Toh, *Ad Hoc Mobile Wireless Networks: Protocols and Systems*. Prentice Hall, 2001.
- [2] K. Fall and K. Varadhan, "ns notes and documents," The VINT Project. UC Berkeley, LBL, USC/ISI, and Xerox PARC, February 2000, available at <http://www.isi.edu/nsnam/ns/ns-documentation.html>.
- [3] Task Group p, "IEEE P802.11p: Wireless access in vehicular environments (WAVE)," IEEE Computer Society, 2006.
- [4] S. Marinoni and H. H. Kari, "Ad hoc routing protocol performance in a realistic environment," in *Proceedings of the International Conference on Networking, International Conference on Systems and International Conference on Mobile Communications and Learning Technologies (ICN/ICONS/MCL 2006)*, Washington, DC, USA, October 2006.
- [5] A. Mahajan, N. Potnis, K. Gopalan, and A. Wang, "Modeling vanet deployment in urban settings," in *International Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2007)*, Crete Island, Greece, October 2007.

- [6] M. Torrent-Moreno, P. Santi, and H. Hartenstein, "Inter-vehicle communications: assessing information dissemination under safety constraints," in *Proceedings of the 4th Annual Conference on Wireless on Demand Network Systems and Services (WONS)*, Obergurgl, Austria, January 2007.
- [7] J. Yoon, M. Liu, and B. Noble, "Random waypoint considered harmful," *Proceedings of IEEE INFOCOMM 2003*, San Francisco, California, USA, March 30-April 3 2003.
- [8] F. J. Martinez, J.-C. Cano, C. T. Calafate, and P. Manzoni, "Citymob: a mobility model pattern generator for VANETs," in *IEEE Vehicular Networks and Applications Workshop (Vehi-Mobi, held with ICC)*, Beijing, China, May 2008.