

# Vehicular Network Simulation Propagation Loss Model Parameter Standardization in ns-3 and Beyond

Joseph Benin, Michael Nowatkowski, and Henry Owen  
 School of Electrical and Computer Engineering  
 Georgia Institute of Technology, Atlanta, Georgia, USA  
 {semperjoe, nowatkom, owen}@gatech.edu

**Abstract**—Vehicular Networks (VANETs) continue to mature and their installation is becoming a reality. Meanwhile, simulation has become an indispensable tool for validating design and providing insight into how complex systems work. Yet the results of a simulation are only as good as the simulator’s configuration. The network simulator 3 (ns-3) provides a host of propagation loss models, some of which are applicable to VANETs. In this work, we evaluate these models and then offer standard values for the propagation loss model parameters in an effort to normalize VANET simulation and provide researchers the ability to compare their work. The proposed values are then demonstrated to achieve the desired effective range as empirically determined in other work.

**Keywords** – VANET; simulation; ns3; propagation loss model

## I. INTRODUCTION

Vehicular ad hoc networks (VANETs) continue to garner the interest of academic and industry researchers because of the safety and convenience they have the potential to provide. Their installation is becoming a reality [1] and the appeal of “smart vehicles” is being touted by major automobile manufacturers including Ford and Toyota [2]. In vehicular networks, mobile vehicles possess on-board units (OBUs) that are able to communicate with each other (vehicle-to-vehicle or V2V) as well as with stationary road-side units (RSUs) that comprise the network’s infrastructure (this communication is often characterized as vehicle-to-infrastructure or V2I). To date, various aspects of VANET simulation have been addressed including mobility [3, 4], urban environments [5, 6], and physical propagation characteristics [7, 8]. However, with any simulator, the parameters one uses significantly affects the results. Thus it is desirable that a baseline set of propagation loss parameters be published to aid researchers and interested parties in evaluating simulation output. In this study ns3, a modern, freely available, and robust simulator was used [9]. The goal of this work is an investigation of the free space range of 802.11p within the VANET environment and the appropriate propagation loss model parameters for use in simulation.

## II. CONTRIBUTION

The primary contribution of this work is an overview of the various propagation loss models offered and the appropriate model parameters to use when simulating VANETs. These values are then offered to the research community as a starting point for standardization.

## III. BACKGROUND

### A. Propagation Loss Models

A large variety of propagation loss models are available for use. The network simulator 3 release 10 (ns-3.10) natively supports eleven different such models, listed in Table 1, and discussed in the subsequent subsections. The propagation loss models can be categorized as deterministic, empirical, or statistical, and ns-3.10 provides at least one of each. Furthermore, ns-3.10 also provides the ability to cascade models, including the addition of the probabilistic Nakagami fast fading model.

Table 1. Native propagation loss models of ns-3.10

Category	Model
Deterministic	Fixed RSS, Matrix, Range, Log Distance, Three Log Distance, Friis, Two-Ray Ground
Empirical	COST 231
Statistical	Random
Fading (Cascade)	Jakes, Nakagami-m

Table 2 lists the variables used in this paper. In general, simulators use a defined minimum receive power as the threshold to determine if a packet can be successfully received. The simulated receive power (enumerated in Equation 1) is compared to this minimum required receive power and either the packet is received or “lost.” For 802.11p simulated in ns-3, the default transmit power ( $P_{TxPowerStart}$  and  $P_{TxPowerEnd}$ ) is 16.0206 dB and the  $EnergyDetectionThreshold$  is -96 dB, which represents the minimum receive power for the receiver. Thus a loss of 112.0206 dB renders a packet “lost” in ns-3 [10].

$$P_r = P_t - L \quad (1)$$

Table 2. Variables used

d	Distance
t	Specifies transmitting/sending node
r	Specified receiving node
P	Power
G	Gain
h	Height of respective antenna
n	Path loss distance exponent
L	Path loss
$L_0$	Path loss at reference distance
$\lambda$	Wavelength (inverse of the frequency)
$\omega$	Average Receive Power
N	Number of rays
M	Oscillators per ray
m	Fading depth parameter

### B. Non-Applicable Models to VANETs [11]

When modeling the VANET environment, some of the offered models within ns-3 simply do not apply. The `FixedRssLossModel` for example yields a constant received power regardless of the distance between sender and receiver. The `MatrixPropagationLossModel` is equally unusable for VANET modeling as it fixes the propagation loss for each pair of nodes regardless of their actual positions. Finally, the `RandomPropagationLossModel` is also a poor choice as it simply selects a value each time a packet is received following a user defined random distribution. Finally, the `RangePropagationLossModel` uses the transmit power as the received power for distances between sender and receiver less than or equal to the specified “range” and a received power of -1000 dBm beyond this distance.

### C. Non-Applicable Empirical Model [11]

From April 1989 until April 1996, the European Union sponsored the COperation européenne dans le domaine de la recherche Scientifique et Technique (COST) forum that produced the COST 231 propagation loss model for use in dense locations (both indoors in the midst of a many-walled office or outdoors in dense urban environments) [12]. As an empirical model, it uses previously collected data as its basis and thus is very fast but generally less accurate for a given scenario. Furthermore, this model was only designed for use in 1.5 to 2 GHz frequency range and as such is not a good choice to model VANET propagation loss.

### D. Basic Models [11]

Four basic propagation loss models, all deterministic in nature, are provided for in ns-3.10: Log Distance, Three Log Distance, Friis, and Two-Ray Ground.

The `LogDistancePropagationLossModel` and the `ThreeLogDistancePropagationLossModel` incorporate the same calculation for propagation loss except that the three log model provides for four distance fields. Equation 2 is known as the log distance equation while Equation 3 provides the complete three log distance equation. The log distance model provides for basic attenuation and is normally associated with indoor environments, such as for use with wireless LANs. It is worth noting that it is the default propagation model of the YANS physical layer helper class in ns-3.10. The three log-distance model provides for additional tuning but is generally seen as an indoor or urban propagation loss model.

$$L = \begin{cases} 0 & d < d_0 \\ L_0 + 10 \cdot n_0 \log_{10} \left( \frac{d}{d_0} \right) & d \geq d_0 \end{cases} \quad (2)$$

$$L = \begin{cases} 0, & d < d_0 \\ L_0 + 10 \cdot n_0 \log_{10} \left( \frac{d}{d_0} \right), & d_0 \leq d < d_1 \\ L_0 + 10 \cdot n_0 \log_{10} \left( \frac{d_1}{d_0} \right) + 10 \cdot n_1 \log_{10} \left( \frac{d}{d_1} \right), & d_1 \leq d < d_2 \\ L_0 + 10 \cdot n_0 \log_{10} \left( \frac{d_1}{d_0} \right) + 10 \cdot n_1 \log_{10} \left( \frac{d_2}{d_1} \right) + 10 \cdot n_2 \log_{10} \left( \frac{d}{d_2} \right), & d_2 \leq d \end{cases} \quad (3)$$

The `FriisPropagationLossModel`, is a simplified version of the log distance propagation loss model. Rather than using loss coefficients that must be empirically acquired and validated, it simplifies the propagation loss calculation to that given in Equation 4. It is not accurate for very small distances (the default minimum distance in ns-3.10 is .5 meters).

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2 L_0} \quad (4)$$

The `TwoRayGroundPropagationLossModel` considers both the direct path and a ground reflection path when calculating the received power in accordance with Equation 5. This model is often viewed as an accurate selection when modeling rural environments [13]. Thus for research in strictly rural environments, this simple propagation loss model may be of use.

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} \quad (5)$$

### E. Accounting for Fading in ns-3 [11]

It is possible in ns-3 to account for fading when using the propagation loss models discussed in sections III.C and III.D. by applying either the Jakes or Nakagami models (to be implemented normally in addition to a propagation loss model).

The `JakesPropagationLossModel` implements a modified Jakes model (concisely presented in [14]) which seeks to incorporate Rayleigh fading and simplify its calculation. It uses a set of electromagnetic rays that would depart the transmitter in order to determine which ones would reach the receiver. These sinusoidal rays are then summed to determine the received power level. Jakes propagation loss is defined by Equations 6 and 7 [14]. It is worth noting that the initial phase shifts ( $\phi$ ) can be randomly generated according to a specified distribution, which however by default is a constant in ns-3.10. This fading model is most appropriate where multipath is a significant issue and no line of sight exists between the sender and receiver, which is often the case in urban (or indoor) environments.

$$X(t) = X_c(t) + jX_s(t) \quad (6a)$$

$$X_c(t) = \frac{2}{\sqrt{M}} \sum_{n=1}^M \cos(\psi_n) \cdot \cos(\omega_d t \cos \alpha_n + \phi) \quad (6b)$$

$$X_s(t) = \frac{2}{\sqrt{M}} \sum_{n=1}^M \sin(\psi_n) \cdot \cos(\omega_d t \cos \alpha_n + \phi) \quad (6c)$$

$$\alpha_n = \frac{2\pi n - \pi + \theta}{4M}, n = 1, 2, \dots, M \quad (7)$$

The `NakagamiPropagationLossModel` applies the Nakagami fast fading distribution to the received power level and serves to transform otherwise deterministic propagation loss models to probabilistic ones. The Nakagami probability density function is defined in Equation 8 and, similar to the three log-distance model, is defined over three distance fields (0 to  $d_1$  is  $m_0$ ,  $d_1$  to  $d_2$  is  $m_1$ , and  $d_2$  to  $d_3$  is  $m_2$ ). When  $m$  equals one, the Nakagami distribution equals the Rayleigh distribution.

$$p(x; m, \omega) = \frac{2m^m}{\Gamma(m)\omega^m} x^{2m-1} e^{-\frac{m}{\omega}x^2} \quad (8a)$$

$$= 2x \cdot p_{Gamma} \left( x^2, m, \frac{m}{\omega} \right) \quad (8b)$$

## F. Summary

The preceding paragraphs demonstrate that ns-3.10 provides those who desire to simulate vehicular networks three propagation loss models geared for urban environments, one for rural environments, and the ability to make these more realistic by adding Nakagami-m or Jakes fading.

## IV. VANET COMMUNICATIONS RANGE

The exact range of VANET communications is difficult to determine. Such factors as terrain, vegetation, and buildings, as well as RF interference from other transmitters in the 5.9 GHz spectrum have direct impact. Furthermore, policy and standards serve to limit the effective range to maximize the number of supportable users. The literature reflects a maximum range of 300 m for VANETs [15-17] which is consistent with experimental measurements of dedicated short range communications (DSRC) performed to date [18-20]. In these studies, it is noted that communications in urban environments normally involve a range of approximately 140 meters while those in non-urban environments achieve a range of approximately 300 m. It is for this reason that we have set out to produce two sets of propagation loss parameters to support simulation in each of these environments.

### A. Ns-3.10 Default Values

Table 3. Default simulation parameters

ns-3.10 Default Values	
Prop Loss	Log (-46.6777dB at 1 m)
Mac Helper	NqosWifiMacHelper
Mac Type	AdhocWifiMac
Phy Standard	WIFI_PHY_STANDARD_90211_10Mhz
YansWifiPhy	
TxPowerStart	16.0206 dB
TxPowerEnd	16.0206 dB
EnergyDetectionThreshold	-96 dB

Using the default values of ns-3.10 (based on MAC and PHY layer parameters specified in Table 3) yields a maximum range of 151.5 meters over ten simulation runs (which provides a 95% confidence interval (CI) of being within  $\pm 2\%$  of the maximum range). These results are shown in Figure 1. As can be seen, this is a simplistic view of propagation loss with an almost infinite slope at the maximum range. In addition, this range exceeds (albeit it by only 11.5 m) the measured 140 meter maximum of urban environments and does not reflect the 300 m measured range for non-urban environments [18-20]. Given these differences from the expected communications range in VANETs, this work to find appropriate loss parameters that researchers can uniformly use is justified.

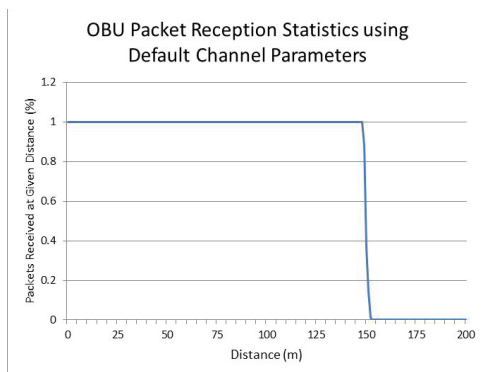


Figure 1. Default value range in ns-3.10

## V. PROPOSED VANET PROPAGATION LOSS PARAMETERS

This section outlines the proposed parameters for researchers to use when simulating VANETs in ns-3. All values were derived following the methods outlined in [21] in order to obtain a 95% CI with a half-width of 2% of the mean simulated value.

### A. Propagation Loss

The proposed ns-3 propagation loss model parameters are summarized in Table 4 for both urban and rural simulation environments. Recall that the Two Ray Ground model has been identified as the most realistic propagation loss model for use in simulating rural environments with fewer obstructions while the log distance, three log distance, and Friis are more appropriate for urban environments.

Table 4. Summary of proposed propagation loss model parameters.

U/R	Prop Loss Model	Parameter	Value	Units
Both	Two Ray Ground	Lambda	0.05093	meters
Urban	Two Ray Ground	MinDistance	140	meters
Rural	Two Ray Ground	MinDistance	300	meters
Urban	Log Distance	ReferenceLos	37.35	dB
Rural	Log Distance	ReferenceLos	47.2	dB
Urban	Three Log Distance	Distance0	1	meters *
Urban	Three Log Distance	Exponent0	2.5	unitless
Urban	Three Log Distance	Distance1	75	meters
Urban	Three Log Distance	Exponent1	5	unitless
Urban	Three Log Distance	Distance2	114	meters
Urban	Three Log Distance	Exponent2	10	unitless
Rural	Three Log Distance	Distance0	1	meters *
Rural	Three Log Distance	Exponent0	1.9	unitless *
Rural	Three Log Distance	Distance1	210	meters
Rural	Three Log Distance	Exponent1	15	unitless
Rural	Three Log Distance	Distance2	286	meters
Rural	Three Log Distance	Exponent2	3.65	unitless
Both	Friis	Lambda	0.05093	meters
Urban	Friis	SystemLoss	26.7	unitless
Rural	Friis	SystemLoss	122	unitless

\*indicates a default value

### B. Fading

Adding fading is considered an important means to make a simulation of propagation more realistic. The Jakes fading model is parameter-less, while the proposed parameter values for the Nakagami-m model are listed in Table 5 for both urban and rural environments.

Table 5. Summary of proposed fading model parameters.

U/R	Fading Model	Parameter	Value	Units
Both	Jakes	None		*
Urban	Nakagami-m	m0	1.5	unitless *
Urban	Nakagami-m	Distance1	60	meters
Urban	Nakagami-m	m1	0.75	unitless *
Urban	Nakagami-m	Distance2	145	meters
Urban	Nakagami-m	m2	0	unitless
Rural	Nakagami-m	m0	1.5	unitless *
Rural	Nakagami-m	Distance1	80	meters *
Rural	Nakagami-m	m1	0.75	unitless *
Rural	Nakagami-m	Distance2	320	meters
Rural	Nakagami-m	m2	0	unitless

\*indicates a default value

## VI. NS-3.10 SIMULATION RESULTS

### A. Simulation Setup

Two metrics were used to measure the effectiveness of the parameters proposed in Section V. Each second a hundred packets were sent from a stationary RSU to a moving OBU traveling away from the RSU at a speed of one meter per second. The first metric was the greatest distance at which all 100 packets were received and was entitled the "effective

range” (and labeled “Max 100% Dist” in the figures). The second metric was the maximum distance at which any packet was received and was primarily used to ensure consistency of the results (labeled in “Max Distance” in the figures). The aim of this work was to identify which propagation loss parameters would result in an effective range of 140 m (for urban) and 300 m (for rural) while running the necessary simulations to demonstrate the 95% CI of being within 2% of the mean.

### B. Propagation Loss Model Results

Our results demonstrate an acquired effective range in an urban environment of 140.3, 139.9, 140.1, and 139.9 meters for the log distance, three log distance, Friis, and two ray ground models respectively and 299.5, 299.9, 299.5, and 299.9 meters respectively in a rural environment. These results are shown in Figures 2 and 3, with the error bars indicating the 95% CI of the mean effective distance.

Furthermore, the maximum distance achieved reflects the nature of the probability loss models. As an example, the maximum distance of the log distance propagation loss model is a few meters greater than the three log distance model that uses progressively greater loss coefficients. Given that the two ground ray model uses a deterministic cut-off of received signal power, it stands to reason that the range of 100% reception and the maximum range be almost identical.

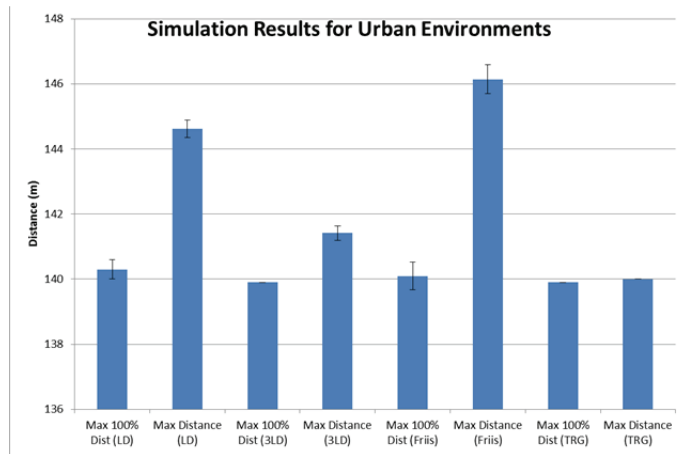


Figure 2. Propagation loss simulation results (urban)

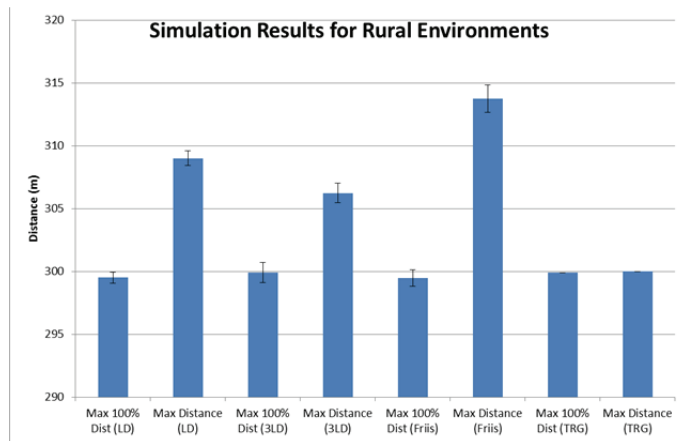


Figure 3. Propagation loss simulation results (rural)

### C. Fading Model Results

Fading was added to a selection of propagation loss models to demonstrate their impact. These results are shown in Figure 4. To illustrate the difference between simulating packet transmissions without and with fading, a scenarios of log distance propagation loss without and then with Nakagami-m fading was simulated, the results of which are illustrated in Figures 5 and 6.

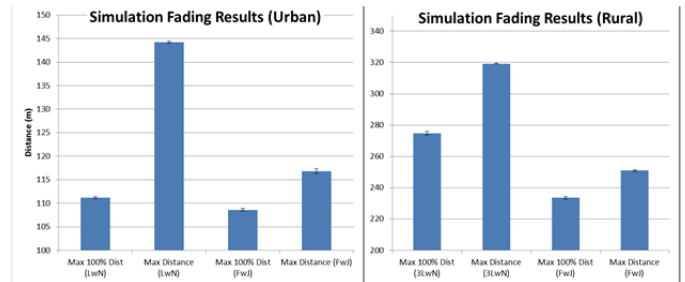


Figure 4. Fading simulation results (urban and rural)

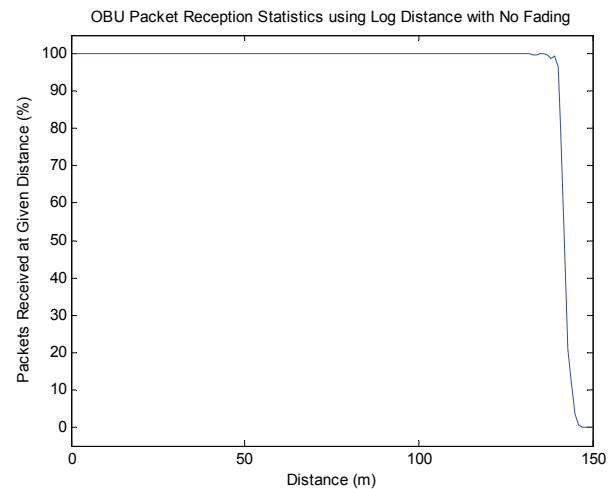


Figure 5. Packet reception plot with log distance propagation loss

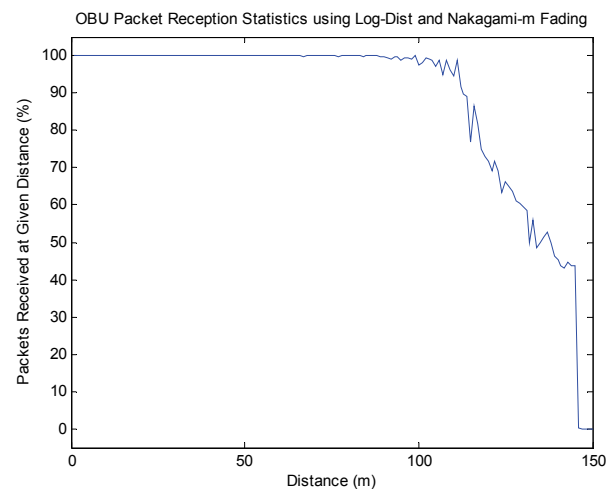


Figure 6. Packet reception plot with log distance propagation loss and Nakagami-m fading in an urban environment

## VII. CONCLUSION

The use of simulators to provide insight into the workings of complex systems is an invaluable tool of the modern researcher. The ability to fine-tune a simulation configuration is a powerful asset to establishing causal relationships between design and performance. However the need to compare work across various efforts is an important necessity for true peer review. In this work, we have reviewed the nine propagation loss and the two fading models provided by ns-3.10 and evaluated their applicability to simulating vehicular networks. We proposed propagation loss and fading model parameter values to adapt ns-3 for VANET use. These proposed values were then validated through a series of ns-3 simulations within two percent of the mean values with a 95% confidence interval. It is our hope that these standardized values can provide a good reference for VANET researchers utilizing ns-3 (as well as potentially other simulators) as we all work towards a future of safer, more efficient, and more environmentally friendly vehicular travel.

## REFERENCES

- [1] (9/3/2009, 5/12/2010). *TMC Develops Onboard DSRC Unit to Improve Traffic Safety*. Available: <http://www2.toyota.co.jp/en/news/09/09/0903.html>
- [2] W. D. Jones. (2011, 2/23/2011). *Smarter Cars? There's an App for That*. Available: <http://spectrum.ieee.org/green-tech/advanced-cars/smarter-cars-theres-an-app-for-that/0>
- [3] L. Kun-chan and C. Chien-Ming, "Realistic mobility models for Vehicular Ad hoc Network (VANET) simulations," in *ITS Telecommunications, 2008. ITST 2008. 8th International Conference on*, 2008, pp. 362-366.
- [4] C. Sommer and F. Dressler, "Progressing toward realistic mobility models in VANET simulations," *Communications Magazine, IEEE*, vol. 46, pp. 132-137, 2008.
- [5] Y. Wang, *et al.*, "An integrated propagation model for VANET in urban scenario," presented at the Proceedings of the 6th International Wireless Communications and Mobile Computing Conference, Caen, France, 2010.
- [6] A. Mahajan, *et al.*, "Modeling vanet deployment in urban settings," presented at the Proceedings of the 10th ACM Symposium on Modeling, analysis, and simulation of wireless and mobile systems, Chania, Crete Island, Greece, 2007.
- [7] C. Sommer, *et al.*, "Realistic Simulation of Network Protocols in VANET Scenarios," in *2007 Mobile Networking for Vehicular Environments*, 2007, pp. 139-143.
- [8] F. J. Martinez, *et al.*, "Realistic radio propagation models (RPMs) for VANET simulations," presented at the Proceedings of the 2009 IEEE conference on Wireless Communications & Networking Conference, Budapest, Hungary, 2009.
- [9] (2011, 2/23/2011). *The ns-3 network simulator*. Available: <http://www.nsnam.org/index.html>
- [10] (6/29/2011). *ns3::YansWifiPhy Class Reference*. Available: [http://www.nsnam.org/doxygen/classes3\\_1\\_1\\_yans\\_wifi\\_phy.html](http://www.nsnam.org/doxygen/classes3_1_1_yans_wifi_phy.html)
- [11] (2011, 2/23/2011). *ns3::PropagationLossModel Class Reference*. Available: [http://www.nsnam.org/doxygen-release/classes3\\_1\\_1\\_propagation\\_loss\\_model.html#\\_details](http://www.nsnam.org/doxygen-release/classes3_1_1_propagation_loss_model.html#_details)
- [12] (1999, 2/23/2011). *COST 231*. Available: <http://www.lx.it.pt/cost231/>
- [13] (2/23/2011). *Deterministic Two Ray Model*. Available: <http://www.awe-communications.com/Propagation/Rural/DTR/index.htm>
- [14] Z. Yahong Rosa and X. Chengshan, "Simulation models with correct statistical properties for Rayleigh fading channels," *Communications, IEEE Transactions on*, vol. 51, pp. 920-928, 2003.
- [15] D. Jiang, *et al.*, "Optimal data rate selection for vehicle safety communications," presented at the Proceedings of the fifth ACM international workshop on Vehicular Internetworking, San Francisco, California, USA, 2008.
- [16] M. Torrent-Moreno, "Inter-Vehicle Communications: Assessing Information Dissemination Under Safety Constraints," in *Wireless on Demand Network Systems and Services, 2007. WONS '07. Fourth Annual Conference on*, 2007, pp. 59-64.
- [17] Y. Fan and S. Biswas, "A Self-Organizing MAC Protocol for DSRC based Vehicular Ad Hoc Networks," in *Distributed Computing Systems Workshops, 2007. ICDCSW '07. 27th International Conference on*, 2007, pp. 88-93.
- [18] V. Kukshya and H. Krishnan, "Experimental Measurements and Modeling for Vehicle-to-Vehicle Dedicated Short Range Communication (DSRC) Wireless Channels," in *IEEE 64th Vehicular Technology Conference, 2006*, 2006, pp. 1-5.
- [19] C. Lin, *et al.*, "Mobile Vehicle-to-Vehicle Narrow-Band Channel Measurement and Characterization of the 5.9 GHz Dedicated Short Range Communication (DSRC) Frequency Band," *Selected Areas in Communications, IEEE Journal on*, vol. 25, pp. 1501-1516, 2007.
- [20] F. Bai, *et al.*, "Toward understanding characteristics of dedicated short range communications (DSRC) from a perspective of vehicular network engineers," presented at the Proceedings of the sixteenth annual international conference on Mobile computing and networking, Chicago, Illinois, USA, 2010.
- [21] J. Banks, *Discrete-Event System Simulation*, Fifth ed.: Prentice-Hall, 2009.