Evaluating the Impact of Transmission Power on Selecting Tall Vehicles as Best Next Communication Hop

Yu Qiao, Wouter Klein Wolterink, Georgios Karagiannis, Geert Heijenk

University of Twente, the Netherlands

Abstract. The relatively low height of antennas on communicating vehicles in Vehicular Ad Hoc Networks (VANETs) makes one hop and as well multi-hop Vehicle-to-Vehicle (V2V) communication susceptible to obstruction by other vehicles on the road. When the transmitter or receiver (or both) is a Tall vehicle, (i.e., truck), the V2V communication suffer less from these obstructions. The transmission power control is an important feature in the design of (multi-hop) VANET communication algorithms. However, the benefits of choosing a Tall vehicle when transmission power is varied are not yet extensively researched. Therefore, the main contribution of this paper is to evaluate the impact of transmission power control on the improved V2V communication capabilities of tall vehicles. Based on simulations, it is shown that significant benefits are observed when a Tall vehicle is selected rather than a Short vehicle as a next V2V communication hop to relay packets. Moreover, the simulation experiments show that as the transmission power is increasing, the rate of Tall vehicles that are selected as best next V2V communication hop is significantly growing.

Keywords: VANET, V2V multi-hop communication, Tall vehicles, OMNET++ simulation

1 Introduction

Vehicular networking serves as one of the most important enabling technologies required to implement a myriad of applications related to vehicles, vehicle traffic, drivers, passengers and pedestrians. A Vehicular Ad-hoc Network (VANET) is a vehicular network that allows for Vehicle to Vehicle (V2V) communication. The proposed technology to perform this information exchange is the IEEE 802.11p technology [1], which is a member of the Wireless LAN family adapted for use in vehicular environments. A VANET enables a wide range of Intelligent Transportation System (ITS) applications, ranging from entertainment to traffic safety and efficiency, see e.g., [2]. Communication between vehicles can for example be used to realize driver support and active safety services like collision warning, up-to-date traffic and weather information, or active navigation systems.

The quality of communication between a sender and receiver in a VANET is determined by the quality of the received electromagnetic signal, and especially by the strength of the signal. As a signal propagates from sender to receiver it is affected by obstacles in its path, such as surrounding buildings, foliage, but also other vehicles. In particular, the relatively low height of antennas on communicating vehicles in VANETs makes one hop and as well multi-hop V2V communication susceptible to obstruction by other vehicles on the road. When vehicles on the road communicate amongst themselves, other objects (e.g., buildings, other vehicles) could affect the wave propagation strongly. Existing research, see [3], [4], has shown that that other non-communicating vehicles often obstruct the line of sight (LOS) between the communicating vehicles, thus significantly decreasing their received power. In [4] the authors propose a propagation model that is able to model this effect. Furthermore, [4], [11] have shown how vehicles that have a greater height (i.e., trucks) suffer less from vehicle obstruction: when the transmitter or receiver (or both) is a Tall vehicle, the maximum distance over which communication is still possible is significantly larger than when neither the transmitter nor the receiver is a Tall vehicle. Tall vehicles can therefore better serve as next hop in multi-hop communication, because of their ability to communicate with nodes positioned further away. Choosing Tall vehicles as next hop may therefore significantly improve multi-hop communication algorithms.

However, a major limitation of the study presented in [4], [11] is related to the fact that only a limited number of parameters have been taken into account, and only a single scenario: the authors chose a single road topology in which they varied the ratio of Tall vehicles and the used transmission bit rate. Parameters that were not taken into account include the transmission power and traffic density. It is therefore unclear how this effect – the improved communication capabilities of Tall vehicles – is affected when the transmission power is varied.

Current VANET research is actively focusing on transmission power control as a means to create communication algorithms that are energy efficient, effective and scalable [5], [6]. In high traffic density situations these algorithms keep the transmission power low, in order to minimize the use of energy and to keep communication effective and scalable. As there is less traffic the transmission power can be increased, to ensure that a maximum amount of vehicles can reach each other. Transmission power control is currently being standardized by ETSI [7] and can be performed on a per-packet basis.

The transmission power control is an important feature in the design of (multi-hop) VANET communication algorithms. Furthermore, it is clear that the effect of choosing a Tall vehicle as a next hop can also significantly improve multi-hop V2V communication. However, the benefits of choosing a tall vehicle when transmission power is varied are not yet extensively researched. Therefore, the main contribution of this paper is to evaluate the impact of transmission power control on the improved V2V communication capabilities of Tall vehicles. Such V2V communication capabilities are the *Packet Success Rate (PSR)* and the *Rate of Tall vehicles selected as best next hop* to relay packets. *PSR* is defined as the ratio of the successful received beacons by all vehicles (under study), divided by the total number of beacons sent by all vehicles (under study), within a predefined transmission range. The research questions answered by this paper are:

- What is the impact of transmission power on the packet success rate in V2Vcommunications when different vehicle heights are used?
- How does the variation of the transmission power affect the effectiveness of choosing a Tall vehicle as a best next V2V communication hop?

The rest of the paper is organized as follows. Section 2 describes the simulation environment. The simulation experiments, the simulation results and their analysis are given in Section 3. The two research questions listed above are answered in Section 3. Finally, Section 4 concludes the paper and gives recommendations for future work.

2 Simulation Environment

For the simulations accomplished in this research work the OMNET++ network simulator v4.1 [8] combined with the MiXiM framework v2.1 [9] are used. To model the behavior of the IEEE 802.11p protocol as accurately as possible we have altered the IEEE 802.11 medium access module in such a way that all parameters follow the IEEE 802.11p specification [1]. In particular, the used carrier frequency is set to 5.9 GHz. In addition to the parameters used to emulate the IEEE 802.11p behavior, additional parameters are used, which are specified in Sections 3.2 and 3.3. More details on the used simulation environment can be found in [12].

2.1 Simulation Topology

The road topology used in this work is based on the parameters of Portuguese highway A28, which is a north-south motorway with length of 12.5km. The vehicle density on the road and the mix of Tall and Short vehicles are determined according to the Portuguese highway data set, see [4]. However, the two parameters can be varied in simulation to achieve different road traffic. In this paper, the vehicle density considered is 7.9 veh/km/lane. The mix of Tall and Short vehicles is: 15% Tall vehicles and 85% Short vehicles.

The topology used in the performed simulations is a 4-lane road, see Figure 1. Note that a bold black line in Figure 1 represents the center of a lane. The length of this road is 10km. The inter-lane distance is defined according to Trans-European North-South Motorway (TEM) Standards [10]. The used values are shown in Figure 1. In order to avoid border effects, the torus (set parameter ‘useTorus’ to true) topology is used in simulations, which means that the playground represents a torus with the borders (the begin and the end of axes) connected. Thus the distance between two hosts on the torus cannot be greater than 5km.

The vehicles are placed on the road based on:

- *number of vehicles on the road*: depends on the vehicle density
- *inter-vehicle spacing*: the distance between two adjacent vehicles moving on the same lane, see Figure 1. It is defined using an exponential distribution, see [4], [12]

- *type of vehicles*: two types of vehicles are distinguished, Tall, and Short vehicles, see [4], [12]
- *dimensions of vehicles*: this represents the length, width and height of both Tall and Short vehicles, see Table 1. These dimensions are random variables, but their values are set before placing the vehicles on the road.

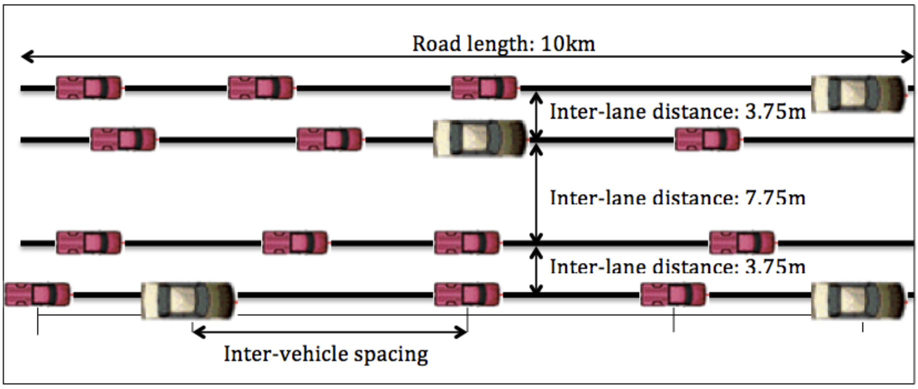

Fig. 1. Simulation topology

The vehicles are carrying transmitter/receiver antennas on their roofs, see [4]. In particular, each Short vehicle is carrying one antenna that is located on top of the vehicle and in the middle of the roof. Each Tall vehicle is carrying two antennas on the roof, one in the front and another in the back of the vehicle, see [11]. The height of each antenna is set to 10 cm and the antenna gain is set to 3dBi.

Table 1. Vehicle dimensions

Type	Parameters	Estimate
Short	Width	Mean: 175cm; Std. deviation: 8.3cm
	Height	Mean: 150cm; Std. deviation: 8.4cm
	Length	Mean: 500cm; Std. deviation: 100cm
Tall	Width	Mean: 250cm
	Height	Mean: 335cm; Std. deviation: 8.4cm
	Length	Mean: 1300cm; Std. deviation: 350cm

After the vehicles are placed on the road, simulation experiments are run in the following way. During one simulation run all the vehicles placed on the road will be transmitting in a sequential order at different (2 seconds) time intervals. This means that during a time interval of 2 seconds only one vehicle is transmitting one beacon with a length of 3200 bits. The other vehicles will successfully receive the beacon only if the power of the received signal is higher than a minimum receiver sensitivity threshold. The power of the received signal is measured at each receiving vehicle at the physical layer module incorporated in the OMNET++/MiXiM framework.

2.2 PROPAGATION MODEL

This section gives a brief description of the propagation model applied in this research.

Several propagation models applied in VANET research can be used to quantify the impact of vehicles as obstacles on the electromagnetic wave propagation. Since any channel model is a compromise between simplicity and accuracy, the target of this research is to construct a propagation model that is simple enough to be tractable from an implementation point of view, yet still able to emulate the essential V2V channel characteristics, mainly diffraction caused by mobile obstacles. A geometry-based deterministic model with computation reduction is suitable for the research presented in this paper. Geometry-based deterministic models, see e.g., [4], [13], [14], are based on a fixed geometry (sufficient information about environment and road traffic) and are used to analyze particular situations. The electromagnetic field arriving at receiver results from the combination of all components: direct component, reflected components, diffracted components and scattered components. Usually the ray-tracing method is used to analyze the characteristics of these components. A highly realistic model, based on optical ray tracing was proposed in [13]. The model is compared against experimental measurements and showed a close agreement. However, the accuracy of the model is achieved at the expense of high computational complexity and location-specific modeling. There are simplified geometry-based deterministic models, see e.g., [4][14]. In particular, the research work proposed by Boban et al. in [4] derive a simplified geometry-based deterministic propagation model, in which the effect of vehicles as obstacles on signal/wave propagation is isolated and quantified while the effect of other static obstacles (i.e., buildings, overpasses, etc.) is not considered. The research work in [4] focuses on vehicles as obstacles by systematically quantifying their impact on LOS and consequently on the received signal power. Although the propagation model calculates attenuation due to vehicles for each communicating pair separately, it is still computationally efficient. Based on these facts, i.e., realistic features, reduced computation, and concentration on mobile obstacles, we decided to enhance, implement and use the propagation model proposed in [4]. For the received power level, the impact of obstacles can be represented by signal attenuation. The attenuation on a radio link increases if one or more vehicles intersect the Fresnel ellipsoid corresponding to 60% of the radius of the first Fresnel zone, independent of their positions on the transmitter-receiver (Tx-Rx) link. This increase in attenuation is due to the diffraction of the electromagnetic waves. To model vehicles obstructing the LOS, we use the knife-edge attenuation model, see [15].

When there are no vehicles obstructing the LOS between Tx and Rx, we use the free space path loss model, see e.g., [16]. If only one obstacle is located between Tx and Rx, then the single knife-edge model described in ITU-R recommendation [15] is used. For the case that more than one vehicles (i.e., more than one obstacles) are located between Tx and Rx, the multiple knife-edge model with the cascaded cylinder method, proposed in [15], is used.

The knife-edge model described in [15] applies when the wavelength is fairly small in relation to the size of the obstacles, i.e., mainly to VHF and shorter waves (f > 30 MHz). Since the frequency of DSRC radios is 5.9 GHz the wavelength is approximately 5 cm, which is significantly smaller than the size of vehicles.

The propagation model is implemented in the OMNET++/Mixim framework.

3 Experiment Results and Analysis

Two sets of experiments are performed using the static parameters described in Section 2, such as road information, dimension of vehicles, antenna height, vehicle density and percentage of Tall vehicles. The first set of experiments answers the first research question and it evaluates the impact of transmission power on the *packet success rate* in V2V communications when different vehicle heights are used. The second set of experiments answers the second research question and it evaluates how the variation of the transmission power does affect the effectiveness of choosing a tall vehicle as a best next V2V communication hop.

In order to guarantee a high statistical accuracy of the obtained results, multiple runs have been performed and double-sided 90% confidence intervals have been calculated. More specifically, up to 50 runs are performed for the first set of experiments, and up to 200 runs are performed for the second set of experiments. Several graphs are depicting in addition to the average values also the confidence intervals in the form of upper and lower bars around their associated average values. For all performed experiments, the calculated confidence intervals are lower than the ±5 % of the shown calculated mean values.

3.1 Performance Metrics

Two performance metrics are defined and used in this paper.

3.1.1 Packet Success Rate (PSR)

The *Packet Success Rate (PSR)* is defined as the ratio of the successful received beacons by all vehicles (under study), divided by the total number of beacons sent by all vehicles (under study), within a predefined transmission range. A transmission range is defined by the radio coverage area of a transmitter.

A beacon is successfully received if the received power is higher than a minimum sensitivity threshold. The minimum receiver sensitivity threshold used in this research is -85dBm (data rate: 3Mbps, modulation: BPSK), see [17].

3.1.2 Rate of Tall vehicles selected as best next hop

In multi-hop routing it is usually desirable to cover a communication distance in as little hops as possible. This can be done by consistently having nodes select that neighbor node as a next hop that adds the largest number of second hop neighbors.

The best next hop in this paper is therefore defined as the one-hop neighbor that adds the largest number of second hop neighbors to the vehicle under consideration.

The *Rate of Tall vehicles selected as best next hop* is defined as the ratio of the total number of Tall vehicles in the system, selected as best next hop to relay packets, divided by the total number of vehicles in the system.

This performance metric is calculated based on the steps defined in [11]:

- With a certain percentage of Tall vehicle and a certain density, for each vehicle on the road, we find the farthest neighbouring Tall and farthest neighbouring Short vehicle that receives a packet correctly
- Next, we determine which of the two has the largest number of new neighbours (i.e., which adds the largest number of second hop neighbours to the vehicle under consideration)
- Finally, if the largest number of new neighbours is gained by using a Tall vehicle, we select it; otherwise, we select the Short vehicle as the best next hop.

3.2 Evaluation of the Impact of Transmission Power on the Packet Success Rate (PSR)

This section describes the first set of experiments and answers the first research question. The goal of this set of experiments is to evaluate the impact of the transmission power on the *Packet Success Rate (PSR)* in V2V communications when different vehicle heights are used. The parameters used during this set of experiments are given in Table 2.

In this set of experiments four types of transmission/reception (Tx/Rx) links are applied: (1) Tx and Rx are both Short vehicles (Short-Short), (2) Tx and Rx are Tall vehicles (Tall-Tall), (3) Tx is a Short vehicle while Rx is a Tall vehicle (Short-Tall) and (4) Tx is a Tall vehicle while Rx is a Short vehicle (Tall-Short).

Table 2. Parameters used in first set of experiments

Density	7.9 veh/km/lane
Spacing Mean	125m
Tx Power	{10, 18, 25, 33}dBm ({10, 63, 316, 1996}mW)
Ratio of Tall Vehicle	0.15 (15% Tall vehicles in the network)
Receiver Sensitivity threshold	-85 dBm (3 Mbps, BPSK)

Figure 2 shows the *PSR* results versus the transmission power for the 4 types of transmission/reception (Tx/Rx) links. From this set of experiments it can be concluded that:

1. all the *PSR* values associated with the Tall-Tall transmission/reception links are higher than all the *PSR* values associated with all other transmission/reception links

2. all the *PSR* values associated with the Short-Short transmission/reception links are lower than all the *PSR* values associated with all other transmission/reception links
3. all the *PSR* values associated with the Tall-Short transmission/reception links are higher than all the *PSR* values associated with the Short-Tall transmission/reception links
4. when the transmission power is increased the *PSR* average values for all types of transmission/reception links (i.e., Short-Short, Short-Tall, Tall-Short and Tall-Tall) are increasing
5. for the same transmission power and when the transmission range is increased then the average values of the *PSR* for all types of transmission/reception links are decreasing
6. as the transmission range is increasing, (i.e., 200m, 400m, 600m, 800m) the differences between the *PSR* average values associated with each of the transmission/reception links become larger when the transmission power is increased.

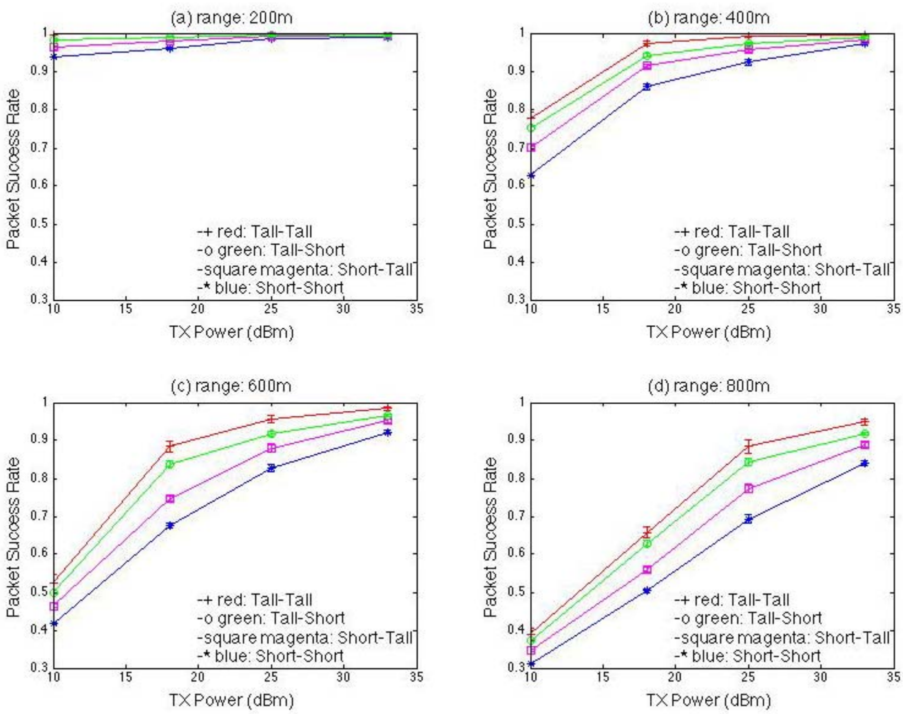

Fig. 2. *Packet Success Rate* (*PSR*) versus Transmission Power, for different transmission ranges (**a**): 200m, (**b**): 400m, (**c**): 600m, (**d**): 800m

3.3 Evaluation of the Impact of Transmission Power on Selecting Tall Vehicles as Best Next Hop

This section describes the second set of experiments and answers the second research question. The goal of this set of experiments is to evaluate how the variation of the transmission power does affect the effectiveness of choosing a tall vehicle as a best next V2V communication hop. The performance metric used in this set of experiments is the *Rate of Tall vehicles selected as best next hop*, see Section 3.1.2. The parameters used during this set of experiments are given in Table 3.

Table 3. Parameters used in second set of experiments

Density	7.9 veh/km/lane
Spacing Mean	125m
Tx Power	{10, 14, 18, 22, 25, 30, 33}dBm
Ratio of Tall Vehicle	{0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.5 }
Receiver Sensitivity threshold	-85 dBm (3Mbps, BPSK)

Figure 3 shows the *Rate of Tall vehicles selected as best next hop* results, when the transmission power and the ratio of Tall vehicles present on the road are varied.

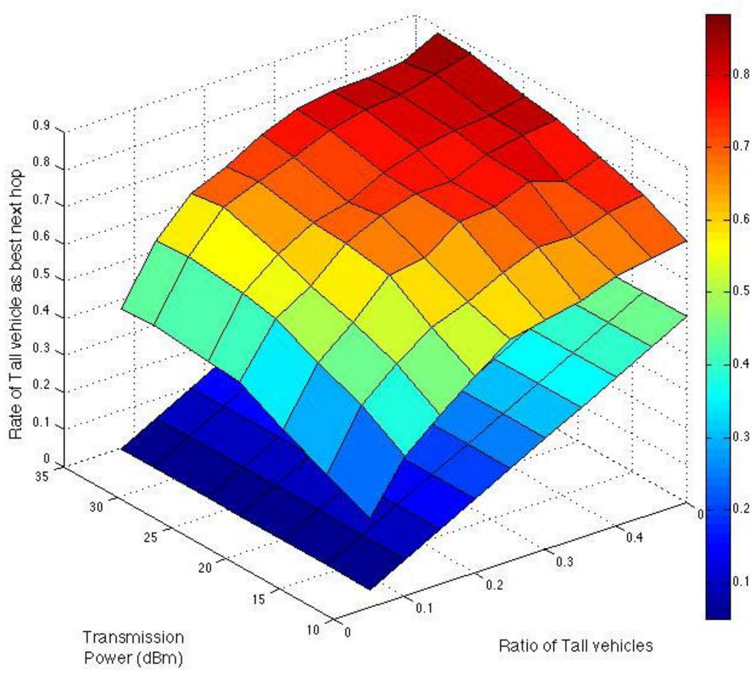

Fig. 3. *Rate of Tall vehicle as best next hop*, when varying transmission power and Ratio of Tall vehicles present on the road

The lower surface shown in Figure 3, represents a reference plane, where the value of the *Rate of Tall vehicles selected as best next hop* metric for each used transmission power is equal to the actual ratio of Tall vehicles present on the road. The upper surface represents the results of our simulation experiments. From this set of experiments it can be concluded that:

1. for all transmission power values and all ratios of Tall vehicles present on the road, the *Rate of Tall vehicles selected as best next hop* is higher than the ratio of Tall vehicles present on the road (the lower plane in Figure 3), which indicates that compared to Short vehicles, the Tall vehicles are better next V2V communication hops, regardless of the transmission power used.
2. as the transmission power increases, Tall vehicles become even better next V2V communication hops. The reason of this is that by increasing the transmission power, the maximum communication range increases and Tall vehicles have the ability to better exploit this large communication range as they have a larger probability of having a LOS with more vehicles that are located far away.

Note that additional simulation experiments have been performed and presented in [12], but due to page limitations these experiment results are not shown in this paper.

4 Conclusions and Future Work

In this article we evaluated the impact of transmission power control on the improved V2V communication capabilities of Tall vehicles. In particular, this paper evaluates (1) the impact of transmission power on the packet success rate in V2V communications when different vehicle heights are used and (2) how the variation of the transmission power does affect the effectiveness of choosing a tall vehicle as a best next V2V communication hop.

Based on simulations, it is shown that significant benefits are observed when Tall vehicles are selected rather than Short vehicle as a next communication hop to relay packets. Moreover, the simulation experiments show that as the transmission power is increasing the rate of Tall vehicles that are selected as best next V2V communication hop is significantly growing. In particular, the increase of this rate is amplified when in addition to the transmission power, also the ratio of Tall vehicles present on the road is increased.

Furthermore, based on the simulation experiments, we conclude that for realistic situations (i.e., inter-vehicle spacing mean: 125m, Tall vehicles percentage: 15%) the communication links that are using Tall vehicles as transmitter and/or receiver perform consistently and significantly better than the communication links that use Short vehicles, from the point of packet success rate. Moreover, when the transmission power is increased the packet success rate average values for all types of transmission/reception links (Short-Short, Short-Tall, Tall-Short and Tall-Tall) are increasing. However, for the same transmission power and when the transmission range is increased then the average values of the packet success rate for all types of communication links are decreasing. Furthermore, as the transmission range is increasing, the differences between the packet success rate average values associated with each of the transmission/reception links become larger when the transmission power is increased.

As future work, we will use the model presented in this paper and focus on the investigation of VANET multi-hop and geo-cast communication algorithms and protocols, when (1) the effect of Tall vehicles on the V2V communication and (2) the benefit of choosing a Tall vehicle as a next hop are taken into account.

References

1. IEEE standard for information technology – telecommunications and information exchange between systems – local and metropolitan area networks – specific requirements part 11: wireless LAN medium access control (mac) and physical layer (phy) specifications amendment 6: wireless access in vehicular environments. 2010. IEEE Computer Society. IEEE P802.11p.
2. Karagiannis, G., Altintas, O., Ekici, E., Heijenk, G.J., Jarupan, B., Lin, K., Weil, T., Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions. IEEE Communications Surveys & Tutorials, vol. 13, nr. 4., pp. 584-616, 2011.
3. Meireles, R., Boban, M., Steenkiste, P., Tonguz, O., Barros, J., Experimental study on the impact of vehicular obstructions in vanets, Proc. of IEEE Vehicular Networking Conference (VNC), pp. 338-345, 2010.
4. Boban, M.; Vinhoza, T.T.V.; Ferreira, M.; Barros, J.; Tonguz, O.K.; Impact of Vehicles as Obstacles in Vehicular Ad Hoc Networks, Selected Areas in Communications, IEEE Journal on , vol.29, no.1, pp.15-28, January 2011.
5. Mittag, J., Eisenlohr, F.S., Killat, M., Härri, J., Hartenstein, H., Analysis and design of effective and low-overhead transmission power control for VANETs, Proc. of the 5th ACM international workshop on VehiculAr Inter-NETworking, 2008.
6. Torrent-Moreno, M., Mittag, J., Santi, P., and Hartenstein, H., Vehicle-to-Vehicle Communication: Fair Transmit Power Control for Safety-Critical Information, IEEE Transactions on Vehicular Technology, September 2009.
7. ETSI TS 102 687, Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range, 2010.
8. OMNeT++ official website, to be found via (visited on April 2012): http://www.omnetpp.org.
9. MiXiM introduction in the sourceforge website, to be found via (visited on April 2012): http://mixim.sourceforge.net/.
10. TEM Project Central Office. Trans-European north-south motorway (TEM) standards and recommended practice. United Nations Economic Commission for Europe, 2002.
11. Boban, M., Meireles, R., Barros, J., Tonguz, O. and Steenkiste, P., Exploiting the height of vehicles in vehicular communication. IEEE Vehicular Networking Conference (VNC), 2011.
12. Qiao, Y., Karagiannis, G., Wolterink, W.K., Evaluating the Impact of Large Vehicles in Vehicular Communication, IP Research assignment, University of Twente, the Netherlands, March 2012, to be found via (visited on April 2012): http://www.utwente.nl/ewi/dacs/assignments/completed/bachelor/reports/2012-yuqiao.pdf.
13. Maurer, J., Fügen, T., Schäfer, T. and Wiesbeck, W., A new inter-vehicle communication (ivc) channel model. IEEE 60th Vehicular Technology Conference (VTC 2004-Fall), vol. 1, pp. 9-13, 2004.

14. Ledy, J., Boeglen, H., Poussard, A.M., Hilt, B. and Vauzelle, R., A semi-deterministic channel model for VANETs simulations. International Journal of Vehicular Technology, 2011.
15. ITU-R, Propagation by diffraction. International Telecommunication Union Radiocommunication Sector, Geneva, Recommendation P.526, 2007.
16. Rappaport, T. S., Wireless Communications: Principles and Practice. Prentice Hall, 1996.
17. Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems - 5GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specification, ASTM E2213-03, Sep. 2003.